American Society of Cinematographers Motion Imaging Technology Council Progress Report 2022

By Curtis Clark, ASC; David Reisner; Jay Holben, Wendy Aylsworth; Greg Ciaccio, Tim Kang, Jesse Korosi, Patrick Renner, David Hall; Michael Goi, ASC, David Morin; Gary Mandle, James Fancher; Gary Demos

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Vice-Chair: Richard Edlund, ASC
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Vice-Chair & Council Secretary: David Reisner, dreisner@d-cinema.us

Introduction

Chair, ASC Motion Imaging Technology Council (MITC):
Curtis Clark, ASC

The ASC MITC has provided leadership throughout the transition of our industry from film to digital including the development of digital techniques and technologies for making movies and television. Continued developments in digital motion imaging technologies, along with significant changes in the production environment, require our continued participation to best ensure that these rapidly advancing technologies effectively serve the creative interests of cinematographers and their filmmaking collaborators in ways that enhance their ability to achieve their creative vision.

Our 2022 Report includes an update on the much-needed StEM2 project (a follow-on from the original StEM, which provided vital film-based reference images for evaluation of digital cinema projection vs. traditional film print projection). StEM2 provides crucial motion imaging digital reference images for evaluating the performance of digital displays for both projected and emissive image content. StEM2 has been recently completed and is proving to be a resounding success. We have now started work on our StEM3 (Virtual Production) project with the goal of providing reference imaging material that will aid in the processing, evaluation, and calibration of in-camera visual effects between the LED wall and the camera.

This report reflects our emphasis on creating an environment of greater proactive collaboration between MITC committees that will better facilitate our agenda to develop project driven solutions to challenges emerging in the adoption of software defined, nonlinear production/post-production workflows that utilize cloud-based connectivity and storage for image processing and sharing, along with metadata.

This report showcases the work of various MITC projects that are crucial to the evolution of advanced software defined, nonlinear workflows.

I would like to express my appreciation to all those who have demonstrated their dedication and applied their tremendous skills to MITC's important projects and analytical research.

Secretary's Comment

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

Modern motion picture equipment, workflows, and technology are predominantly digital, and we are seeing the rapid pace of change, development, and deployment that are characteristic for digital products and industries. For nearly two decades the ASC MITC (was ASC Technology Committee) has led the moving image industries through developing and utilizing these technologies in support of moving image artforms. This has been made possible by the participation of an exceptional collection of ASC and industry volunteers, with an exceptional collection of knowledge and experience.

Recent manifestations of this intense change include virtual production, enabled in part by new display technologies and new workflows, and now "daily" things like previsualization have remade how most features are made. And ASC MITC continues to develop and introduce essential tools – ASC CDL, and the new ASC MHL and ASC FDL.

For a review of the steps leading up to today see our 2021 and older Progress Reports. To see what is happening right now, see this 2022 Progress Report and our coming articles. (Like AI, Computational Imaging is now unnoticed in most of the developed world's pockets. Plenoptic Imaging – not yet.)

The ASC was formed 104 years ago by and for cinematographers 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.

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Next Generation Cinema Display Committee

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

Standard Evaluation Material Version 2.0 (StEM2) Project

Chair: Jay Holben

In 2004, the original StEM (ASC-DCI Standard Evaluation Material) set the quality requirement for the more than $3.5B transition from film to digital systems for theatrical exhibition. With the march of technology, significant changes have occurred in the methods for capturing and distributing imagery, and the expectations and needs of both cinema and TV production and exhibition systems have changed. Following on our own tradition, the American Society of Cinematographer's Motion Imaging Technology Council (ASC MITC) created the Standard Evaluation Material II (StEM2) as a 17-minute short film called *The Mission* that is available for open industry access.

The Mission has been carefully crafted by ASC cinematographers and Associate members, image scientists, colorists, manufacturers, and technologists; all of whom closely collaborated to conceive this production. *The Mission* provides a cinematic selection of media that is indicative of a typical Hollywood tentpole production.

The project was accomplished under the leadership of the ASC MITC Next Generation Cinema Display Committee (NGCD). In **Fig. 1**, the left images are shots from the actual film and the right images are from the behind-the-scenes footage. The behind-the-scenes video and other information about the creation of *The Mission* are now available on the ASC website at https://theasc.com/asc/stem2.

The Mission contains a wide variety of locations; including daylight interior and exterior, night interior and exterior, from bright high-contrast desert to dimly lit dank cave. The narrative also includes action, multiple examples of high dynamic range (HDR), wide color gamut (WCG) material, high-resolution detail, diversity of skin tones, computer graphic animation, and the incorporation of the latest production techniques including in-camera visual effects (ICVFX) shot on a light emitting diode (LED) volume. Additionally, various audio tracks are available from Dolby Atmos to 5.1 surround sound for evaluation. The production used the Academy Color Encoding System (ACES) and employed strict color calibration across all devices and

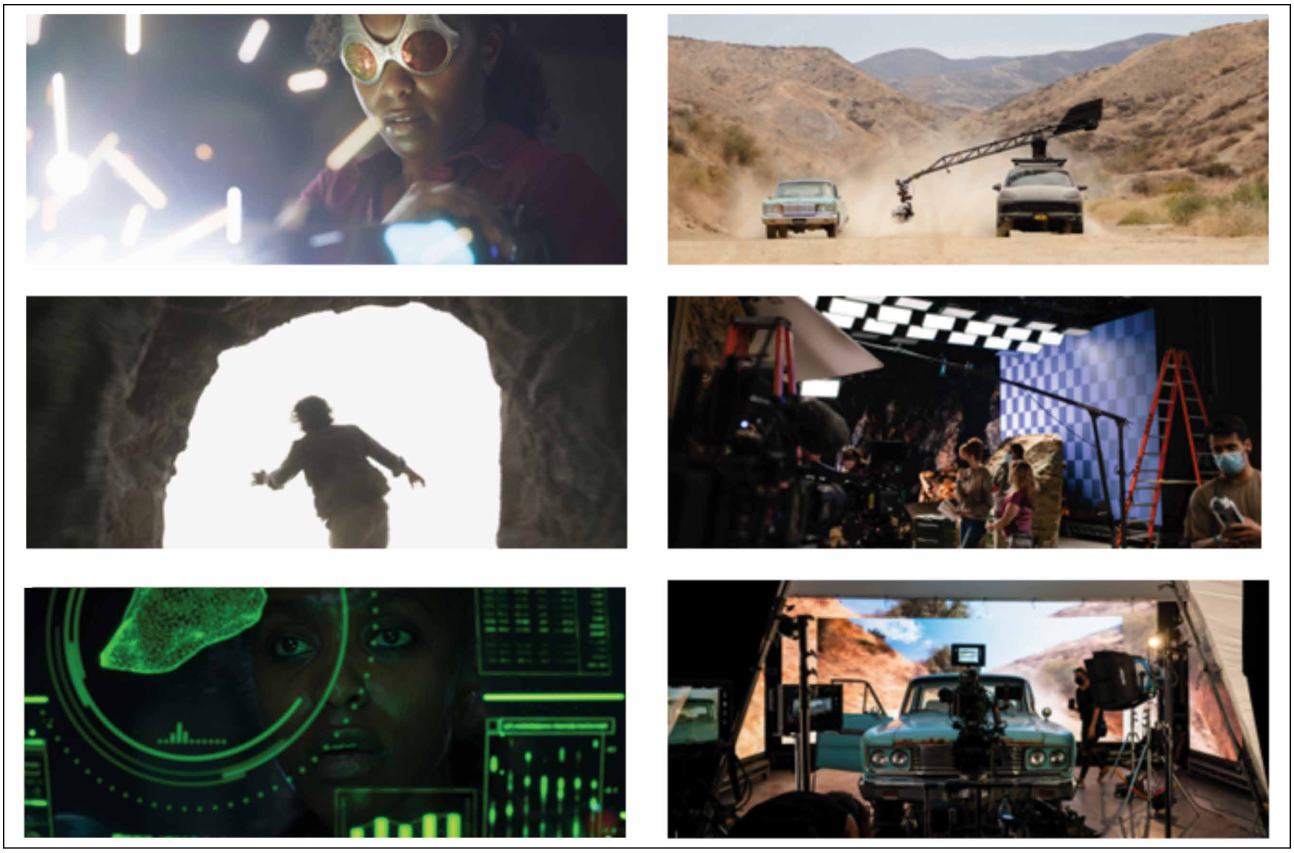
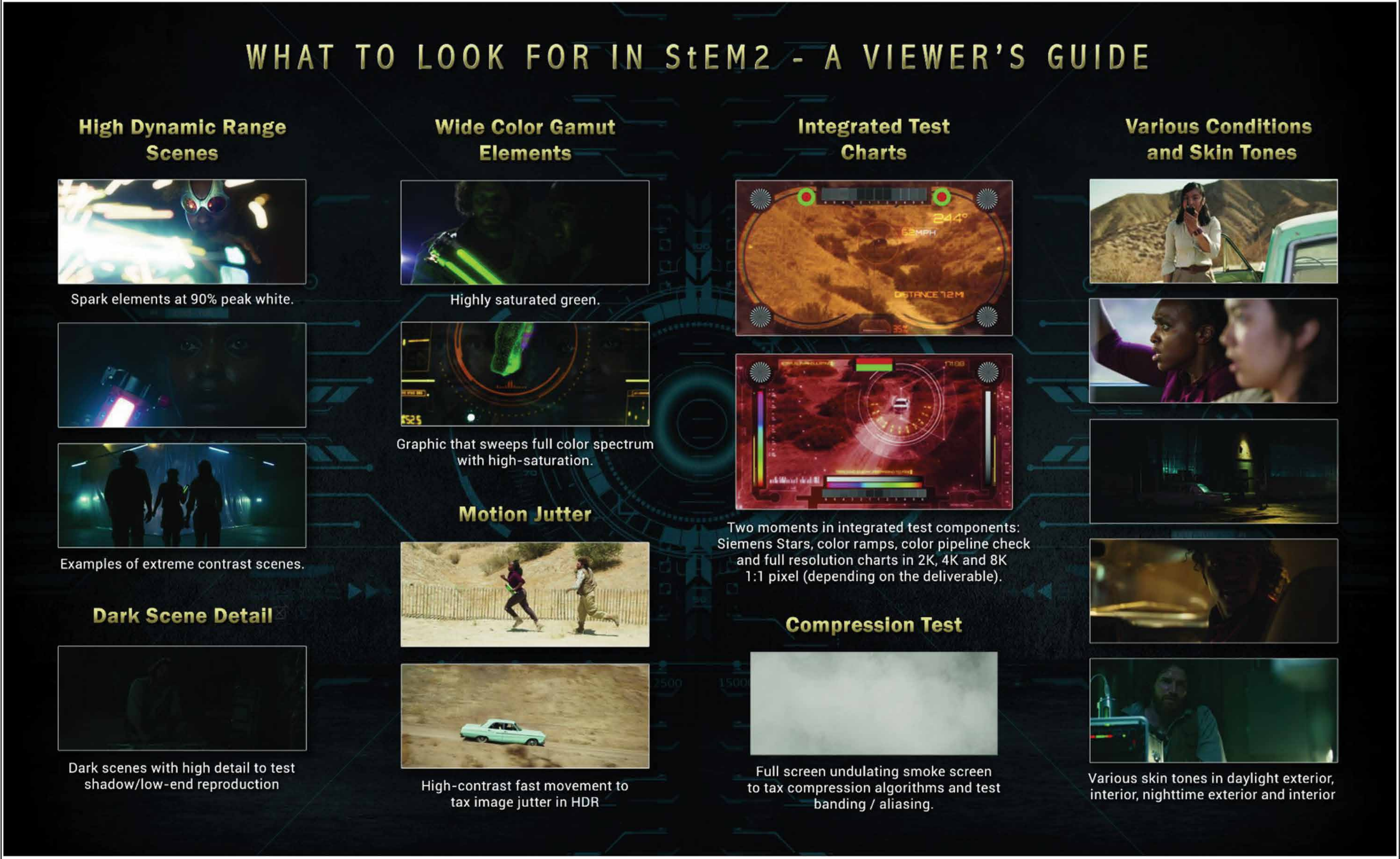


