American Society of Cinematographers Motion Imaging Technology Council Progress Report 2021

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ASC Motion Imaging Technology Council Officers
Chair: Curtis Clark, ASC
Vice-Chair: Richard Edlund, ASC
Vice-Chair: Steven Poster, ASC
Vice-Chair & Council Secretary: David Reisner, dreisner@d-cinema.us

Introduction

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

As we reflect on the disruptive impact that the pandemic has inflicted upon our personal and professional lives, I marvel at the resilience of our Motion Imaging Technology Council's determination to continue addressing the rapidly evolving digital imaging technology challenges that are confronting filmmakers. Since its formation in 2002 as the ASC Technology Committee, our agenda over the years has consistently identified the critical technology developments driving the evolution of digital production workflows. The unique nature of our mission has always been the fusion of a solid scientific and engineering knowledge base with a laser focus on how these technologies can best benefit the cinematographer's ability to utilize them to enhance their creative vision.

2021 has been a profound watershed for advancing a new breed of workflow technologies highlighted by virtual production, location flexibility of cloud-based connectivity for all production data storage and image processing, along with the rapidly emerging use of photo-real 3D previs powered by a new generation of gaming engines. No longer dependent on centralized post-production facilities, this new paradigm enables flexible, software-defined nonlinear workflows incorporating realtime, in-camera, compositing linked to geographically dispersed locations that could also include remote access to color grading and editorial, as well as VFX.

Software-defined, nonlinear workflows facilitate enhanced creative collaboration between a director and cinematographer, along with their creative teams, providing more effective and efficient communication throughout all stages of production.

I should also mention that MITC is producing a StEM 2 project, based on a 12-minute short film entitled *The Mission*, written and to be directed by Jay Holben. It will provide new Standard Evaluation Material designed for more reliable evaluation of today's motion imaging performance, including HDR; wide color gamut; ACES color management; 4K vs. 8K image capture; along with display devices for both digital cinema and home.

Our MITC committee reports address the above referenced advances and more.

As always, I want to extend my grateful thanks to all the MITC committee, subcommittee and working group members whose enthusiastic dedication has enabled MITC to be a respected and influential voice within the filmmaking community.

Secretary's Comment

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

The 11 March 2011 magnitude-9 earthquake off northeastern Japan caused a devastating tsunami and triggered a nuclear disaster at the Fukushima Daichi Nuclear Power Plant. The disaster stopped the production of HDCAM-SR tape for some time, forcing many productions to switch suddenly from linear tape to tapeless, file-based digital workflows, and greatly boosted the already well in-progress development of both tapeless recording systems and digital television and movie cameras.

The COVID-19 pandemic of 2020/2021 has had an analogous effect – greatly accelerating already in-progress developments and trends in many areas of human activity, including remote work for general business and very nonlinear, cloud-based post and even sometimes production for movies and television.

The huge disruption of traditional production by these new techniques and technologies, although somewhat masked by the pandemic's disruption of our

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entire world, is pervasive and, like the now common and widespread use of video conferencing and work and school from home, will almost certainly be permanent. But, while we are still exploring, developing, and learning these new approaches and workflows, they are not entirely unfamiliar. They build directly from work that, since its inception, the ASC MITC has been actively exploring and often helping create and guide.

We have already seen some of the great artistic potential of these techniques and workflows. While they will lead us to some unfamiliar places and ways of doing things, these changes are almost certainly permanent and, once we learn how to use them well, will give us new ways to achieve and share our creative intent. The work of every one of our MITC Committees supports both these new and also more traditional ways of creating content.

The ASC was formed 102 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.

Motion Imaging Workflow Committee

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

While 2020 brought with it some significant challenges both personally and professionally for many of us, the Workflow Committee saw most of its activity in the Advanced Data Management (ADM) Subcommittee. Explosive growth, accelerated due to COVID, was realized in virtual production and in remote production, which relies heavily on *software-defined workflows* (see MovieLabs white paper https://movielabs.com/production-technology/sdw/) to help provide for seamless and secure workflows, automating repetitive tasks to further drive efficiency.

Though ADM covers both data and metadata management, we have re-organized our ADM groups to reflect our current initiatives:

- Advanced Data Management Subcommittee
  - ASC MHL (Media Hash List)
  - ASC FDL (Framing Decision List)

Production in the Cloud

Like the SAG strike and tsunami in the early 2010s, which hastened the move from film to tape and then digital files, he pandemic of 2020 accelerated the inevitable transition to cloud-based workflows. Pre-production, production, and post have continued to blend as nonlinear operations and remote collaboration has allowed for many processes to happen simultaneously in a shared environment, with the result of producing 'final pixel'-worthy assets early in the process, and with proxy versions created on-the-fly for Previs or editorial work.

To help ensure that the cinematographer's vision is realized from acquisition to end user, we have already begun laying the groundwork for Cloud and Security work within our committee.

A few members of our Workflow Committee helped produce USC/ETC's latest R&D short "Ripple Effect," which included use cases for SafetyVis, virtual production, and remote production. It was showcased at SMPTE Hollywood Section's April meeting. The ASC MHL was first used on this production. For more info on "Ripple Effect," see www.rippleeffectfilm.com.

Advanced Data Management Subcommittee

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

The Advanced Data Management (ADM) Subcommittee has several initiatives under way, each with a specific and unique problem the teams have set out to solve. Each of these initiatives have their own Virtual Working Group with production and post-production subject matter experts chosen based on the initiative, along with key implementers of tools that would ultimately be used in solution implementation.

We feel strongly about ensuring the preservation of the cinematographer's intent throughout production and believe our initiatives will not only streamline workflow efficiency, but also cut down on human error and communication deficiencies.

Here are the updates from two of our ADM Subcommittee initiatives.

FIGURE 1. Shooting a Framing Chart.

