A GUIDE TO ACES

UNDERSTANDING AND INTEGRATING THE ACADEMY COLOR ENCODING SYSTEM

ACES PRIMER

The Legend of Tarzan and Tarzan of the Apes courtesy of Warner Bros. Entertainment Inc.

The Lego Movie courtesy of Warner Bros. Entertainment Inc.

Photo of Sekonic meter courtesy of Sekonic Corporation.

SMPTE® is a registered trademark of The Society of Motion Picture & Television Engineers®.

080718-1

WELCOME TO THE WORLD OF ACES

The Academy Color Encoding System (*ACES*) is an industry standard for managing color throughout the life cycle of theatrical motion picture, television, video game, and immersive storytelling projects. From image capture through editing, VFX, mastering, public presentation, archiving and future remastering, ACES ensures a consistent color experience that preserves the creator's vision.

The goal of this Primer is to provide a foundation for using ACES. It outlines the history of ACES, including why it was developed, as well as its current and future value in production and postproduction workflows.

The resources listed below will provide additional information.

Primer Glossary – Throughout this guide, ACES terms that may be unfamiliar to some readers have been *italicized*. They also appear with a brief definition in the end glossary.

Contact Information – Have follow-up questions? Want to adopt an ACES workflow? Find ACES resources at the end of this Primer.

Getting Started with ACES – www.ACESCentral.com is the place to expand your ACES knowledge and join the community forum. It is the most comprehensive and up-to-date website for all things ACES. Active ACES users, equipment manufacturers, and Academy staff are available to answer questions and share their experiences. Registration is **free**.

TABLE OF CONTENTS

CHAPTER ONE

WHAT'S NEXT

SWINGING THROUGH THE JUNGLE?

In 1912, Edgar Rice Burroughs published a story in a pulp magazine about a character named Tarzan. By 1918, Tarzan had found his way onto the silver screen in a silent film based on Burroughs's novel "Tarzan of the Apes." Since then, Tarzan (often with Jane or Cheetah by his side) has been swinging through the jungle and onto a variety of screens, keeping pace with the latest technology. He's gone from the silver screen to CinemaScope, from black-and-white broadcast television to High Definition, from animation to 3D and Premium Large Format, even to video games and direct-to-video films.

Leveraging the Tarzan story in different media was Burroughs's own idea, and he continued to feed his writing into his Tarzan machine well into the 1940s. Burroughs proved that a good story can, to quote another successful film franchise's character, "live long and prosper" in the entertainment industry.

Fast-forward almost 100 years to 2016. Tarzan hasn't lost his touch. *The Legend of Tarzan*, complete with digital surround sound and astonishing visual effects, was released by Warner Bros. in 2D, 3D and Premium Large Format. It enjoyed much box office success.

To live long and prosper, the Tarzan story had to be coaxed into shape for changing norms and audiences. In the latest version, for example, Tarzan spoke good English, and Jane herself was a force to be reckoned with. The production adapted to the latest filmmaking processes as well.

THE DIGITAL JUNGLE

The evolution of the celluloid workflow is about as old as Tarzan. It developed at a slow-enough pace that productions had no difficulty tracking the standardized regime, film after film after film. Navigating technology was not perceived as a major problem, but rather as a process. Workflows were settled, secure and efficient.

In recent years, however, digital production has grown as fast as jungle vegetation. New capture and display technologies have taken center stage with proprietary color systems and features such as high dynamic range. And unlike the single-camera coverage from days of old, directors are pointing a variety of digital cameras onto a single scene, and audiences are watching those images on an even greater variety of displays.

Digital technology's many new creative opportunities come with some drawbacks. Navigating the digital jungle often means creating a unique workflow configured around an individual project. This one-off "snowflake" workflow generates a new learning curve every time out, which increases digital laboratory costs.

And unlike early Tarzan conversations, which may have consisted of simply "me Tarzan, you Jane," new imaging technologies face extremely complex communication challenges.

For example, the old film archiving standards that evolved with the motion picture industry have become irrelevant for new and remastered content. Digital cameras and projection or video display systems don't always use the same color parameters, and they are likely to interpret color images differently. And at the end of a digital production, creating a digital motion picture master without an experienced guide or translator may place inherent limits on its own future.