FIGURE 1. Production images on the left: top and center showing shots stressing dynamic range, bottom showing CGI image stressing color gamut. Behind-the scenes images on the right: top showing live location, center and bottom showing use of virtual set for cave scene and interior close-ups of car chase.



WHAT TO LOOK FOR IN StEM2 - A VIEWER'S GUIDE

High Dynamic Range Scenes

Spark elements at 90% peak white.

Examples of extreme contrast scenes.

Dark Scene Detail

Dark scenes with high detail to test shadow/low-end reproduction

Wide Color Gamut Elements

Highly saturated green.

Graphic that sweeps full color spectrum with high-saturation.

Motion Jutter

High-contrast fast movement to tax image jutter in HDR

Integrated Test Charts

Two moments in integrated test components: Siemens Stars, color ramps, color pipeline check and full resolution charts in 2K, 4K and 8K 1:1 pixel (depending on the deliverable).

Compression Test

Full screen undulating smoke screen to tax compression algorithms and test banding / aliasing.

Various Conditions and Skin Tones

Various skin tones in daylight exterior, interior, nighttime exterior and interior

TABLE 1. StEM2 *The Mission* download formats.

QUICKTIMES
Quicktime with stereo, 1.78 @ 2K, 100 nits, Rec709, 1920x1080
Quicktime with stereo, 1.78 @ UHD, 100 nits ProRes422HQ, Rec709, 3840x2160
Quicktime with stereo, 1.78 @ UHD, 1000 nits DNxHR_HQX, Rec2020
Quicktime with stereo, 1.78 @ UHD, 1000 nits ProRes4444XQ, Rec2020
Quicktime with stereo, 2.39 @ 4K, 100 nits ProRes422HQ, Rec709, 4096x1716
Quicktime with stereo, 1.78 @ 8K, 1000 nits MPEG-5, Rec2020, 8192x343
DCPS
48 nits, EOTF 2.6, P3
108 nits, EOTF PQ, P3
300 nits, EOTF PQ, P3
IMF
lossy SDR App 2E
lossy HDR App 2E
lossless HDR App 2E
DCDM App 4 (HTJ2K)
App 5
SINGLE FILE EXR
Single file movie in EXR - ACES AP0 LIN ST2065-1, 2.39, 4096x1716
Single file movie in EXR - ACES AP0 LIN ST2065-1, 1.78, 3840x2160

processes. A Viewer's Guide (**Fig. 2**) of some of these complex elements of the production photography can be found on the previous one-page spread.

Over the course of nearly three years of planning, production and post, *The Mission* was created by a cast and crew of over 100 individuals. Actual production was shot over the course of five days on location in and around Los Angeles, California as well as on stage and utilizing a virtual environment on an in-camera visual effects LED Volume. More than 30 of the industry's leading studios, manufacturers, support facilities, and trade organizations lent a helping hand to see this project come to fruition.

The Mission is a fast-paced high-octane short film following three scientists in search of a mysterious ore. As they excavate the glowing element from within a deep cave, the forces of evil close in to thwart their efforts. The scientists get their prize and are immediately pursued by the darker forces requiring a fast and fantastic escape. As a neutral third-party, the ASC originated this short to provide meticulously curated and entertaining material that will technically stress and demonstrate imaging tools without concern of copyright violation or conflict of origination. Information about StEM2 and the creation of *The Mission* is now available on the ASC website at https://theasc.com/asc/stem2. The site also provides a link to the Academy Software Foundation (ASWF) https://dpel.aswf.io/asc-stem2/ where the material can be downloaded in a multitude of delivery formats (**Table 1**) for the professional imaging community to test and demonstrate theatrical projection and emissive displays, professional and consumer monitors, and postproduction image-processing software and hardware.

The ASC StEM2 team thanks the ASWF for their on-going collaboration to host these materials for public access. This project could not have been accomplished without the tremendous support of many volunteers and corporate contributions of services and funds.

Motion Imaging Workflow Committee

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

Since our last report, our Workflow Committee saw most of its activity in the Advanced Data Management (ADM) Subcommittee. We continue to experience rapid changes in workflow, accelerated due to COVID, requiring flexible inter-connected frameworks as pre-production, production, and post-production teams work together, yet remotely. We are certainly continuing to walk down the path outlined in MovieLabs' white paper on software-defined workflows (see MovieLabs white paper https://movielabs.com/production-technology/sdw/).

StEM2—The Standard Evaluation Materials (StEM2) project presented another opportunity to develop new workflows involving metadata capture to help tie various production elements together, such as on-set virtual production. We realized that there's still much to be done to truly develop integrated systems leveraging the myriad of metadata generated by disparate tools. Various efforts are under way with a solid cross-section of ASC MITC members and other groups, such as SMPTE Rapid Industry Solutions (RIS). See the full report from StEM2 working group leads in this issue.

ACES—ACES 1.3 has recently been released. New features and enhancements include new gamut compression that fixes the blue clipping issue, and an update to the ACES Metadata File (AMF) to make it more flexible transferring looks in production workflows.

A new set of Output Transforms (RRT – Reference Rendering Transforms) is in the works for ACES v2.0.

Advanced Data Management Subcommittee

Chair: Jesse Korosi
Working Group Leads: Patrick Renner (ASC MHL), David Hall (ASC FDL)

The Advanced Data Management (ADM) Subcommittee of the American Society of Cinematographers (ASC) MITC has been hard at work over the last year hitting several noteworthy milestones. The subcommittee takes on multiple initiatives, each with its own virtual working group that includes subject matter experts across the production lifecycle. The working groups are chosen based on the specific initiative at hand, along with key implementers of tools that would ultimately roll out the solution.

Ensuring the cinematographer's intent is preserved through the course of any project is something our team at ASC MITC feel passionately about. We believe the ADM initiatives will not only streamline workflow efficiency, but also reduce human error and communication deficiencies.