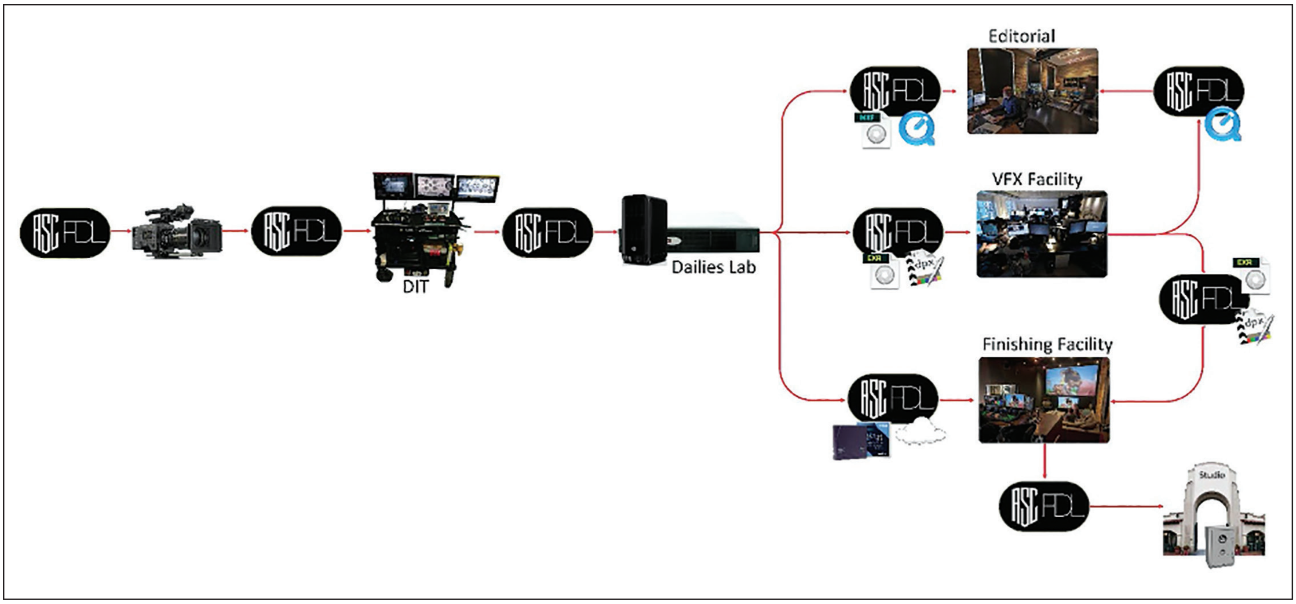


FIGURE 2. ASC FDL Workflow Example.

Framing Decision List - ASC FDL

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 job. Even with this added complexity, the process for providing framing information between departments has for the most part remained the same. ASC Framing Decision List (FDL) aims to standardize the necessary information required to translate framing from initial capture through to final delivery.

Within the film/television industry, the method for providing framing information from set has traditionally been to shoot a framing chart **(Fig. 1)** and provide the recorded camera master to post-production.

These shot framing charts are often distributed to the dailies lab, editorial, VFX, and finishing teams to communicate how to crop and make adjustments to the captured image, ensuring they're working on the cinematographers intended frame.

Some camera systems provide accurate frameline metadata embedded in their recorded files, however these values are often expressed in proprietary schemas that are not universally translatable, nor easily accessible between systems.

If framing metadata is not generated, or is inaccessible, then downstream stakeholders will manually align to the shot charts. Getting all four corners of the frame of a shot chart to line up perfectly along with the four sides of your frame, is near impossible. Factors like lens distortion and spatial misalignment increase the likelihood of inaccurate representation of original framing intent.

So, what does this imply? If two different people or companies were to receive the same captured file with currently available information, there is a high likelihood they will come to different conclusions on what the intended framing is and how to get there. Additionally, scaling and cropping is introduced in many phases of post-production (e.g., editorial, visual effects, finishing) with each phase offering an opportunity for errors to concatenate. With so many handoffs and translations along the chain, there is a significant amount of manual intervention and validation necessary to ensure the final outputs for a project truly represent the filmmaker's intended framing.

The ADM FDL subcommittee is composed of industry professionals from virtual reality, camera manufacturers, DITs, post facilities, visual effects, and studios. Together, we are exploring the creation of a more open, repeatable, and mathematically consistent way of conveying framing information between any departments in production and post that deal with the image in a critical way.

Figure 2 illustrates some of the places in production and post that ASC FDL could be used.

Media Hash List - ASC MHL

The application of ASC MHL is to maintain the integrity and history of a managed data set, such as a camera card with original camera files **(Fig. 3).** With ASC MHL, a film production's staff can create a chain of custody for the managed files and folders. Each copy made after the creation is verified, and the process for each copy is formally documented in its own manifest file. ASC MHL uses hash values for verification (computed using established hashing algorithms, such as MD5, xxhash, C4, and others) and defines procedures to store, transfer, and process these hash values.

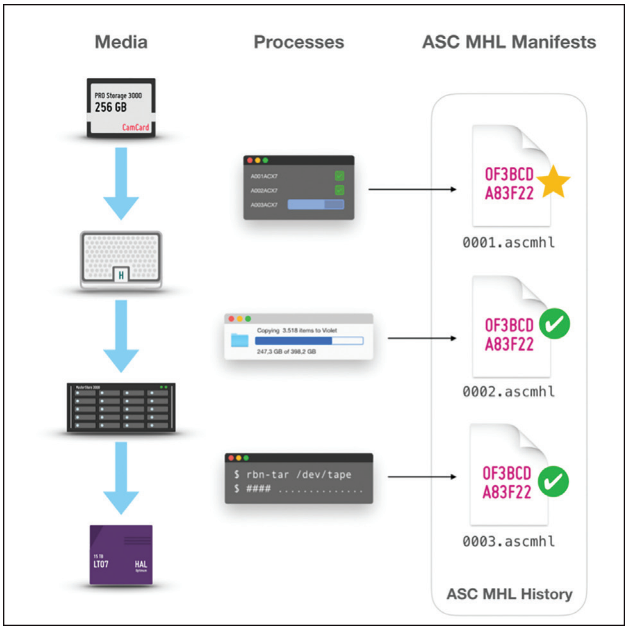


FIGURE 3. History of camera files.

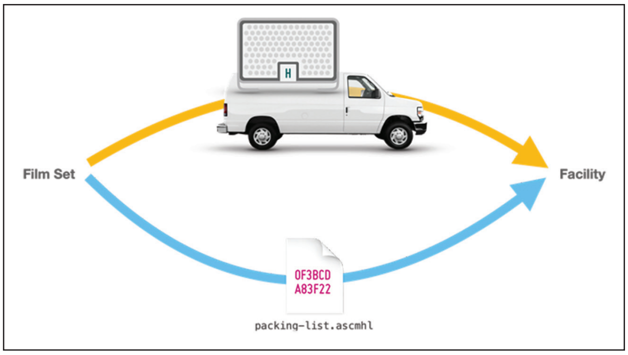


FIGURE 4. MHL Manifest used as packing list for data transfer.

The working group started with a set of basic use cases, such as documenting the copies of files and folders, supporting the use of multiple hash formats, grouping folders together, and carrying informational metadata about the data management process, such as operator information and information about the used storage media and file systems.

Specifying New Use Cases

In discussions over the last few months, it became clear that the scope needs to be extended. With the data flow of the entire production and post-production laid out – starting from the first offload on set to the LTO (Linear Tape Open) archive and final grading – the group discovered several "secondary" use cases that were found to be essential parts of the activities targeted by ASC MHL.