INTRODUCING ACES 1.0

The Academy of Motion Picture Arts and Sciences has always been committed to supporting the advancement of the motion picture industry. In recent years, the Academy dedicated itself to studying the current problems of digital production with an eye to creating masters for long-term archiving. Other goals were easy to envision, but not so easy to accomplish. The Academy wanted to:

- Create a digital image file interchange and color management system that was not dependent on any specific camera, display, or production or postproduction tool.
- Create a system that could enable new innovations, such as *high dynamic range (HDR)* and wide *color gamut*.
- Encourage manufacturers to integrate this new system into their products.
- Enable producers and studios to create digital masters suitable for long-term archiving, so they would no longer have to remake a movie each time display capabilities advanced.
- Enable standardized workflows to reduce digital laboratory costs.
- Provide education and support for the motion picture and television communities to incorporate these benefits into their workflows.
- Make this new system available for free.

After ten years of development, and with the contributions of top minds in the industry, the Academy met its goals by introducing ACES—the Academy Color Encoding System. With ACES 1.0, the solutions are not only here and available, but are already making a mark on all manner of motion picture, television, video game and immersive storytelling workflows.

And Tarzan once again swings in with a shining example. The 2016 theatrical feature *The Legend of Tarzan* incorporated ACES in its workflow—a workflow that included the participation of nine separate visual effects facilities. By using ACES as the unifying image interchange and *color management* system, maximum image fidelity was achieved throughout the production process.

PRODUCING WITH ACES

A producer, of course, looks at the big picture—the whole jungle, so to speak. And as with any new adventure, ramp-up time is needed to create a new roadmap, and to acquaint the production team with processes and workflows that incorporate advanced technology. Incorporating ACES is no different—it requires planning and consideration. But it can yield three important returns: budget savings, improved image quality, and a future-proof archival master.

As ACES is an entire system, incorporating it into a workflow for the first time requires a discussion of color management with the technical team. And not just with cinematographers and camera operators at the start of filming, where hands-on application of ACES begins. VFX artists, editors and colorists need to be included in the discussion as well. The simplified overview of color science in the following chapter can serve as an introduction.

Once an ACES-based workflow has been established, subsequent projects will follow a consistent, more efficient process. The process will increase predictability, save time and may save money. As with the old photochemical process, using ACES will become second nature.

Another benefit of incorporating ACES is image quality. For digital images, ACES offers a level of precision that was previously available to only ultra-high-end facilities. ACES also simplifies versioning—maintaining the highest quality deliverables for all distribution platforms. From a collaboration standpoint, ACES paves the way for more seamless interactions throughout the production process.

And finally, close to the Academy's heart and purpose, there is long-term archiving. Using ACES future-proofs digital content and enables it to be repurposed in perpetuity[1] for the ever-higher-quality distribution channels to come. Even today, when any ACES-formatted archive material is being incorporated into new projects (as flashbacks, or in sequels), the preparation time for that archive material is greatly reduced. The new projects reap the benefits of ACES standardization even before the green light is given.

[1] *Assuming adequate digital data management practices*

COMING SOON TO A THEATER NEAR YOU

From beginning to end, ACES provides a unified approach to digital image management. No more snowflake workflows—ACES provides a path that leads safely through and directly out of the digital jungle. And in this fast-moving digital realm, who can say what's next? When silver stopped being used to make the early movie screens on which Tarzan first appeared, who knew that it would be back as part of many of today's 3D screens? Who can predict what cameras will be capable of in the future? Someday, perhaps, a camera will be able to capture exactly what the human eye can see. Someday.

The Academy, which is just a few years younger than the original Tarzan, understands the inexorable march of technology. It therefore created ACES to align the jungle-like profusion of digital color and file formats. ACES provides a set of mathematical concepts and best practices that enable reliable, high-quality interchange of color content between cameras, digital processing systems, software applications and displays. Rather than defining workflows, ACES provides a common set of components that can be used to design them.

ACES enables the ACES Logo Program Partners—the people behind the design of cameras, color correctors, and other production and postproduction tools—to meet in this common space, this clearing in the jungle. The studios, producers, artists and technicians who incorporate ACES into their workflows can feel confident that the image quality of their motion pictures will be carried consistently and completely through their current project, and also well into the future.