Framing Decision List

The complexity of accurately preserving the filmmakers' framing intent has become much more challenging over the last decade. Cameras record in a myriad of resolutions, while having different protection areas and varying delivery aspect ratios on every project. Even with this added complexity, the process for providing framing information between departments has for the most part remained the same. ASC MITC aims to take on this challenge in our subcommittee. The ASC Framing Decision List (FDL) will standardize the necessary information required to translate framing from initial capture through to final delivery, reducing human error and operational inefficiencies.

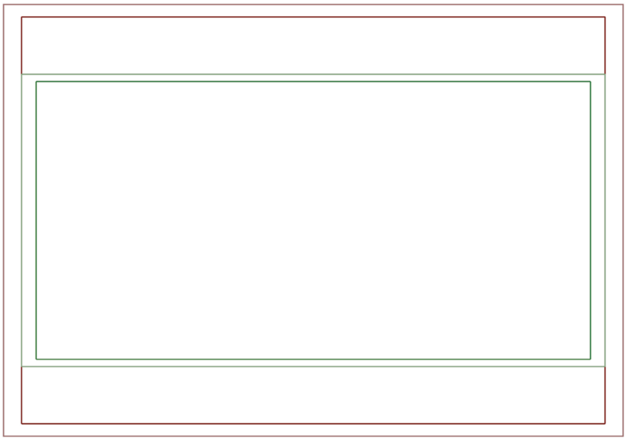


FIGURE 3. Organization of the data within an FDL (in JSON format).

For a more thorough introduction to this initiative please see last year's Progress Report in the *SMPTE Motion Imaging Journal,* which thoroughly describes the problem we're attempting to solve. Here, we introduce some of the key classes that comprise and organize the data within an FDL (in a JSON format). Illustrated in (**Fig. 3**).

Framing Intent/Framing Intent Protection

This is the region within which an image author will compose content intended for the viewing audience. A project (and therefore, FDL) may contain multiple Framing Intents. In this key first step, the intended frame is a chosen aspect ratio, unbounded by the constraints of any camera or device. For example: 2.39:1. A Framing Intent can be reduced in size relative to a region you intend to capture. The resulting bounding region is called Framing Intent Protection. While this region is defined outside of the Framing Intent, because of its association it maintains the aspect ratio of the Framing Intent. A Framing Intent Protection can be used to account for stabilization, reframing in post, and more.

Canvas/Effective Canvas

This region defines the active coordinate system of an application, file, or video stream. An FDL is associated with those active coordinates. For example, a camera may have various recording modes with different pixel dimensions, each requiring its own FDL. A Canvas can only be generated once the system creating it understands what the recorded/generated area is going to be. A Canvas can be effectively constrained to prevent a Framing Intent and its Framing Intent Protection

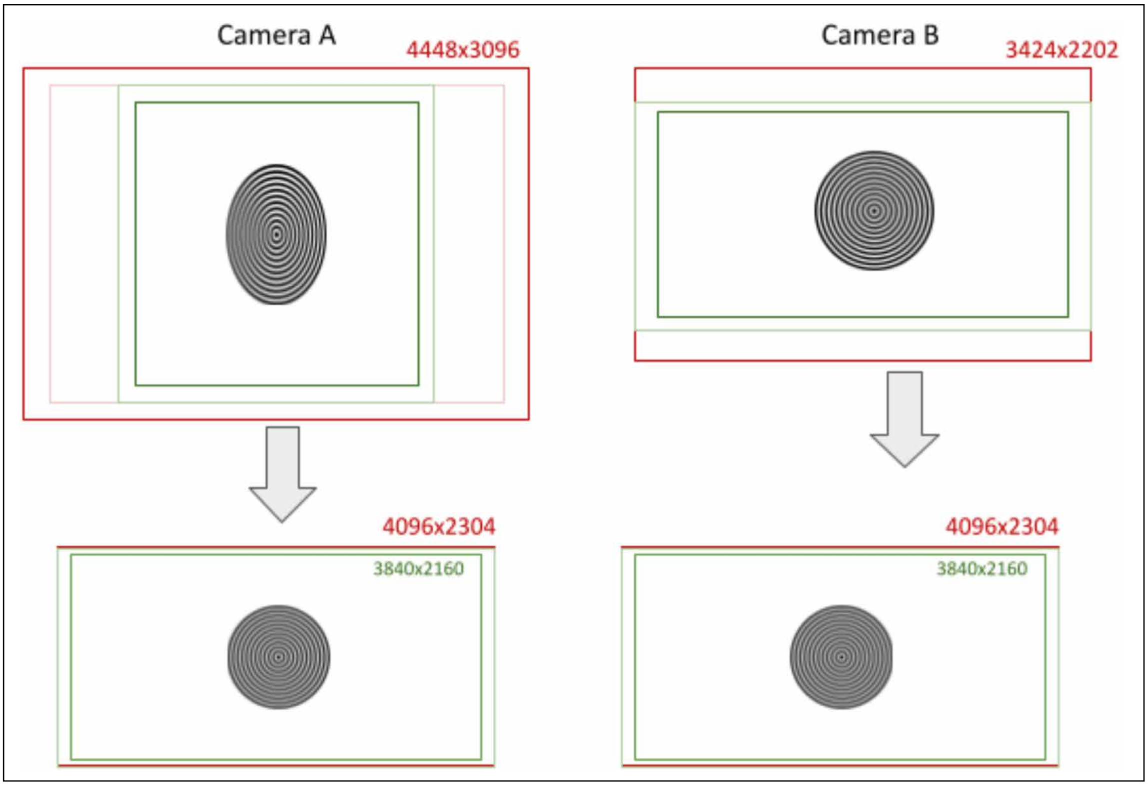


FIGURE 4. Using a Canvas Template to normalize two incoming formats.

from being applied outside its bounds. This is called an Effective Canvas. As an example, an image author may choose to use an Effective Canvas if a lens adds vignetting to the image, making the outer regions of the canvas unusable.

Framing Decision/Framing Decision Protection

When a Framing Intent (and its Framing Intent Protection) is applied to a Canvas, two decisions are produced:

1 – The final and most important decision describes the region of content intended for a viewing audience, applied within a particular Canvas. This is called a Framing Decision.

2 – The outer decision defines the pixels you have protected for. This is called the Framing Decision Protection.

Each of these key classes contain attributes that allow the ASC FDL to be able to be shared between previsualization, on-set, and post-production stakeholders to convey the intended frame across phases of production. This significantly reduces the need for manual work to verify and preserve creative intent.

In addition to the core FDL classes, the ADM committee created an additional class of attributes defined as a *Canvas Template*. If the key classes shown in **Fig. 3** are a receipt of sorts for known captured sources and their framing data, a Canvas Template is a set of framing instructions that map unknown source canvases (and their associated FDL data) into a new, defined canvas.

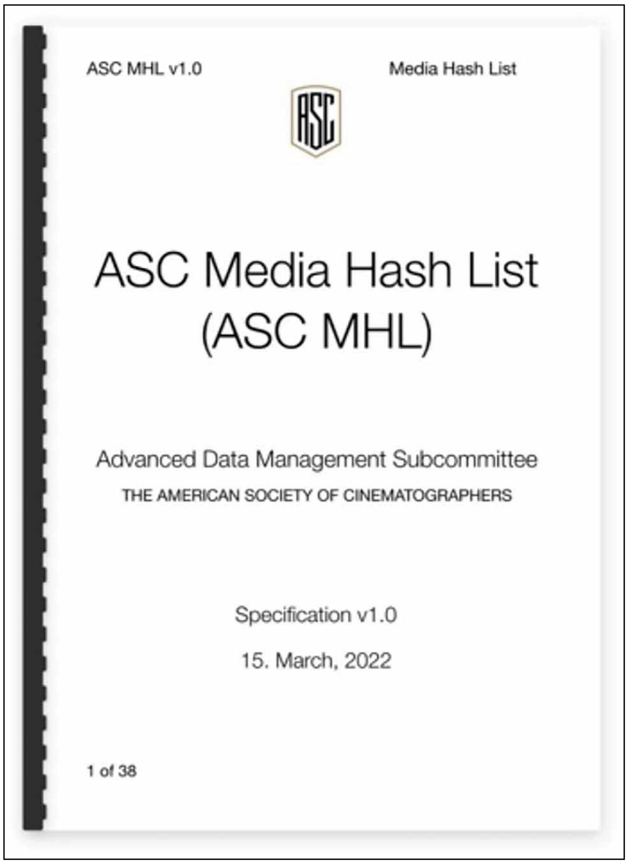
As an example, if various cameras and resolutions were captured during a production, the VFX Supervisor or Picture Finishing Facility may want to ensure that all VFX plates generated from those sources are normalized to a common container before delivery to vendors. While an ASC FDL does not require a Canvas Template, the Canvas Template provides the mechanisms to ensure the above scenario, regardless of incoming sources.

In this example in (**Fig. 4**), we see two different incoming formats. By utilizing a Canvas Template and its associated attributes, we can normalize each of these, so the Framing Decisions fit into the UHD 3840 x 2160 raster, and the resulting canvas has a defined maximum dimension.