For example, when transferring media from one place to another, the sender and the receiver may want to ensure the completeness of a data transfer separately from the actual data transferred. For that, the group extended the use of ASC MHL manifests to the use case of a "packing list" – representing a snapshot of the transferred data with all known hash values. Such a packing list manifest can be sent, for example, by email or transferred to a cloud system before the actual data arrives **(Fig. 4).**

Other use cases added to ASC MHL's scope: Not all files need to or should be managed by the ASC MHL. Therefore, the group added an "ignore" concept for excluding files or folders from the data management process. The discussions unearthed use cases where renaming camera files cannot be avoided, and tracking the new names needs to be part of the history of managed media. The human-readability aspect of ASC MHL had also been extended by introducing directory hashes for quick verification of an entire folder structure by comparing just one pair of hash values.

For these new features to be properly specified, the existing draft of the specification document for the ASC MHL required a major editorial review. With input from group members with technical writing experience, the specification was rewritten to serve as a solid foundation for the latest changes. The new version also specifies the use cases outlined above and includes smaller additions, such as support for new xxhash3 hash algorithms. The group expects to close the last open details in the specification in the coming weeks.

In addition to the work on the specification document, in December 2020 the group also published a "One-Sheet" document on the ASC website (https://theasc.com/reports/asc-mhl-one-sheet) that summarizes the basic use cases and outlines the concepts of ASC MHL for an interested audience.

Reference Implementation

The design work in the specification document was aided by continuous work on an accompanying implementation of ASC MHL. The group moved the basic sample implementation towards a reference implementation that is intended to cover all features of ASC MHL as a command-line tool and Python library. Providing an early implementation of sometimes complex features helped to surface edge cases and limitations and gave the group opportunity to test that the developed specification could actually work in practice.

An early version was evaluated on the "Ripple Effect" project (USC/ETC, https://www.rippleeffect-film.com) in production as well as in post-production in August 2020. A second "kick the tires" test took place in October 2020 by the data management teams of three major post-production facilities. All tests showed that the specification defines a practical set of actions that produce relevant and valuable output for productions.

Outlook

The goal of the group is to ratify the specification as a final draft in the coming weeks. That version will then contain all information required to implement the relevant actions of an “ASC MHL-compliant” software system.

After that, a three-month implementation and evaluation phase will follow where the major vendors of on-set data management software will include ASC MHL in their products for a larger field test on real productions.

The group targets a successful end of the ASC MHL project by publishing the finished and evaluated specification and reference implementation towards the end of 2021.

Joint Technology Committee on Virtual Production

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

Whereas 2019 was a watershed year that saw the invention of new virtual productions workflows such as “in-camera visual effects” (ICVFX), in 2020 we witnessed an ultra-rapid adoption of those workflows, at a faster rate of speed than we normally observe with new technologies in the motion picture and television industry. Hundreds of ICVFX stages of all size and shapes opened throughout the world, from the very large “Mandalorian class” ICVFX stages to the very small “pick-up shot” stages. As highlighted in the first conference solely focused on virtual production, ICVFX stages have been activated in Germany, France, Italy, Spain, Ireland, Russia, Morocco, Brazil, Japan, South Korea, China, Australia, Canada, the United Kingdom, the United States, and more **(Fig. 5).**

FIGURE 5. A video showcasing many ICVFX stages from around the world, along with recorded presentations from the first conference on virtual production, “Unreal Build: Virtual Production,” can be found at https://www.unrealengine.com/en-US/events/unreal-build-virtual-production-2020

FIGURE 6. A Westworld behind-the-scene video explaining how the production shot ICVFX on film for its season 3 can be found at https://youtu.be/7uhtzVN0VNo?t=166 . All material copyright HBO.

HBO’s Westworld season 3, was the first production to shoot on an ICVFX stage *using film* **(Fig. 6).**

The accelerated adoption can be attributed to two main factors. As we noted in last year’s report, the first factor is the development of a new game engine technology stack that makes it possible to visualize remote locations or visual effects in realtime on set, allowing filmmakers to make better creative decisions about the movie they are shooting, while they are shooting it.

The second factor is the COVID-19 pandemic, that affected everyone in 2020, and severely restricted filmmakers ability to fly around the world, shoot on location or with large production crews. This situation made ICVFX an attractive solution to “bring the world to the stage” instead of travelling to the world and spurred another round of development around remote workflows. During the year, the Joint Technology Committee on Virtual Production contributed to the “Virtual Production Field Guide, Volume 2” **(Fig. 7),**

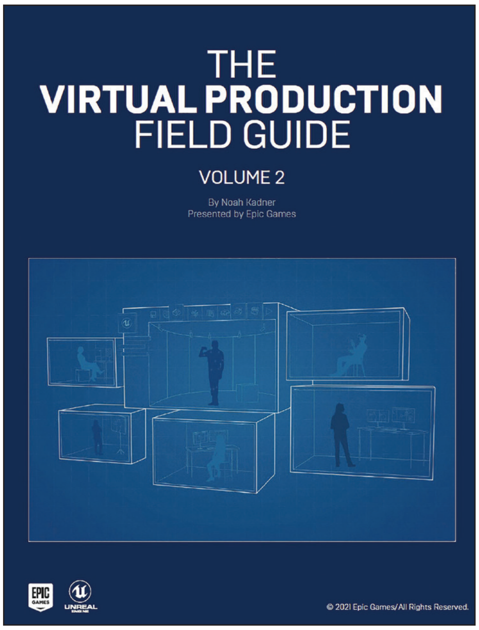


FIGURE 7. The “Virtual Production Field Guide” Volume 1 and 2 can be downloaded for free at uevirtualproduction.com.

an important resource for filmmakers wanting to learn more from their peers about virtual production.

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

Lighting Committee

Chair: Tim Kang
Vice-Chair: Jon Miller

In response to systemic color workflow problems resulting from rapid adoption of light emitting diode (LED) illuminants in motion picture production, the ASC MITC Lighting Committee (LC) formed in 2019 to answer this question for cinematographers, lighting technicians, and lighting fixture manufacturers: what kinds of photographic illuminants does a motion picture photography workflow need to function?

We started by defining an overview of the key elements in a motion picture color workflow (**Fig. 8**). By its spectral power distribution (SPD), or spectral fingerprint, an illuminant creates the energy information that "communicates" an object's spectral modifying properties (transmissive, reflective, and fluorescent) to a photographic workflow that senses, computes, repackages, and transmits this color information.