CHAPTER TWO

DELIVERING THE MASTER

THE BIG PAYOFF

Let's face it. Completing the final master of any motion picture or television project is the payoff. It's where the efforts of cast and crew finally come together, where the project is saved in its "hero" form. The mastering stage also happens to be where many of the advantages of an ACES-based workflow are best observed. So let's swing over to the end of the production process and take a closer look.

DOWNSTREAM COLOR SPACES

When television distribution progressed from standard to high definition, many studios were able to go back to an original film negative, with its inherently greater level of image detail, to create and sell new high-definition programming. Many of those negatives will be coming out of the vault once again to exploit their full dynamic range for emerging High Dynamic Range (HDR) displays. So when an original film negative is the archived master, it can be used to render new display masters for downstream distribution targets.

In contrast, digital workflows tend to finish their masters with the color limitations of the displays on which they will be presented. If designed for theatrical release, for example, the masters are produced using a range of colors suitable for digital projection known as *DCI-P3*. (DCI is short for Digital Cinema Initiatives, LLC, a trade association of motion picture studios that defined technical specifications for digital projection.)

When high-definition television (HDTV) shows are mastered, a different, more limited color encoding specification, *Rec. 709*, is used. It's a standard created specifically for that medium. But the Rec.

709 color space was defined by the most limiting piece of video technology, the cathode ray tube (CRT). So even though CRTs are no longer manufactured, they've left us with an unfortunate legacy.

With the emergence of digital visual effects, nonlinear editing, and computer-based color correcting, a third color space called *sRGB* evolved. The sRGB color space has limitations similar to those of Rec. 709, because of the shared legacy of CRT technology.

MASTERING FOR THE DISPLAY

In all three of these color space examples—digital cinema projection, HDTV and computer displays—masters are created based on the limits of the target display. The color palette chosen for the master is determined by what the display can show, which results in what is known as *Display-Referred Color*. At first glance, this seems quite sensible, as a greater range of color in the master would not improve the quality of the viewed image. This approach, however, has serious pitfalls.

If a long-lived motion picture or television program shows signs of even longer prosperity, re-releasing will be on executives' minds. But like the overgrown digital jungle, digital distribution channels continue to change and new display opportunities will arise. For example, 4K ultra-high definition television (*UHDTV*) displays can use a color standard called *Rec. 2020*, which has a larger palette than both its predecessor, Rec. 709, and DCI-P3.

For theatrical motion pictures moving downstream to television or the Web, a DCI-P3 master will usually suffice. With a color palette that exceeds Rec. 709 or sRGB, the DCI-P3 master can be reduced to fit most television and computer displays.

On the other hand, a television master cannot be easily expanded to take advantage of the DCI-P3 color space for projection, nor can DCI-P3-mastered content be easily expanded for Rec. 2020. To fully utilize the advantages of the larger space, re-release of such content generally means completely remastering the project. This entails the lengthy and expensive process of returning to camera-original material to recover the original image quality.

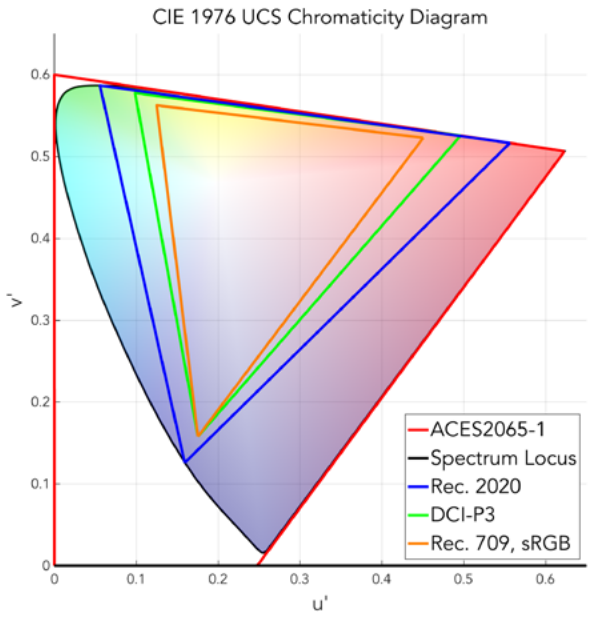
On the camera front, current digital motion picture cameras can capture a broader dynamic range and wider color gamut than displays can present—they're not limited by display-referred color. Furthermore, each camera brand has its own unique color encoding. For productions that use more than one manufacturer's camera (and most motion pictures generally do), those color differences need to be reconciled with one another. ACES provides a mechanism for this while preserving the unique capabilities of the different cameras.