ASC Media Hash List

Using hashing algorithms (such as SHA265 and xxhash) is the established way of verifying file integrity for data storage and transport. In the past years, file-based workflows have become more and more integrated (e.g., between locations, vendors, service providers, etc.). Therefore, a standardized way to transport hash values and their association with media files as a record of integrity has become a vital requirement.

In the last two years, the ASC MHL working group developed the ASC MHL (ASC Media Hash List)



ASC MHL v1.0

Media Hash List

ASC Media Hash List
(ASC MHL)

Advanced Data Management Subcommittee
THE AMERICAN SOCIETY OF CINEMATOGRAPHERS

Specification v1.0
15. March, 2022

1 of 38

FIGURE 5. ASC Media Hash List (ASC MHL) Specification v1.0, March 15, 2022.

specification to respond to this requirement. ASC MHL defines an exchange format that records hashes and files and keeps track of the history and life-cycle of media files throughout media workflows. It is intended to be implemented by facilities and vendors to extend their data management systems to enable reliable and interoperable data exchange workflows.

Group members from data management vendors, studios, facilities, and end-users from set and post-production transformed a range of typical data management use cases into a robust specification. The use of ASC MHL ensures the integrity of files and the completeness of data sets consisting of many files.

The group finalized its documentation and released the “ASC Media Hash List (ASC MHL) Specification” in version 1.0 on 15 March 2022 (**Fig. 5**). The specification document is published on theasc.com.[i] Also, an open-source reference implementation is available on github.com.[ii]

Different vendors have already announced the development or even availability of new versions of their data management software with support for ASC MHL. An implementation guide that is currently in the works by the working group will further support such efforts. More implementations are expected to become available in the following months, and facilities and studios should be able to start implementing the first workflows based on ASC MHL soon.

Joint Technology Committee on Virtual Production

Chair: David Morin
Vice-Chair: Michael Goi, ASC
Vice-Chair: Mike Sander
Vice-Chair: Jay Holben

2021 has seen an extraordinary growth in virtual production, particularly in the field of in-camera visual effects (ICVFX) on LED volume XR stages for motion picture and episodic production. What was a pioneering concept from Lucasfilm on *The Mandalorian* in 2018 has now become the modus operandi for many productions of all scales. With continuing series such as *The Mandalorian* (season 2), *The Book of Boba Fett*, and *Obi-Wan Kenobi,* Disney and Lucasfilm continue to capitalize on transporting the production to new worlds without ever leaving the stage. One of the pioneers of this technology, Greig Fraser, ASC, ACS, who initially incorporated LED wall interactive lighting on *Rogue One: A Star Wars Story*, carried the technology with him to the latest incarnation of the Caped Crusader in *The Batman*. Former ASC President Michael Goi, ASC, ISC, is currently deeply embroiled with virtual production and one of the biggest LED XR stages in the world for Netflix’s *Avatar: The Last Airbender* series, serving as director and cinematographer on the first two episodes of the epic production as well as being an executive producer of the series. Additional high-profile productions include Paramount Plus’ *Star Trek: Discovery* (**Fig. 6**) as well as scenes in the new season of *Picard and Strange New Worlds*. Netflix recently released *Our Flag Means Death,* that was shot entirely on an ICVFX stage, and *Through My Window*, a teen romantic drama shot in Spain (See **Fig.** 7 for an example of a Netflix production virtual stage.). In India, motion pictures such as *Radhe Shyam* have shot on ICVFX stages. In another use of LED walls, the *Muppets*: *Haunted Mansion* exploited the technology during the height of the COVID-19 pandemic to craft the environments of the famous amusement park ride for nearly the entirety of the production. In the last year, the number of ICVFX stages have grown at an accelerated pace into the triple digits worldwide (**Fig. 8**). Epic Games has just released Unreal Engine version 5, which is slated to soon be rated for production use and is poised to be yet another game changer for the technique. Smaller

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[i] https://theasc.com/asc/asc-media-hash-list
[ii] https://github.com/ascmitc/mhl

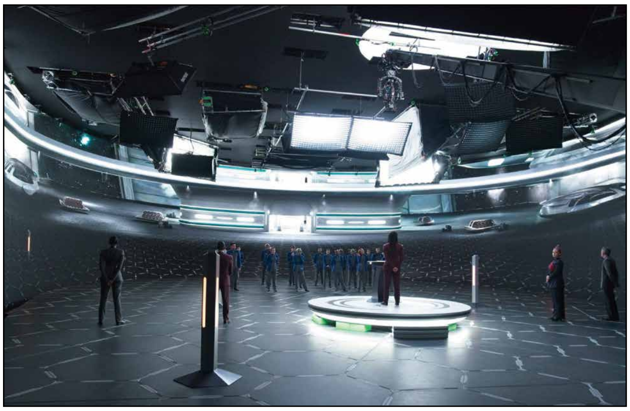

FIGURE 6. Star Trek Discovery Season 4 premiered in November 2021, ushering in a new era for the franchise as it incorporated virtual production for the first time.

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FIGURE 7. Netflix is using Dark Bay at Studio Babelsberg to produce its coming mystery series “1899.” Courtesy Netflix/Studio Babelsberg.

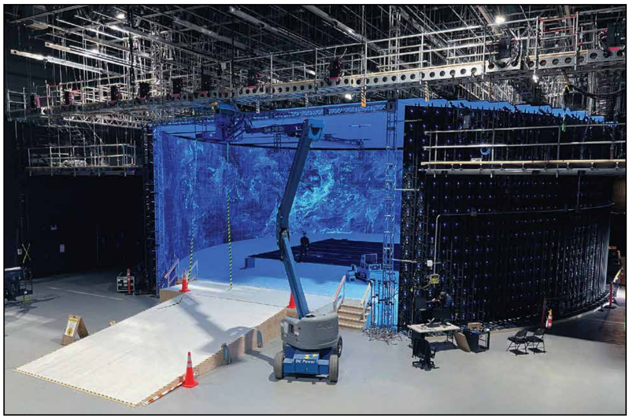

FIGURE 8. Pixomondo virtual production stage in Vancouver, currently in production on a project to be announced soon.

stages are now regularly employed for car process photography, product photography, music videos, commercials, and much more. What was previously under the control of a select few has now grown to become a worldwide phenomenon with more crews and more support specialists coming online nearly every day.

While ROE Visual has dominated the marketplace with the Black Pearl 2 LED panels, many more manufacturers are coming to the fray including Sony and AOTO to provide competitive products.

For cinematographers facing the current proliferation of virtual production LED stages of all sizes and shapes, the following question comes to mind: Is there standard evaluation material that I can use to get familiar with this ICVFX stage in front of me? Today the answer has to be: No.

To this end, the ASC is embarking on a new project to help aid creatives in their continuity of vision and eliminate some of the obstacles of technology in achieving that. Following on the historical success of the ASC-DCI Standard Evaluation Material (StEM) project that was released in 2004 to aid in the qualification of digital theatrical projection systems, and on the recent success of the StEM2 project (see Next Generation Cinema Display – StEM2 in this report), the ASC MITC and MITC Virtual Production Committee will embark on creating StEM3-VP – a collection of material packages that may be utilized to evaluate LED XR Stages and help creatives obtain their visions. The goal of this project is to provide material that will aid in the processing, evaluation, and calibration of in-camera visual effects stages between the LED wall and the camera. This project is still in its infant stages but will be under the leadership of industry veterans David Morin, Michael Goi, ASC, Jay Holben, Curtis Clark, ASC, Wendy Aylsworth, Joachim Zell, Rod Bogart, Gary Mandle, Tim Kang, and other ASC cinematographers, Associate members, color scientists, technologists, and manufacturers to design and craft this material. It will continue the ASC’s legacy of project-based initiatives that serve the cinematographic community in achieving their goals. By providing a package of materials that will offer checks and balances for the whole pipeline of the visual system of a virtual production stage, the ASC MITC StEM3-VP will help refine the workflow to ensure the needs of the cinematographer, director, visual effects supervisor and production designer are met.

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

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

Professional Monitors Committee

Chair: Jim Fancher
Co-Chair: Gary Mandle

We are starting to see a major change in the monitor industry fueled by consumer TV and semi-professional monitor demands. As reported at the 10 May Society of Information Display business conference, the panel

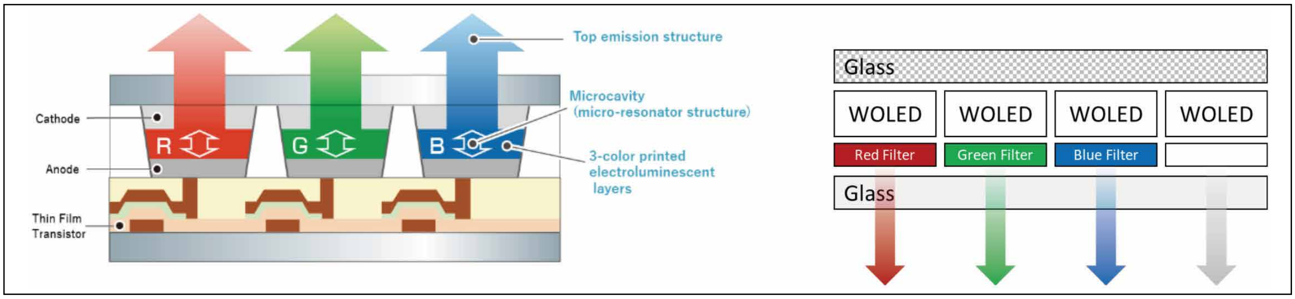

FIGURE 9. JOLED Architecture[1] on the left, WOLED shown on the right.

technology suppliers are split into those staying with LCD manufacturing (mostly in China) and those investing into new display technologies. Primarily QD, OLED, and LED (MiniLED and MicroLED).