The search for "ideal" reference illuminants of both white and saturated colored light required us to define the SPDs of a) any white point defined by CCT (**Fig. 9**) and

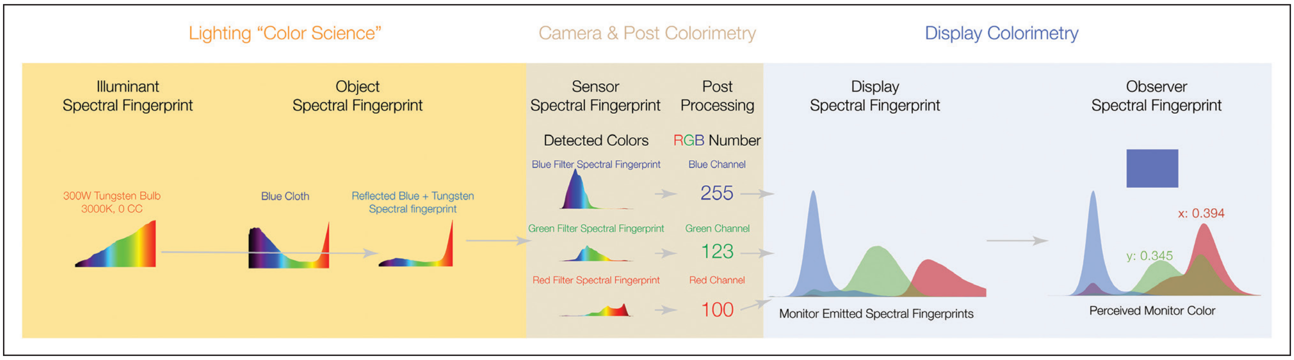


FIGURE 8. Digital Photography Color Workflow Spectral Pathway.

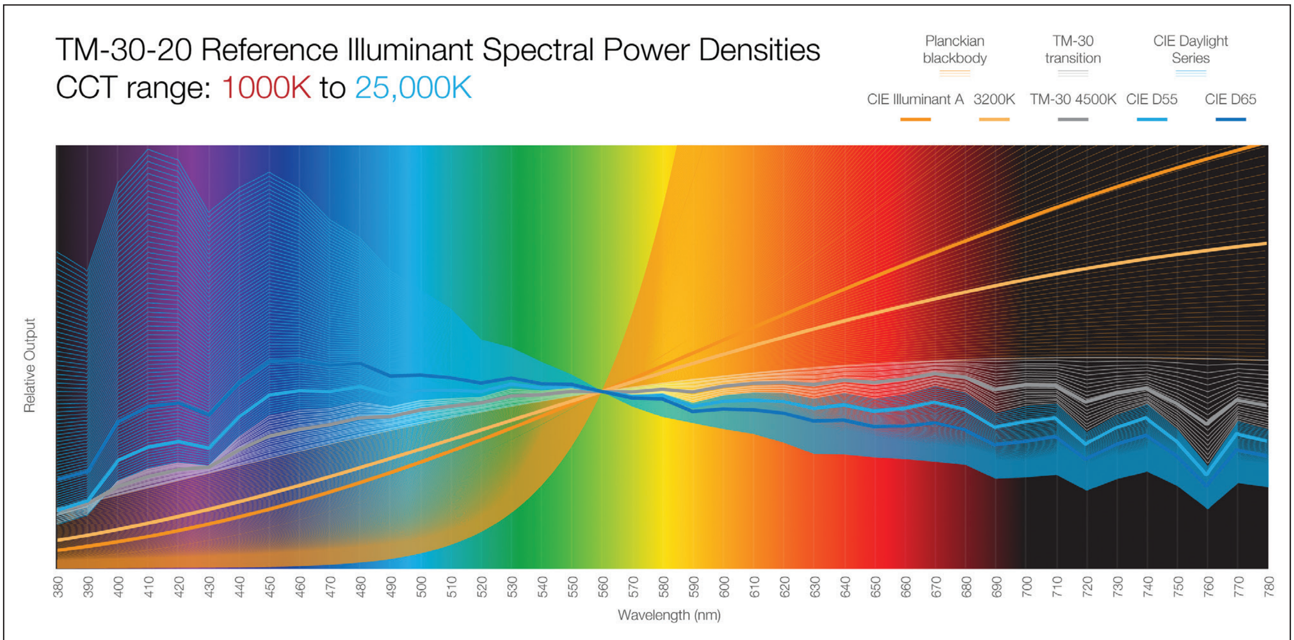


FIGURE 9. TM-30-18 Reference Illuminant Series, from CCT 1000K to 25,000K, normalized to 560nm. The most commonly perceived colors of the spectrum provide context for the relative energy distribution across the electromagnetic spectrum.

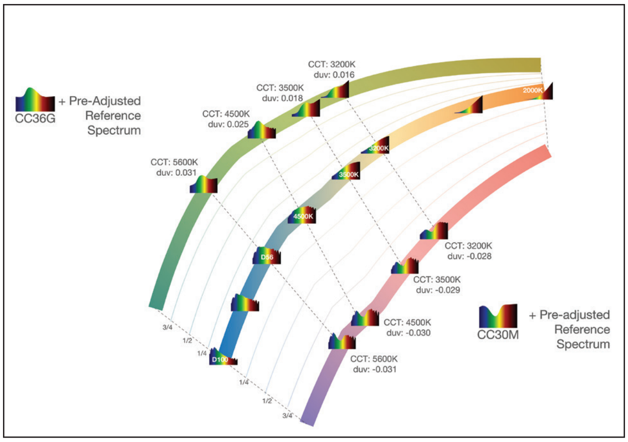


FIGURE 10. CIE 1976 u',v' chromaticities of the TM-30 Reference Spectrum combined with Full Plus Green Filtration & Full Minus Green Filtration.

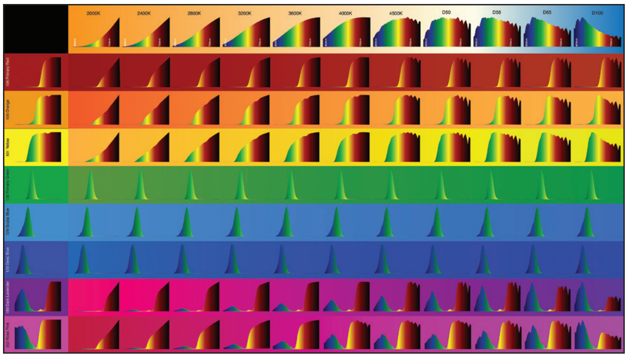


FIGURE 11. Common Saturated Primary & Secondary Hue lighting filters convolved with a full CCT range of TM-30 reference illuminant SPDs. Each row represents one saturated filter combined with the CCT range in the first row, and each column represents one TM-30-20 reference illuminant combined with the range of saturated primary and secondary hues.

green or magenta tint (**Fig. 10**), and b) any saturated hues (**Fig. 11**) that render similarly across different observer or device spectral sensitivities.