ACES — ALL THE EYE CAN SEE

At the heart of ACES is its ability to encode the totality of the visual information captured by cameras and *Computer Generated Imagery (CGI)* tools. Unlike the limited color spaces of cameras and displays, the core ACES color space includes every color visible to the human eye and a dynamic range of light levels exceeding 30 camera stops. Once again, that's every color visible to the human eye. At no time in motion picture or television history have content creators been able to store color details to this extent. But seeing and storing is different from capturing and mastering.

In the digital world, the ACES all-you-can-see color space is referred to as *ACES2065-1* ("ACES twenty-sixty-five, dash one"). It was created at the Academy, and in 2012 it was adopted as a standard by the *Society of Motion Picture and Television Engineers (SMPTE)*, the industry's standards development organization. When ACES is used in a motion picture workflow, every department processes their output to this vast color space.

In the diagram to the right, the large outer triangle represents the ACES2065-1 color space. Contained within that triangle is a colorful rounded hull shape, the spectrum locus, which represents all colors visible to the human eye.



The three smaller triangles represent color spaces for digital cinema projection (DCI-P3), television (Rec. 2020, Rec. 709) and computer screens (sRGB). At the vertices of each triangle is the maximum amount of each of the three primary colors—red, green and blue—for each color space.

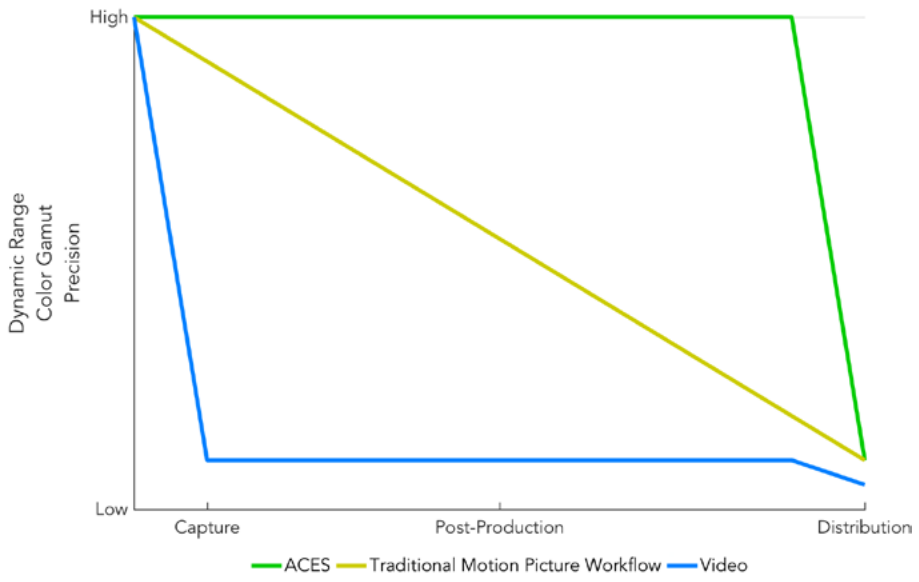
Notice that the much larger ACES2065-1 color space encompasses all of the other spaces. (Illustration note: The ACES triangle has been truncated for the graph.)

No cameras or display technologies in use are capable of reproducing all the colors that the human eye can see or that ACES can encode. Yet working with this much color data has real advantages.

MASTERING IN ACES

In traditional film-based workflows, the captured image degrades in a cumulative way as it moves through the production pipeline. The camera negative has the best image quality, then with each processing step—optical effects, inter-positive, inter-negative and distribution prints—some fidelity is lost. In the diagram below, if the upper left corner is the starting point of a project, the film-based quality loss is represented as the yellow downward diagonal line.