These new technologies are expected to be sharing an additional $100B in new revenue above the peak last year in the display market already of $160B. The majority of this is due in part to smartphones and computer displays moving to OLED. The professional monitor market should see a significant benefit from this.

The question becomes "where are the OLEDs coming from?" Most new sources are developing OLED for smartphones. We may see this add to the availability of more models of small on-camera displays with more features such as better touchscreen technology and even "under-display camera" architecture with the camera being placed behind the display.

For professional monitors, we are seeing a quick shift with monitor manufacturers using panels developed by JOLED. There new panels include sizes in 32, 27, and 22 in. The technology uses top emission RGB OLED with micro resonance cavity tuning. This may sound familiar as it is a similar OLED technology that Sony used for their professional panels. The difference being that Sony manufacturing used a vapor deposition method where JOLED is using a lithographic method called "TriPrint." This is no surprise, as JOLED is a partnership between Panasonic and Sony. This differs in many ways from the technology LG is using (WOLED) where every pixel is an OLED stack combining emitters to make a white pixel and then applying RGB filters for each color primary (**Fig. 9**).

With a new OLED supplier, several new 4K monitor models have been announced that will work for production including models from ASUS (ProArt PA32DC) EIZO (Foris Nova), and SmalHD with the MON-OLED-22 and 16-2701. There are also rumors that LG may consider using JOLED panels, though not for their TVs.

Besides developments in OLED, several new and very promising technologies are close to delivery.

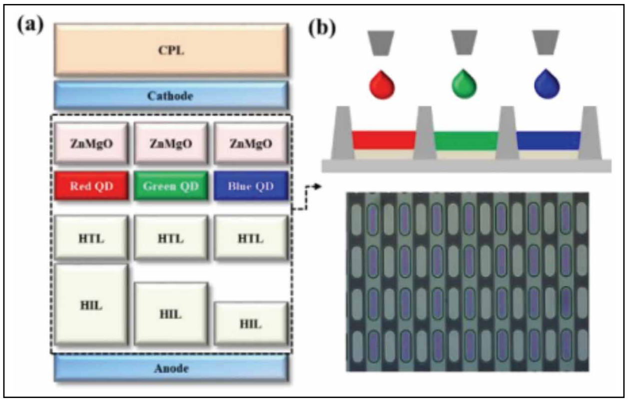

FIGURE 10. Schematic of a "all inkjet-printed" EL-QD device. (a) CPL = refractive index capping layer, ZnMgO = Zinc magnesium oxide, QD = emitter quantum dot, HTL = hole transport layer, and HIL = hole injection layer. (b) Inkjet, emitter solution, and hydrophobic pixel pattern bank.[2]

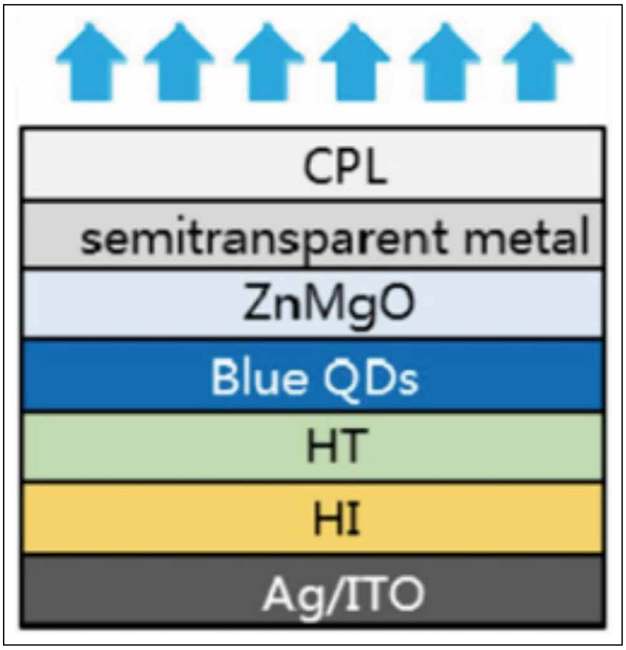

FIGURE 11. Diagram of a basic stacking structure of a QLED device.[3]

At this year's SID conference, a number of companies were talking about new developments in quantum dot. Many appear to be available in the market this year. TCL, BoE, Sharp, and Samsung all talked about Electroluminescent Quantum Dot (EL-QD), as AUO and PlayNitride showed QD color conversion systems (QDCC) and both Samsung and Nanosys showed Quantum Dot OLED (QD-OLED) display panels which were quite impressive.

Samsung presented a paper on an EL-QD that doesn't use cadmium. This technology can be applied

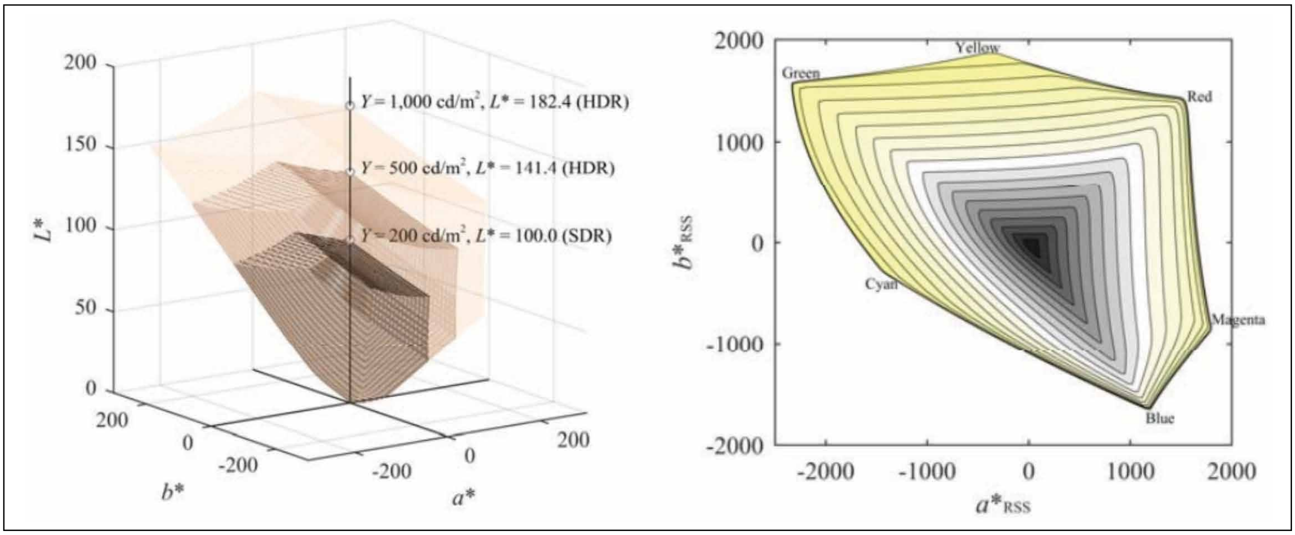

FIGURE 12. On the left is a three dimensional presentation of a display measured at 200, 500, and 1000 cd/m^2. On the right is a gamut ring diagram showing the display at 1000 cd/m^2.[4]

using lithography techniques which has the promise of lower cost and lower environmental impact (**Fig. 10**).

With these developments, Quantum Dot LED (QLED) is moving from a dual layer system to more efficient stacking structures (**Fig. 11**).

Not to be out done, there are still many people working on LCD. One new technology is replacing the RGB filter layout, with which we are all familiar, and using a field sequential backlight system synchronized with the LCD, which would refresh at three times the framerate. The advantage being that there are no subpixels (all pixels are sequentially displaying each color) and resolution can be easily increased.

Display metrology is also changing. It is not that uncommon to graph a display's gamut in a two-dimensional CIE 1931 plot. Prior to HDR this was acceptable. But with the advent of HDR comes the realization that color is a three-dimensional property, and any real measurement needs to include luminance if accurate comparison is needed. The CIE published CIE 168:2005, which defined a criteria for a three dimensional color gamut measurement. New this year, the International Committee for Display Metrology published a revised metrology standard which embraces this CIE procedure.[iii] But they've added a new twist called "Gamut Rings" based on research at NHK.[4] This provides a graphic that easily shows any hue or chroma shifts as well as gamut size throughout the display's full luminance range using CIE L*a*b* scaling as a two-dimensional graph (**Fig. 12**).

Also added to the International Display Metrology Standard are sections on gamut intersection measurement, gamut volume, HDR measurement, color-based image retention measurement and measurement of light field displays.

8K seems to be gaining more acceptance with a large number of models available for the consumer. Professional monitors are just now coming to market. Two companies who have introduced 8K professional monitors are Astrodesign and Postium. Both are LCD based.