Later this year, the *SMPTE Motion Imaging Journal* will run an article from the ASC MITC Lighting Committee with fuller discussion of the problem, the research we conducted, and some direct, practical recommendations for manufacturers and filmmakers to follow.

Advanced Imaging Committee

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

In the process of exploring many topics relevant to high dynamic range (HDR) and wide color gamut (WCG), the issue of invertibility has captured our primary interest. Three common constructs in models of color appearance are worth examining since color appearance models require inversion in order to be useful.

Matrices

In the absence of offsets, typical color processing matrices are 3x3 (e.g., red, green, blue to red, green, blue). If all matrix terms are positive, the result will fit within the target container. For example, BT.2020 RGB primaries use a matrix having all positive (and one zero) terms when transformed into ACES AP0 RGB primaries. ACES AP0 RGB thus "contains" BT.2020 RGB within its larger color space if the red, green, and blue values are non-negative.

BT2020_D60 to ACES_RGB_AP0_D60 (inverse of below):
Red_AP0 = 6847914 * Red2020 + .1514042 * Green2020 + .1638024 * Blue2020
Green_AP0 = .0459818 * Red2020 + .8597984* Green2020 + .0942223 * Blue2020
Blue_AP0 = 0.0 * Red2020 + .0277513 * Green2020 + .9722461 * Blue2020

ACES_RGB_D60 to BT2020_D60 (inverse of above):
1.47728 -.252896 -.224381
-.0792524 1.18028 -.101031
.00226209 -.0336893 1.03143

The inverse process is not a lossless container, however, since ACES AP0 can contain colors outside of BT.2020's gamut. The appropriate 3x3 matrix has negative off-diagonal terms. It is easily seen that pure ted, green, and/or blue will yield corresponding negative BT.2020 red, green, and/or blue results due to the negative matrix terms.

A roundtrip from BT.2020 to ACES AP0 and back to BT.2020 will not have issues since the values are constrained. However, this invertibility is a special condition, and is not true in general.

Asymptotes

Asymptotes appear when modelling cone color response in the eye. The simplest example asymptote is x/(x+1). See **Figs. 12** and **13**. Note that zero maps to zero with a slope of 1.0, one maps to 0.5 with a slope of 0.5, and 100 maps to 100/101. As x increases beyond 100, the asymptote trends toward 1.0 in the limit with a slope of 0.0.

This x/(x+1) asymptote is reasonable to invert over a range up to five or ten. However, approaching a hundred the asymptote has gone flat, and becomes impractical to invert. It can only be invertible with perfect precision. This becomes significant for high dynamic range.

Hue Angle

CIELAB defines a hue angle as the arctangent of the ratio of an X-Y term over a Y-Z term in CIE 1931 XYZ tristimulus (see the well-documented CIELAB for details of these terms). When approaching neutral, and for darker colors, the hue angle will become highly sensitive to small variations in X, Y and Z. A small change

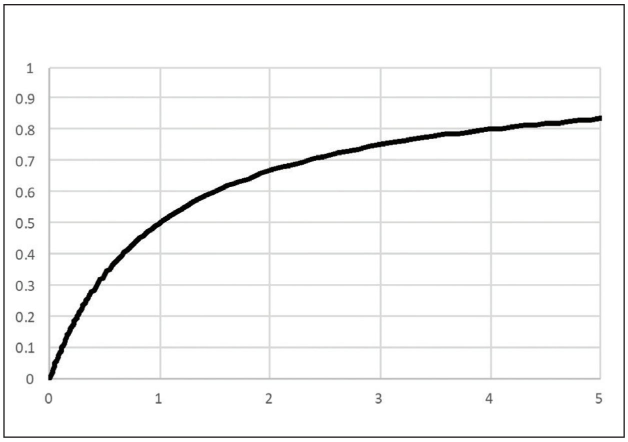


FIGURE 12. Example Asymptote for x/(x+1) over the range of x between 0.0 and 5.0.

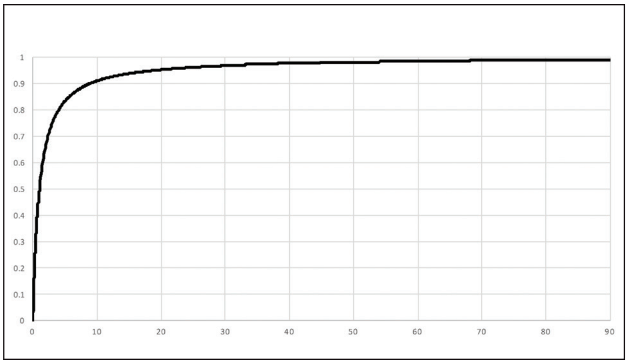


FIGURE 13. Example Asymptote for x/(x+1) over the range of x between 0.0 and 90.0.

in the white balance can swing the hue angle around 180 degrees. The CIELAB hue is invertible with perfect precision but cannot be considered invertible in the general case. Further, the hue angle's instability near neutral carries no practical information, but rather is probably best considered an artifact of the construction.

Summary

In summary, matrices, asymptotes, and hue angles are present in most color appearance models. Such models require inversion in their application. However, these key ingredients are not generally invertible in practice, although they are invertible in some forms of constrained use. Careful scrutiny of the use of these common mechanisms is necessary if viable results are to be achieved.

HDR Display Testing

The challenge of determining the capability of a display for HDR is essentially no different than testing any other video domain. Create test signals that challenge the parameters of the system and then evaluate the results of displaying them. Seemingly simple, it isn't really that simple. The first hurdle in using video test patterns for evaluation is the user of the display often doesn't see in pictures what is measured in test patterns. The solution is to come up with still and motion images that are as challenging as any test patterns. Stills are as important in testing a display as motion when it comes to resolution and an image being on screen long enough so the viewer can see what's in it.

Partially based on a display device evaluation meeting at the ASC in October 2019 **(Fig. 14)**, with the help of ASC and HBA members, we've assembled 10 minutes of content that in tests so far has done more to educate the monitor and post-production communities on HDR than anything we've seen elsewhere. There is something about seeing real pictures that makes it easier to define what's going on in a display.

The current test sequence opens with a few test patterns as we need to know that black level has been set properly, color decoding is taking place properly and that the set is in fact responding to a PQ based HDR source. We're currently in the final stage of creating PQ based content in 4320p, 2160p and 1080p. Most of the original material came from above 8K to nearly 8K (7360 instead of 7680 in the horizontal direction). A small part of the material has been up-converted from a source of about 6K. We've done that because there is a lot of up conversion going on in producing content. So, we thought it was necessary to have something of the kind in this example. All of the source material for the edit is in the consumer version of 8K (7680 by 4320) at 16 bits. The pictures are being directly down-converted to 1080p or to 2160p at 12 bits for H.265 encoding. The test signals at the beginning of each segment are sourced in the domain of the final output.