Traditional video processing is even harsher. The blue line on the left side of the graph illustrates the early and severe reduction in image quality during video production. This was, however, a practical decision. In the original analog system, the signal was reduced for transmission through the available broadcast bandwidth. Then when digital technologies came along, the television industry jumped in as an early adopter,



because the signal's small size enabled it to be processed and stored on computer equipment in a reasonably cost-effective manner. This adoption occurred, however, at the expense of protecting color and dynamic range for future distribution and display capabilities.

An ACES-based workflow, represented by the upper green line in the graph, avoids quality loss during production and postproduction. By maintaining the data in the ACES2065-1 color space, the maximum color fidelity and dynamic range are preserved from camera to master. It is not until distribution that the image quality must be constrained to accommodate the color spectrum of the particular display technology.

DELIVERING AND ARCHIVING WITH ACES

Faced with often formidable budget and schedule challenges, producers often defer consideration of the long-term storage and archiving of their work to simply "later." For the Academy, however, archiving is a core concern. As a keeper of the archiving flame, the Academy—along with the U.S. Library of Congress, the U.S. National Archives, and thousands of audiovisual archives worldwide—is keenly interested in preserving the history of the motion picture industry at the highest possible quality standard at any given time. Archives are of commercial interest as well, especially to studios and independent producers. Re-releases, directors' cuts, flashback sequences and stock footage sales can all be derived from a properly maintained archive.

In the film era, archiving was largely a matter of storing the finished film negative, outtakes and intermediates in a suitable environment. However, with the evolution of digital capture and processing, archiving has become more complex, with several major considerations. Two issues shared by all businesses generating valuable digital records are the digital file formats and physical data storage medium—that is, how

will data files be retrieved and correctly interpreted in the future, as perpetual advances in technology can render previously stored materials unrecoverable.

Whether capturing digitally or on film, productions using ACES have an advantage when it comes to creating archival masters. As the ACES2065-1 color space encompasses all possible visual information, detail that may not be able to be viewed or used today will be available as soon as future technology can reproduce it. Packaging this information in an *Interoperable Master Package (IMP)* creates a digital "bank deposit" of elements from which a future ACES production can make withdrawals. And because ACES is backward-compatible to earlier versions, future accessibility is assured.

When a production is mastered using ACES, studios can take full advantage of every delivery format: theatrical release, streaming, broadcast, packaged media and mobile device. The final full-color, full-dynamic range, and render-targeted versions for each distribution opportunity will be available, at the highest quality the platform can accommodate, now and into the future.

CHAPTER THREE

DISTRIBUTING

TO SCREENS LARGE AND SMALL

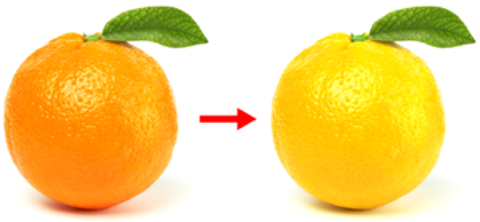
With an ACES master in hand, the next step is getting that master in front of an audience. But how will it be delivered? How can the full quality of the camera-original and computer-generated images that ACES preserves be rendered and correctly delivered to the multitude of display options in a multitude of distribution channels? To prepare an ACES master for final delivery in today's world, it has to be *transformed* for big-screen theaters, small-screen mobile devices and everything in between.

THE LANGUAGE OF TRANSFORMING

In the digital world, the concept of transforming files isn't new. To change an image from one digital representation to another, a specific mathematical formula must be used. One familiar transform is video compression. It takes full-fidelity image data and mathematically reduces it to fewer bits so it can be viewed despite limited transmission bandwidth and display processing capability. Video compression enables, for example, a theatrical motion picture to be uploaded for online viewing.

A *LUT (Lookup Table)* is another type of transform used in digital production. A LUT is a set of numbers that, when applied, modifies the appearance of an image—without changing the original data.

ACES is an entire family of transforms designed to move image data from one color space to another. These transforms have a purpose similar to LUTs. Unlike LUTs, however, ACES transforms are capable of handling colors that fall outside the expected color spaces. They generally provide a smoother and more accurate translation to the target colors. For the technically curious, these ACES transforms are expressed using a computer language called *CTL (Color Transformation Language)*.