Finally, there is a research project hosted by Baylor University, which is working on expanding the gamut of a display by adding more color primaries.

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Lighting Committee

Chair: Tim Kang
Vice-Chair: Jon Miller

Since its formation in 2019, the ASC MITC Lighting Committee—a group including cinematographers, lighting fixture and controller manufacturers, lighting technicians, and color scientists—has focused its efforts upon determining the best industry practices in light fixture technical standards, advanced lighting techniques, and devising educational efforts for cinematographers and lighting technicians to learn about these aforementioned developments as follows:

[iii] Available for free at https://www.sid.org/Standards/ICDM#8271483-idms-download

First, the Color Science (CS) subcommittee identified in 2019 the need to create spectral standards for both white light and for saturated colored light. White light posed little challenge, since the Illumination Engineering Society (IES) created TM-30, a color rendering metric, that specifies Planckian Blackbody spectrum for color temperatures below 4000K, CIE (International Commission on Illumination) Daylight spectrum for color temperatures above 5,000K, and a proportional spectral blend between the two specifications between 4000K and 5000K.Second, saturated light has posed a more significant challenge and, hence, forms a still ongoing task. The current philosophical approach has favored spectral targets as broad as possible for any specific hue on or close to the spectral locus seen by a CIE 1931 2 degree observer. The nature and proper definition of these targets has formed the basis of significant contention.

Third, the CS subcommittee has differentiated spectral definitions for a lighting fixture's given colorimetric coordinate as a distinct, and equally important, technical specification from colorimetry. It has started work with the Education subcommittee to educate the motion picture industry on this distinction and all of its downstream ramifications. Fourth, the Integrated Systems subcommittee has observed and participated in the widespread adoption of Virtual Production workflows. In-Camera Visual Effects (ICVFX) with LED video screens have introduced Image-Based Lighting (IBL)—a lighting method previously used within the computer graphics imagery (CGI) discipline by the VFX community—to principal photography lighting practices in recent years. Unfortunately, typical IBL color management workflows and frameworks have proved inadequate to control lighting due to the lack of spectral standards needed by lighting.

IBL has now evolved into a principal photography lighting workflow where video content can drive lighting fixtures in any filming context. In ICVFX virtual production shoots, the content driving the LED video screens also extends to driving lighting fixtures.

Fifth, although lighting fixtures and media servers have grown in intelligence, the lighting data communication infrastructure currently enabling IBL in practice still depends upon archaic lighting data communication protocols and infrastructure that limit essential lighting color data for fully robust IBL implementations.

While modern lighting fixtures can provide relatively full white light spectral fingerprints for photographic use in multi- or single-pixel arrays, fixture data protocols must evolve to communicate all necessarily color and other device parameters to do so: video colorimetry (color gamut, white point, and electro optical transfer functions), spectral definitions for colorimetry, beam characteristics and orientation, and any other host of advanced fixture control parameters.

Sixth, Integrated Systems will seek and evaluate any unified, device-independent control and metadata infrastructures for video and lighting systems to generate predictable outcomes regardless of manufacturer, device type, color space, media source, and control system.

Finally, the MITC Lighting Education Subcommittee will plan a virtual production and On-Set IBL seminar for ASC Member DPs and industry professionals seeking to understand current lighting demands and challenges to streamline on-set image based lighting.

Advanced Imaging Committee

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

Some color image processing pipelines make use of maximum and/or minimum of color primaries (usually Red, Green, and Blue primaries). One common pipeline uses the maximum with a tone curve as a gain, although there are many ways the maximum and/or minimum may be utilized. Some such systems are quite recent, although others have been around for decades. It seems likely that the implications of such recent pipeline processing steps are not fully recognized, especially in the context of working with high dynamic range (HDR) and wide color gamut (WCG) images.

In the 1970s, the Hue, Saturation, and Value (known also as "HSV") color space was introduced. We will use HSV as a typical example, since HSV is fairly well known. The HSV color space uses the maximum of Red, Green, and Blue primaries for Value, and that maximum minus the minimum of Red, Green, and Blue for "Chroma." Saturation in HSV is Chroma divided by Value. We will use "MAX(RGB)" to designate the maximum of Red, Green, and Blue, and "MIN(RGB)" to mean the minimum of Red, Green, and Blue. Chroma in HSV is thus MAX(RGB)-MIN(RGB).

The use of the maximum (MAX(RGB)) and maximum minus minimum (MAX(RGB) minus MIN(RGB)) of Red, Green, and Blue are problematic. As we shall see, MAX(RGB) and MAX(RGB) minus MIN(RGB) are inconsistent with respect to typical camera noise. Most cameras have lowest noise in Green, higher noise in Red, and often significantly higher noise in Blue than either Red or Green. When the maximum switches from one of Red, Green, and Blue to another of Red, Green, and Blue, the noise level abruptly changes.

Further, MAX(RGB) and MAX(RGB) minus MIN(RGB) have abrupt slope changes (discontinuous first derivatives) at the crossover points. These can be potentially visible, and are known as “Mach Bands” in computer graphics (common with polygon smooth “Gouraud” shading). The human eye sees an edge in some circumstances at the location of the slope change.

Example Scan Line

To demonstrate the issues with MAX(RGB) and MAX(RGB) minus MIN(RGB) we will create a hypothetical scanline having an increasing or decreasing slope for each of Red, Green, and Blue. In order to demonstrate the noise and slope issues, it is necessary to have one or more crossings in the levels of Red, Green, and Blue across the scanline.

In addition to the test scanline having slopes for Red, Green, and Blue, noise is added at a very small level for Green, much larger for Red, and larger still for Blue.

In the case of MAX(RGB), an additional 0.1 is added to the maximum to separate it from the Red, Green, or Blue test signal (whichever is largest). This is done for ease of visibility.

Noise in MAX(RGB)

In **Fig. 13,** left to right scanline plot, Blue rises above Green, crossing near the middle. On the left is then the very low noise of Green. On the right is the very high noise of Blue. This noise change artifact of MAX(RGB) can be highly visible on natural images in smooth regions.

Noise in MAX(R, G, B) Minus MIN(R, G, B)

In the case of MAX(RGB) minus MIN(RGB), the high levels of noise in Red and Blue greatly increase the resulting noise from MAX(RGB) minus MIN(RGB). Red or Blue can be either maximum or minimum, but one or the other, or both, will imprint noise on MAX(RGB) minus MIN(RGB) (**Fig. 14**).

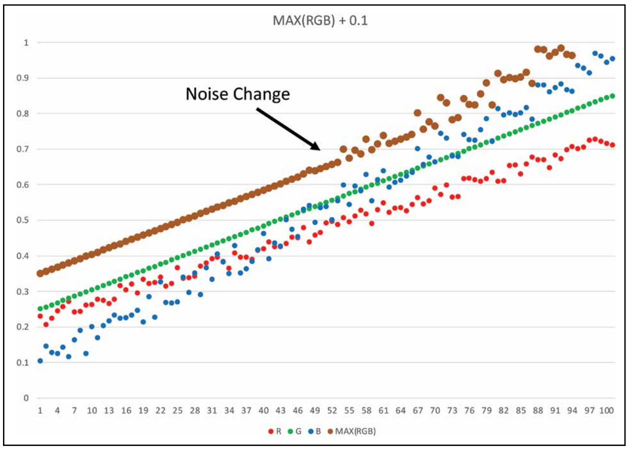


FIGURE 13. Example Plot Showing Noise Change In MAX(RGB). 0.1 is added to MAX(RGB) in order to make the noise change easily visible. The noise is low due to Green on the left. The noise is high due to Blue on the right.

Abrupt Slope Changes Due to MAX(RGB)

When one of Red, Green, or Blue cross to become maximum, the slopes will also change (**Fig. 15**).

The slope change is potentially visible, as with polygon boundaries using Gouraud smooth polygon shading.

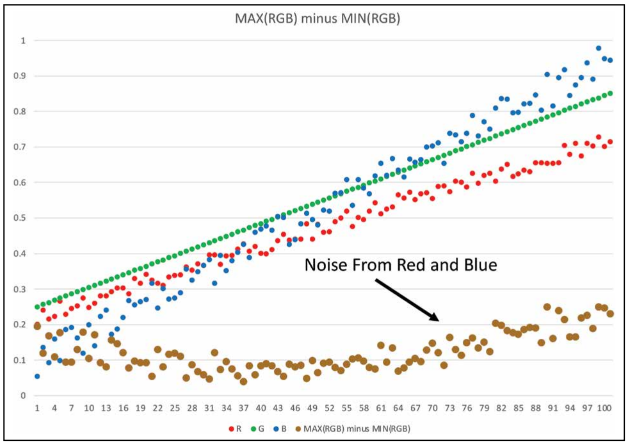


FIGURE 14. Example Plot Showing Noise In MAX(RGB) minus MIN(RGB). The noise level is high due to Red and Blue noise (one or both).