FIGURE 14. Professional Monitors Committee demonstration of professional displays in the 4K HDR world (ASC Clubhouse).

We've included image content such as fog and clouds to test shallow gray scales at low, medium, and high luminance levels. We have small, medium and large bright spots in the pictures. We put things in the pictures to illustrate 4:2:0 versus 4:4:4. The ProRes 4:4:4 files will be available so people can see the difference. We moved dark objects into different lighting conditions so we could look at gray scale tracking at the bottom end of the gray scale. We have images in motion and then going to a rather static condition so we can show the loss of resolution in motion. We've put objects in scenes that are designed to challenge resolution in many directions, horizontal, vertical, and multiple diagonal directions. There are naturally occurring flashes of bright light on a dark background. There are colors we expect to challenge the P3 color space of HDR.

Next-Generation Cinema Display Committee

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

Standard Evaluation Material Version 2.0 (StEM2) Project

Chair: Jay Holben

A major effort within the NGCD is the Standard Evaluation Material II (StEM2) project. This project will produce a 12-minute film, entitled *The Mission,* that will be openly available and easily accessible to the entertainment industry for testing and evaluation purposes. The content will be well-documented regarding the process of creating the material and its intended technical exploitations. The material will be available for use by the industry to evaluate advanced post-production tools (color timing, judder smoothing, etc.), new production workflows, and advanced output technologies (laser projectors, HDR LED displays, HDR OLED displays, etc.). With the support of the industry's leading companies providing both financial and in-kind support of equipment and services, the project started on 14 June 2021, with principal photography occurring after the 4th of July holiday, and post-production completing just before the Labor Day holiday.

The production will be accomplished using the Sony Cine-Alta Venice, the RED Monstro (or Panavision DXL2), and the Arri Alexa 65 (or LF) as a minimum, not used simultaneously, but sequentially on separate sequences to provide master material from a wide sample of modern digital cinema cameras. The color chain of all capture and rendering devices will be measured and calibrated to ensure accuracy. The full camera sensor resolution will be captured, with the intent of generating a 1.78 aspect ratio (AR) for home and a 1.85 AR for theatrical (while protecting for a 2.39 AR for theatrical and a 1.43 for IMAX). All material will be captured at the industry-standard 24 frames per second (fps), but some sequences will also be shot at 120 fps in order to create deliverables at other frame rates (e.g., 60 fps or 120 fps), and also to create a deliverable of mixed frame rates (i.e., a package with some 24 fps sequences, some 60 fps sequences, and some 120 sequences).

With the support of the Academy of Motion Pictures Arts & Sciences, the StEM2 will be supported with a full theatrical sound treatment of dialog, music, and sound effects, minimally including a 5.1 mix, and may include SMPTE ST 2098-2:2019, Immersive Audio Bitstream in the IMF packages described below.

Metadata that is supported by the various product vendors will be captured and maintained for each shot (e.g., camera type, lens, shutter, depth-of-field, framing, ACES AMF, ASC CDL, ASC MHL, etc.) This metadata will be organized to accompany the deliverable files for industry reference. The production will also be fully documented by a "Behind the Scenes" crew.

Table 1 provides the minimum set of deliverables that will be openly available in the cloud to the entertainment industry. Additional deliverable formats, including 8K and multiple frame rates, are also planned, but are yet to be specified in detail. The Rec. 2020 deliverables will include Dolby Vision and either HDR10 or HDR10+. IMF packages will consist of:

- Application #2E: (SMPTE ST 2067-21) Studio masters for feature and episodic content; Image coding using JPEG2000, SD to 4K, SDR and HDR
- Application #4: (SMPTE ST 2067-40) D-Cinema content preservation; Image coding using JPEG2000. Up to 8K XYZ
- Application #5: (SMPTE ST 2065-1) Based on ACES EXR files

TABLE 1. Minimum set of Public Deliverables.

	File Format	Color Space	Frame Rate
Cinema Formats	4K TIFF	P3	24
	4K TIFF	P3	60
	4K TIFF	Rec.2020	24
	4K TIFF	Rec.2020	60
OTT/Television Formats	UHD IMF EXR	Rec.709	24
	UHD IMF EXR	Rec.709	60
	UHD IMF EXR	Rec.2020	24
	UHD IMF EXR	Rec.2020	60

The Mission, is being produced, written, and directed by Jay Holben, (who is also Chair of this project for the ASC). Mr. Holben is supported by an extraordinary group of volunteers:

- Curtis Clark, ASC – Executive Producer
- Joachim Zell – Producer/Post Supervisor
- Wendy Aylsworth – Producer
- Christopher Probst, ASC – Cinematographer
- Tim Squyres, ACE – Editor
- John Muto – Production Designer
- Teri Dorman & Greg Hedgepath – Sound Designers
- Marilyn Vance & Sylvestre Cetina – Costume Designers
- Gerry Quist – Hair & Makeup Designer
- Dave Stump, ASC – VFX Supervisor
- Steve Shaw, ASC – Stunt Coordinator
- Caryn Ruby – Script Supervisor
- Bryan McMahan - Colorist
- Abbey Spacil – BtS Director
- Greg Ciaccio – Metadata Supervisor
- Sheila Gilman – Metadata Production Coordinator

Additionally, the ASC would like to recognize and thank the following supporting companies:

- 8K Association
- Amazon Studios
- Academy of Motion Pictures Arts & Sciences
- ARRI
- Avid
- Barco
- Blackmagic
- Canon
- Christie
- Cinionic
- Colorfront
- Cooke Optics
- Creative Solutions
- DJI
- Dolby
- Drive Studios
- Epic Games
- Frame.io
- Fujinon
- Happy Mushroom
- JL Fisher
- Keslow Camera
- Microsoft Azure
- Panavision
- Pixelworks
- Pomfort
- RED
- Roundabout Entertainment
- Samsung
- Sony Electronics
- Sony Pictures
- The Walt Disney Studios
- USC Entertainment Technology Center
- Warner Bros.
- Zeiss

Professional Monitors Committee

Chair: Jim Fancher
Co-Chair: Gary Mandle

While the world has seemed to stop over this last year, display development has not. 2021 has shown some significant developments in display technology and the many new monitor manufacturers entering our industry.