TRANSFORMING AN ACES MASTER

In an ACES-based workflow, all camera-original and computer-generated images are first transformed to a common color space, ACES2065-1. When those images are needed for viewing or distribution, they are transformed once again to color spaces that match the display device on which the images will be viewed. The ACES transforms used to prepare those images are called Output Transforms (sometimes called Output Display Transforms, or ODTs).

Output Transforms are written specifically for each potential target display. When making a distribution copy of the finished project, the color transformation system operator simply selects the appropriate transform for the target display from a menu of available choices. The system renders out a file in the distribution-appropriate color space. When there are several target displays with corresponding color encodings, it is possible to specify multiple renderings, with different Output Transforms, in one batch operation.

In practice, depending on the display, minor adjustments of color may be made for artistic purposes. This is especially true if action takes place in very bright or very dark regions of a scene. Display technologies differ widely on how they handle highlights and shadows. Action that reads in the shadows on one display might be too dark to be visible on another, and the solution might be a color-correction trim or other adjustment to the final rendered image.

That said, ACES Output Transforms handle the heavy lifting needed to accommodate display differences, leaving artists more time to work with more purely creative elements.

TYPES OF OUTPUT TRANSFORMS

ACES provides Output Transforms for a wide variety of display technologies currently in use. For example, theatrical releases in digital projection require ACES2065-1 to be transformed to the DCI-P3 color space. Once a file is created in DCI-P3, it can move through the process to make a DCI-compliant package in familiar fashion.

For video releases, ACES provides Output Transforms for the standard color spaces of common displays. These include the HDTV color space, Rec. 709, and the new HDR screens using SMPTE standard ST 2084. Other transforms map the ACES color space to Rec. 2020 for UHDTV displays.

Different displays interpret color differently. As an example, the image labeled "RGB MONITOR" was prepared for a computer monitor using sRGB color space. If this Primer is being viewed as a PDF on a computer screen, the image looks absolutely beautiful. It looks correct.

RGB MONITOR

DCI-P3

On the same computer screen, the image labeled "DCI-P3" doesn't look as vibrant. That's because it was prepared for digital cinema projection rather than a computer monitor.

The image labeled "REC. 2020 HDR" does not look correct at all. It was created for a UHDTV (2020 HDR) monitor. For each of these images to look equally beautiful, they would need to be presented on their intended display.

REC. 2020 HDR

FUTURE DISTRIBUTION

Imaging technology develops at a rapid pace—new and interesting display technologies appear every few years. ACES anticipates these improvements by storing all the color and dynamic range of the original capture device, CGI tool, or film scanner, and preserving that original quality throughout the production process. As new distribution formats inevitably appear, ACES ensures that it will be a straightforward matter to extract yet another distribution version from an ACES master.

A DEEPER LOOK INTO TRANSFORMS

While not essential reading, this deeper technical dive goes under the hood of the ACES Output Transform.

The term Output Transform is actually shorthand for a chain of three transformation steps from ACES2065-1 to the monitor or distribution data format.

1. The first step, which is optional, is to apply a Look Transform. Between capture and distribution, this step allows for an overall modification to the default look of the images. Examples include a specific film stock emulation or a bleach-bypass look.

2. The second step is to transform the image to a theoretically "ideal" display device, one with a huge dynamic range and a color space as large as ACES2065-1. Of course, no such device exists. The Reference Rendering Transform, or RRT, transforms the data to this color space, which is larger than can be accommodated by any actual display. This step prepares the image data for all current and future displays to draw from this larger upstream source.

3. The third step takes the output of the RRT and transforms it—one last time—to the specific dynamic range and color encoding of the target display device. Output Display Transforms, or ODTs, are written for each class of displays used to present images.

Taken together, these three steps are referred to as the Output Transform.

CHAPTER FOUR

MONITORING

IS WHAT YOU SEE ~ WHAT YOU GET?

Before a motion picture or television project is released or distributed, it is viewed multiple times by creative and technical teams—on-set, then as dailies, and through several stages of postproduction. The images may be viewed on video monitors, on computer screens, on tablets and in screening rooms. As with any workflow technology, ACES should be fully considered and integrated before any cameras start to roll. From a production standpoint, the first place ACES becomes "visible" is at the on-set monitor.