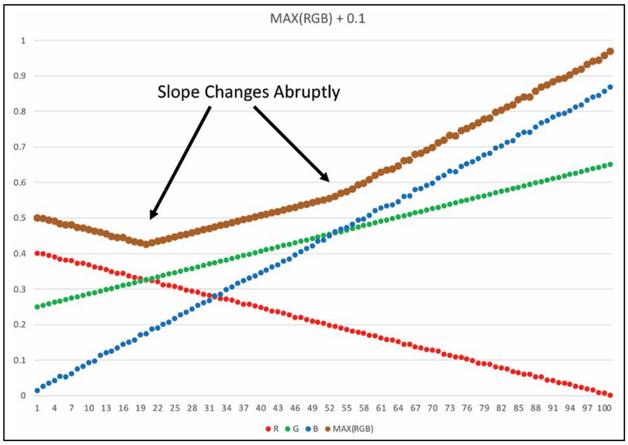


FIGURE 15. Example Plot Showing Abrupt Slope Changes Due To MAX(RGB). 0.1 is added to make the slope of MAX(RGB) easily visible.

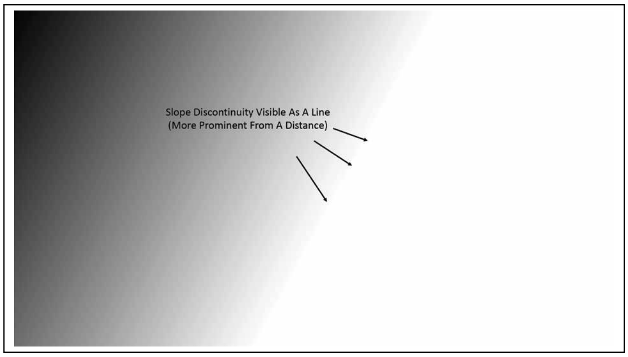


FIGURE 16. Slope Change Example. A line can be seen where the slope changes abruptly. Visibility of the line changes with viewing distance. The line may even disappear when viewed up close.

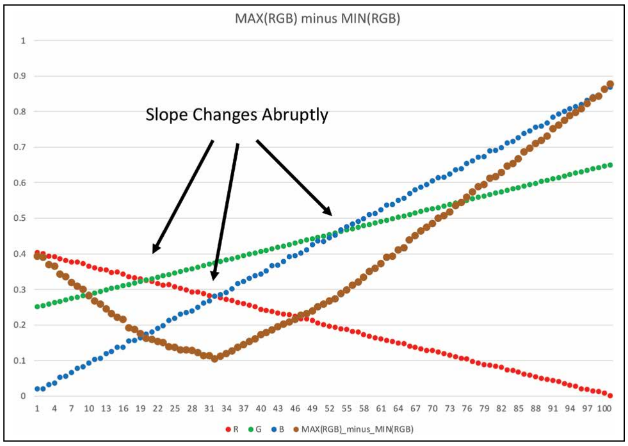


FIGURE 17. Example plot showing abrupt slope Changes Due To MAX(RGB) minus MIN(RGB)

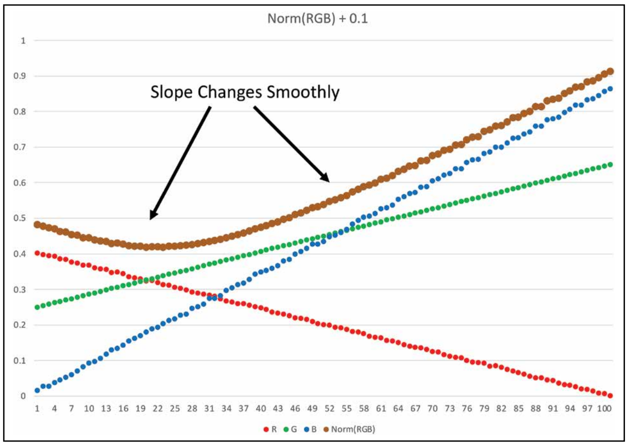


FIGURE 19. Example Plot Showing Smooth Norm(RGB). 0.1 has been added to Norm(RGB) for ease of visibility.

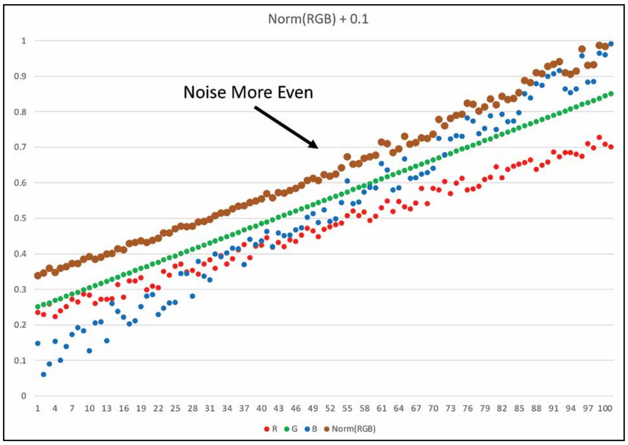


FIGURE 18. Example Plot Showing More Uniform Noise In Norm(RGB). 0.1 is added to Norm(RGB) in order to make the noise level easily visible.

These are also known as “Mach Bands.” An abrupt change in slope, which is a discontinuous first derivative, is still continuous in the zeroth derivative, and yet a line of slope change is potentially visible. The visual prominence of this line is a function of the magnitude of the change as well as the subtended angle (distance to the display). Up close viewing may make the line disappear, whereas the line may be quite visible at a more normal viewing distance (**Fig. 16**).

Abrupt Slope Changes Due to MAX(RGB) Minus MIN(RGB)

In addition to slope changes due to a change in which of Red, Green, or Blue are maximum, MAX(RGB) minus MIN(RGB) adds additional change points wherever the minimum of Red, Green, and Blue changes (**Fig. 17**).

Similar Issues With MID(RGB) and MIN(RGB)

In addition to issues with MAX(RGB) and MAX(RGB) minus MIN(RGB), MIN(RGB) by itself also has similar issues, as does the middle of red, green, blue, which we will call MID(RGB). In other words, MIN(RGB) and MID(RGB) can have noise changes and potential noise magnification, as well as abrupt slope change issues. These issues appear at the crossings, as with MAX(RGB) and MAX(RGB) minus MIN(RGB).

Norm Instead of MAX(RGB)

Instead of MAX(RGB), it is possible to use a norm such as $(R^5+G^5+B^5)/(R^4+G^4+B^4)$. We will call this Norm(RGB). Note that the computation of Norm(RGB) usually requires 32-bit floating point when values of Red, Green, and/or Blue go above one (common in HDR).

The noise level of the norm is more uniform, despite the crossings of which primary is maximum (**Fig. 18**).

Even more significantly, the abrupt slope changes are replaced with smooth behavior, having no visible slope change lines (**Fig. 19**).

Use of the Norm Near Zero

Care must be taken with this norm around zero, and divide by zero must be explicitly handled. The use of an odd power in the numerator over an even power in the denominator allows for negative numbers, although special care is needed given the behavior of this. In particular, the slope is likely to change when any of Red, Green, and/or Blue cross zero into negative values.

Note that thermal camera noise for absolute black may go slightly negative independently in Red, Green, and Blue. Given this, the construction of the norm at black will want to be designed to yield the desired norm result around zero.

We can construct a hybrid for zero and negative numbers being treated differently than positive numbers. For this example, let us assume that we are applying a null tone curve using the norm. A non-unity gain can also be used. This construction yields positive norms for all Red, Green, and Blue values when all are positive.

For zero and negative values, their contribution to the norm is eliminated by setting them to zero if they are negative, and then applying the norm. The norm of one color, let's say Red, becomes Red, if Green and Blue are zero or negative. The norm of two nonzero positive colors becomes $(R^5+G^5)/(R^4+G^4)$ if Blue is zero or negative. Similarly for the other combinations of color primaries.

Zero of Red, Green, and/or Blue remains set to zero. Negative numbers are retained unchanged (or scaled by a gain factor). Thus, if one, two, or three of Red, Green, and/or Blue are negative, they remain negative and unchanged.

It can be seen that this construction is invertible, since any zero-color primary remains zero, and any negative color primary remains negative and unchanged (or scaled by a gain factor).

Single primary colors (with the other two zero or negative) crossing gradually from positive to negative retain a unity (or scaled) slope. All three primaries crossing identically gradually from positive to negative also retain a unity (or scaled) slope. Combinations of two positive non-zero primaries yield a norm that changes slope if they cross zero going negative. This is the only obvious weakness of this construction, with the most beneficial attribute being invertibility.

It should be noted that an average of zero due to thermal noise will still average near zero, with the slope changing a maximum of about 10%. This might be estimated as a noise lift of a few percent on average. Consider this in comparison with clipping up to zero, which will lift the noise floor by about 50% of its magnitude. Also, compare to MAX(RGB), which will also substantially lift the average noise floor.

In the absence of a norm-like and invertible construction including negatives and zero, the input to the norm will probably need to clamp Red, Green, and Blue slightly above zero before applying the norm in its typical form as $(R^5+G^5+B^5)/(R^4+G^4+B^4)$.

This is an area of ongoing exploration.