LCD

LCD is still the dominant technology, but the base of manufacturers is quickly changing. The transition from Japan to Taiwan/Korea and now to Chinese manufacturers shows that the supply from monitor manufacturers will remain steady. This can be seen by LG Display stopping all domestic LCD manufacturing in January 2020 followed shortly by Samsung also abandoning their Korean-based LCD manufacturing. Both moving to expand their OLED lines or start development of microLED. This has followed significant investment in larger fab facilities by BOE (now the world's largest panel manufacturer), China Star, Tianma, TCL, and Topway. This manufacturing base for 8 to 32-in. panels is quickly shifting to lower end as well as lower cost products maximizing at 4K resolutions. For panels larger than 32-in., the consumer market is pushing hard into 8K. Interestingly, while Panasonic has stopped production of their Dual Cell LCD, Hisense has introduced their version for the consumer market.

Quantum Dot

QD development has been ongoing with some significant developments. Samsung has been busy with their development of a display using a combination of OLED and QD technologies. This seems to be Samsung's next step after leaving LCD. This includes an $11.1B investment with the hopes of product delivery in 2022. This contrasts with QD manufacturer Nanosys who has acquired "Glo," which is a microLED developer. As far as the technology of QD goes, the latest advance is the application of Perovskite nano particles - calcium titanium oxide pseudo cubic crystal formations (also used in solar cells). **Figure 15** shows a crystal group.

Using this adds some very important properties to QD backlights and to QD OLED if it does become practical. One will be in brightness efficiency and stability. Other QD development has been in the movement to more non-toxic carbon-based nano dot, but this is still in the lab.

OLED

Samsung continues to be the largest manufacturer of OLED for very small panels used in tablets and cell phones while LG is the leader in OLED for TVs. Both are transitioning manufacturing from Korea to China.

FIGURE 15. Perovskite Crystal.

For professional monitors, JOLED (the combined display development divisions of Sony and Panasonic) have started delivery of their printed OLED panels in 22, 26 and 32-in. These originally were intended for the medical market. Models are already advertised from Dell, ASUS, EZIO and even one from LG using a JOLED panel. We should be seeing more manufacturers entering these areas as equipment for making OLED through lithographic process is becoming more available. Below is a picture of the Notion n.jet printer encapsulator (**Fig. 16**).

MicroLED

There has been a lot of buzz about microLED since Samsung showed a 110-in. prototype at CES. This has been the most visible example, but certainly not the only. A March 2021 report from Omdia, shows investment from 18 different entities and 15 different display manufacturers including Apple, AUO, Hisense, LG, Samsung **(Fig. 17)**, Sharp, Sony, TCL, and Tianma demonstrating 17 prototypes ranging from .7 in. to 395-in. diagonal.

Currently, the intended applications are automotive, desktop monitor and signage. However, given the benefits of microLED, we should expect to see this used for production in the somewhat near term. While there are several sources for microLED, the volumes to date are very small, which is keeping prices high. **Figure 18** shows a typical microLED manufacturing process.

FIGURE 16. n.jet OLED printer.

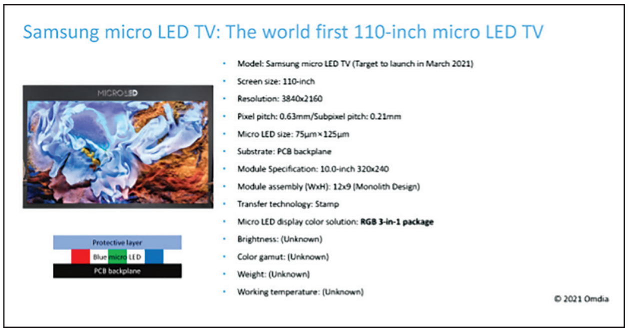


FIGURE 17. Samsung microLED Specifications. Source: Omdia, SAMSUNG—photo taken by Park Ken/Omdia at Consumer Electronics Show (CES) 2020, Las Vegas, NV, January 2020.

New Monitor Manufacturers

Most of the monitor manufacturing is now located in China. This has opened a plethora of small new monitor manufacturers. These include Avinair, Acebil, Acetek, Elvid, FeelWorld, Came-TV, Desview, Laizeske, Muxlab, e2work and more.

Significant Product Developments

Aside from the new manufacturer entries, the established manufacturers are also busy updating their lineups.

Probably the most significant model of late is EZIO's Dual Cell Prominence CG3146. This year it has been awarded both an HPA Engineering Excellence Award and an AMPAS Academy Certificate. What is significant to this model is the automatic calibration system. Normally, the monitor manufacturer will contract to a probe company to build any light measurement tools, but EZIO pulled that development in house. The monitor can be calibrated with the internal probe or using an external probe through their Color Navigator software. Also significant is a new method they have patented for controlling uniformity.

Sony introduced two new midlevel models this year as the PVM X1800 (18 in.) and X2400 (24 in.). A 32 in. has been announced. What is significant with these models is a software update which adds a system where metadata (26 parameters) from the camera describing an HDR image can be read by the monitor. Internal processing in the monitor can then use this metadata to show both the original HDR image and compile a SDR image, which can be output and used downstream.

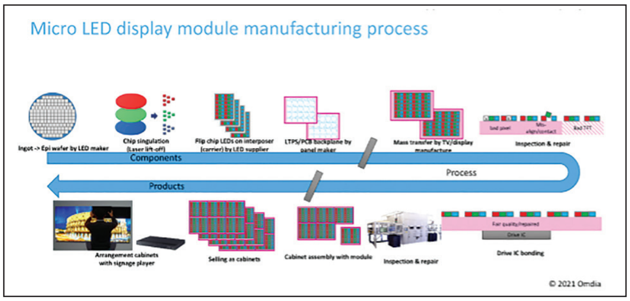


FIGURE 18. MicroLED Manufacturing Process. Source: Omdia, Samsung Electronics.

The algorithms used are the same as those used in their HDRC 4000 down converter.

Flanders Scientific Inc. has introduced two new utility (entry level) models, which are updates from the older AM 210 and BM 210 models. New to these models is a PFS phosphor LED backlight technology developed by FSI. This has increased the color gamut to almost P3 boundaries and provides a better match to their DM and XM series monitors.

Digital Intermediate Committee

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

While we have not accomplished anything of note in the pandemic year, we hope to be working on the following issues in the year ahead:

- 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

Computational Cinematography and Plenoptic Imaging Committee

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

The impact of computational imaging in the consumer space is immediately apparent to anyone using the camera in their latest-model mobile phone, or experimenting with Instagram filters or TikTok effects. As functionality and quality improve, such computational techniques will undoubtedly have significant impact on the professional media and entertainment fields, including cinematography. The term *computational imaging* is used to describe a process of forming pictures by combining optical capture with computational algorithms, and light field – or plenoptic – motion images are one example of an important new technology that is expected to be used in future cinematography. This past year has seen significant advancement in all aspects of plenoptic image capture, processing, encoding, and display. While this technology will not become widely commercially available for a few more years, ASC MITC is tracking the progress carefully, to be prepared for new creative workflows when the time is right.