Summary

MAX(RGB), MIN(RGB), MID(RGB) and MAX(RGB) minus MIN(RGB) are problematic with respect to inconsistent and amplified noise, and discontinuous slope. The noise issues can be especially problematic. These problems are due to noise and slope changes that occur when the maximum, minimum, and/or middle of Red, Green, or Blue changes from one of Red, Green, or Blue to another, and when the maximum minus minimum change either the maximum or minimum of Red, Green, and/or Blue.

We used the example of Hue, Saturation, and Value (HSV) for MAX(RGB), being Value, and MAX(RGB) minus MIN(RGB) being Chroma in HSV, which divided by Value yields Saturation in HSV. However, in addition to HSV, a number of color processing pipelines, including recent ones, have been making use of MAX(RGB), MIN(RGB), MID(RGB) and MAX(RGB) minus MIN(RGB). A norm or other similar mechanisms will usually be preferred.

Digital Intermediate Committee

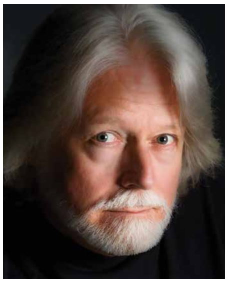
Co-Chair: Lou Levinson
Co-Chair: David Reisner
Co-Chair: Joshua Pines

Key issues for the year ahead remain:

- Updating and clarifying SDR target specs for the 21st century.
- Simplifying and clarifying HDR specs.
- Helping get the snowflakes out of workflows.
- Working to get true full range files to be moveable thru common production and postproduction infrastructure.
- Leave the limits of a broadcast legacy where they belong: behind us.

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 David Reisner at dreisner@d-cinema.us or Lou Levinson at western.light@yahoo.com or Joshua Pines at jzp@technicolor.com.

About the Authors



Curtis Clark, ASC, studied theater directing 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. Curtis received the 2012 American Society of Cinematographers (ASC) President's Award, as well as the prestigious 2019 Motion Picture Academy's John A. Bonner Award in recognition of his extraordinary service to the motion picture industry. As a member of the Academy of Motion Pictures Arts and Sciences (AMPAS), Clark worked on the development and implementation of ACES, the Academy's Color Encoding System. Curtis has also overseen numerous achievements as Chairman of the ASC Motion Imaging Technology Council, which he has helmed since its inception in 2003. Under Clarke's leadership, the Council collaborated with Digital Cinema Initiatives, LLC (DCI) to produce standard evaluation material for assessing the performance of 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. Curtis also supported the Council's groundbreaking project to create cross-platform data exchange for primary RGB digital color correction, known as the ASC CDL (Color

Decision List). The ASC CDL was recognized by the Academy of Television Arts and Sciences with a 2012 Primetime Emmy Award, and Curtis received a 2014 AMPAS Technical Achievement Award for his work on the ASC CDL. Most recently, Clark served as executive producer on the "Standard Evaluation Material V2" (StEM2), the follow-up to the ASC's original StEM project. StEM2 has been created to address the challenges of utilizing an increasingly complex digital motion imaging workflow to create and maintain the integrity of the filmmaker's creative intent. In recognition of his motion imaging technology leadership over the past 20 years, the ASC has created this year a new ASC Award, the "Curtis Clark Technical Achievement Award," which will be awarded annually to a selected recipient acknowledging outstanding technical achievement.

David Reisner received a 2014 Academy Technical Achievement Award, a 2014 Hollywood Post Alliance Judges Award for Creativity and Innovation, and in 2012 was recognized by the Academy of Television Arts and Sciences with a prestigious Prime Time EMMY Engineering Award as co-creator, co-designer, and project lead of the ASC CDL - used in the workflow of nearly every motion picture, scripted TV, and visual effects turnover worldwide. Reisner conceived, proposed, was lead-designer, and co-producer of the ***ASC-DCI StEM Standard Evaluation Material*** which set the quality required to convert the world's movie system from film to digital, and Vice-Chaired the SMPTE Working Groups responsible for digital cinema imaging – showing on nearly all cinema screens worldwide - and security standards – protecting $35B of IP each year. He also had leading roles in conception, design, and production of the ***ASC-PGA CAS Camera Assessment Series***, the ***ICAS Image Control Assessment Series***, and elements of the Academy Color Encoding System. Reisner has been a Founder, a Partner, and a CTO in computer and in entertainment companies. He helped originate digital audio and his "firsts" include the handheld programmable computer, the handheld digital media player, the portable source-level debugger, 57,000-bit Very Very Long Integer arithmetic, and VLIW computer architecture – one of the original enablers of multi-processor computing. He provided editorial assistance on the first textbook on neural network Artificial Intelligence and Machine Learning, originated Pervasive Computing - a parent of Internet of Things/IoT, proposed emergent networking for smart dust, and helped develop the first popular byte-code virtual machine (before Java's JVM). 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 and technical articles, has spoken widely including NAB, SMPTE, IMAGO, and a 29,000-viewer webcast, and on manned space exploration to a standing-room-only crowd at the 2014 International Space Development Conference. He is a SMPTE Fellow; Vice-Chair and Founding-Secretary of the ASC Motion Imaging Technology Council; an ASC Associate; a Member of the Visual Effects Society; a co-author of the "VES Handbook of Visual Effects"; and his committees have recommended some of the highest profile Academy Scientific and Technical Awards.

Jay Holben is an independent producer and director in Los Angeles, CA. A former cinematographer, he is the author of three books on cinematography and editor for *American Cinematographer Magazine*, Holben recently directed, produced and wrote the StEM2 film *The Mission*.

Wendy Aylsworth a Lifetime Fellow and former president of SMPTE, Wendy Aylsworth brings emerging technologies into entertainment production and distribution usage providing technical consulting and strategic board guidance. Wendy is Governor at the Television Academy (Sci/Tech) and on the Hollywood Professional Association board. Wendy received the Jenkins Lifetime Achievement Emmy from the Television Academy. Wendy holds a BSCE (UofMich) and MS/MBA (USC).

Greg Ciaccio, Sr director of Original Content at IMAX, has served in executive operations management positions for Creative Service divisions at Sim, 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.

Tim Kang is a Los Angeles-based cinematographer, working in the film & TV industries primarily as a director of photography on narrative, commercial, music video, and documentary projects.

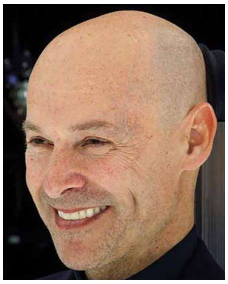
Jesse Korosi is the manager, production technology solutions at Netflix, an Associate Member at the ASC, the 2016 HPA Emerging Leader award winner, Studio Daily Top 50 award winner, the former chair/founder of the HPA's YEP committee, current chair of the ASC's Advanced Data Management subcommittee leading the ASC MHL & ASC FDL initiatives, and HPA's 'Through The Frame' podcast host. With experience in the business and strategy side of post-production, partnered with a technical skill set from working hands on in post and production, and also having personally led several development teams.

Patrick Renner is a specialist in designing and developing media management and video processing applications for production and post-production workflows. He co-founded the software company Pomfort that develops applications and services used in professional film productions worldwide. Renner is a Working Group Lead of the ASC MITC Advanced Data Management Subcommittee and a member of the ACES Implementation Technical Advisory Council.

David Hall is a production workflow technologist at Netflix, providing direct support to a wide range of scripted projects as well as contributing to the evaluation and documentation of emerging technologies and standards.

Michael Goi, ASC, ISC, is a director, cinematographer and producer. He co-chairs the DGA Television Task Force and serves as an alternate to the DGA Western Director's Council and the DGA National Board.

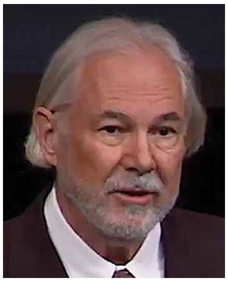
Inquiries regarding the ASC Motion Imaging Technology Council should be sent to Alex Lopez: alex@theasc.com



David Morin is Director, Industry Relations at Epic Games, where he works with the industry and the Unreal Engine team to develop open standards and the use of open- source software. He also serves as the Executive Director of the Academy Software Foundation, a non-profit created by the motion picture industry to develop the use of open-source software in all media.

Gary Mandle is Sr. Research Scientist at Baylor University FDM. He has been working on new display development for more than 35 years as both a design engineer and product strategist. Prior to joining Baylor, he was a Sr. Product Manager at Sony Professional Solutions Group.

Jim Fancher developed next-generation technology in digital asset management for Deluxe Digital Media in Burbank, CA. Previously, he was chief science officer at the Thomson Corporate Research facility in Burbank, where he worked on cluster computing architectures for image processing, 3D color correction systems, and digital asset management technology.



Gary Demos has been a pioneer in the development of computergenerated images and digital image processing for use in motion pictures. He co-founded 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 Demo-GraFX (1988-2003), and Image Essence LLC, Perris, CA (2005 to present). He is a SMPTE Life Fellow, and received the 2012 SMPTE Digital Processing Medal. Demos is also a 2021 VES honorary member. Demos is the inventor of approximately 100 patents.

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