Progress in Holographic and Light Field Displays

During the September 2020 meeting of the ASC Motion Imaging Technology Council, this Committee provided a briefing on the many new immersive display technologies that are now coming to market or being demonstrated in R&D labs. The briefing covered 15 examples of displays falling into three general categories: volumetric displays utilizing light-emitting pixels in a 3D volume, light field displays using a very high angular ray density, and holographic displays. Over the past year, notable new displays were introduced by Looking Glass Factory, Avalon Holographics, Sony, Dimenco, cReal, Brelyon, and others. Based on this survey of progress, it seems clear that a new paradigm of glasses-free high quality 3D immersive displays is imminent.

Light Field Production Demonstrated

Another milestone occurred in October 2020, when Charter Communications demonstrated streaming of a light-field image to an immersive 45-zone display over a 10G cable network, which took place during the Society of Cable Telecommunication Engineers (SCTE) Tech Expo, and included showcasing a new network topology suitable for light field images, along with a gesture control system for the 3D user experience. For this demonstration, a 100-camera array from Visby was used to capture a complete scene as a light field **(Fig. 19)**, producing over 8,000 minutes of raw video footage for the short clip. Both exterior and interior settings in the Los Angeles area were used for the experimental shoot. After computation processing by Visby, the data was streamed at 50 Gbit/sec to an edge compute cluster for compression. The experience provided valuable lessons-learned for future light field production work, as well as network connectivity.

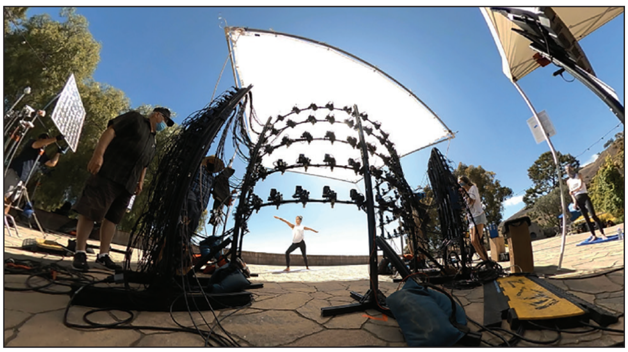


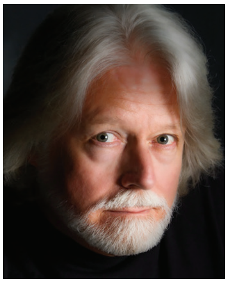
FIGURE 19. Camera array used in a holographic content production. (courtesy of Charter Communications and Visby).

An Interconnected Future

In addition to the notable work on both display and camera technology, the Committee has also been tracking the significant work now underway to standardize image exchange and distribution formats. These include work by MPEG on the MPEG-I (Immersive) format, MPEG Immersive Video (MIV), and Video-based point cloud compression (V-PCC). The JPEG committee continues to work on JPEG Pleno, while industry consortiums have published standards including glTF (GL Transmission Format)) from the Khronos Group, and Immersive Technology Media Format ver 1 (ITMF) from Immersive Digital Experiences Alliance (IDEA). A new industry association – called the Volumetric Format Association – was launched in May 2021.

The degree of progress is very encouraging, and the Computational Cinematography and Plenoptic Imaging Committee is anticipating a lively next year for next-generation entertainment.

About the Authors



Curtis Clark, ASC, 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 subsequently completed two additional highly praised short films, Eldorado and Meridian. Clark received a Motion Picture Academy Technical Achievement Award for his work developing the ASC CDL which also received a Prime Time EMMY Engineering Award. 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. Clark has chaired the ASC Motion Imaging Technology Council since its formation in 2003 as the ASC Technology Committee.

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 in the workflow of nearly every motion picture, scripted TV, and visual effects turnover worldwide. He is a SMPTE Fellow; Vice-Chair and Founding-Secretary of the ASC Motion Imaging Technology Council; an ASC Associate.

Greg Ciaccio, creative technologist, 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. He is head of Production and Post Technology for the ETC and SMPTE Hollywood section manager.

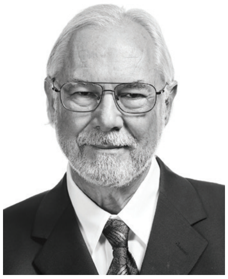
Tim Kang is a Los Angeles-based cinematographer, working in the film & TV industries primarily as a director of photography on narrative, commercial, music video, and documentary projects.

Jesse Korosi is the director of post at the Picture Shop, 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, and HPA's 'Through The Frame' podcast host; Korosi has experience from both the technical/workflow side of the film & television industry, and the operational side of running a post-production division.

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. Hall has provided dailies workflow oversight for hundreds of feature and episodic projects.

David Morin is head of the Epic Games Los Angeles Lab, and 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, he works for the Premier Members to develop the use of open-source software in the motion picture industry.

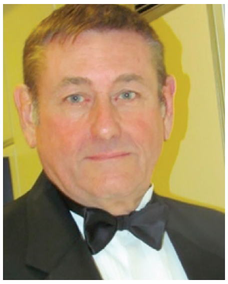


Gary Demos has been a pioneer in the development of computer-generated images and digital image processing for use in motion pictures. He co-founded Digital Productions (1982-1986), and was awarded an Academy of Motion Picture Arts and Sciences (AMPAS) Scientific and Engineering Award in 1984 along with John Whitney Jr. "For the Practical Simulation of Motion Picture Photograph By Means of Computer-Generated Images." Demos also founded DemoGraFX (1988-2003), and Image Essence LLC, Perris, CA (2005 to present). Demos is the inventor of approximately one hundred patents.

Joe Kane specializes in the sciences of electronic imaging, accurately reproducing video signals on electronic display devices. These efforts have been the focus of his company, Joe Kane Productions (JKP) - "It's All About the Art", http://www.videoessentials.com/ - since its founding in 1982.

Wendy Aylsworth is a SMPTE Fellow and past president. She provides consulting and strategic board guidance to entities focused on emerging ecosystems and nascent technologies. Aylsworth is a board member of the HPA, is a co-chair of the ASC's NGCD committee, and is involved in committees at USC's ETC, the AMPAS, and The Television Academy.

Jay Holben is an independent director and producer in Los Angeles, CA. A former cinematographer, he is an Associate Member of the ASC, the author of three books on cinematography, and contributing Technical Editor for *American Cinematographer Magazine*.



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 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.

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

Pete Ludé is a prominent engineering consultant in advanced imaging and sound. He serves as chief technology officer of Mission Rock Digital, a San Francisco-based engineering firm specializing in next-generation media including cinema display technology, immersive sound, and interchange pipelines for plenoptic (light field) imaging. Ludé is a past-president of SMPTE, and a SMPTE Fellow.

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