MONITORING ON SET

A guiding principle behind the development of ACES is to carry the same color quality seen at the on-set monitor all the way through the production process. While ACES is capable of unifying the different color spaces of different production equipment, as always, other factors can affect how an image looks on a monitor: the quality of the display, its calibration, and the lighting conditions where the display is viewed.


2

But how can the director or cinematographer be sure the image everyone sees at an on-set monitor is the same image the editor sees while building the scenes? What does the image look like to the visual effects artists that are manipulating, compositing and creating elements for the story? Or to the colorist who is working in an environment that emulates the ideal theatrical or home viewing experience? What does the image look like there?

In a perfect world, everyone involved in production and postproduction would see exactly the same image on their monitor. But this has never been the case. Monitors and projectors have inherently different color characteristics. Cameras and production

[2] *DP Carlos González, SVC and Local 600 DIT/Colorist Stephen Latty work on location in Purcell, Oklahoma, using ACEScc to develop looks and generate on-set dailies for "The Turkey Bowl." Image copyright 2018 The Turkey Bowl Productions.*

equipment also differ in their color processing, which exacerbates the problem. ACES addresses these issues by providing a collection of mathematical transforms to bring the myriad color spaces into a single common one, as well as to prepare the data for viewing on each of the various screens throughout the production pipeline.

BRINGING BACK THE LIGHT METER

When film cameras dominated motion picture production, there was no way to know what was captured by the camera until the film was processed and a print was returned for the dailies screening. A great deal depended on the cinematographer's ability to estimate exposure by measuring light ratios on the set. This light-meter-driven judgment was critical to the final look of the motion picture.

Later in the film era, on-set video assist appeared. And soon, with the dawn of digital capture, on-set monitoring using HDTV equipment became the primary method for making lighting judgments. This was due to the unintuitive nature of how the captured image was processed for display. However, this method reduced film cameras' basic advantage—their dynamic range, which is larger than that of HDTV displays.

A typical display might have as little as seven or eight stops of range[3], while high-end cameras could have twice that many. What becomes of the extra detail in the image? Often it can be recovered and mapped back into the display's range during the grading stage of postprocessing. On the set, digital imaging technicians (DITs) can help by showing cinematographers what might happen, but the final image quality cannot be assured.

As mentioned in Chapter 2, this approach to managing image color is known as "display-referred," which means that all color judgments and adjustments are made with a specific display in mind, whether it's a digital projector or direct-view monitor.

[3] *The recent introduction of High Dynamic Range monitors mitigate the display issue, but the image data format still needs to be capable of maintaining the dynamic range of the captured image.*

REFERENCING THE REAL SCENE

ACES embraces a different way of managing color. Instead of looking at the end of the process and confining the color space to what the display is capable of presenting, ACES stands on the set, looks at the scene to be photographed and uses as its reference the light and color visible to the human eye. This is called *Scene-Referred Color*.

While the world awaits the development of a camera with the perceptual capabilities of the human eye, ACES provides a mathematical model of such a camera. This hypothetical ideal is called the Reference Input Capture Device.

It may seem odd to use something that doesn't exist as a reference. But it is a foundational principle in any system design, and the Reference Input Capture Device helps achieve the goal of creating and monitoring consistent color from one end of the production pipeline to the other. Here's how:

All cameras diverge from the human visual system model, and in different ways. Each different camera also has unique capture capabilities, technically known as its "spectral sensitivities." ACES specifies how to convert what cameras actually "see" into the common space of its Reference Input Capture Device mathematical model, and thereby preserves an exact representation of the captured image. Furthermore, since CGI tools actually are capable of creating exact scene-referred images as seen by the human eye, ACES provides greater interoperability among visual effects studios, and therefore greater flexibility and likelier success.

PERFECT-VISION MONITORING

Just as ACES uses a mathematical model for the perfect camera, it also uses a mathematical model for the perfect display. This display would be able to show a dynamic range greater than any actual device, and all the colors that can be seen by the human eye. Once again, no such real-world device currently exists. However, this mathematical model enables the ACES Output Transform to prepare image data for viewing on real-world displays.

Ultimately, ACES ensures that the image that artists see at the end of postproduction matches what they saw on-set. And not to be overlooked, cinematographers are free to use their light meters again to make scene-lighting judgments as they work!

CHAPTER FIVE

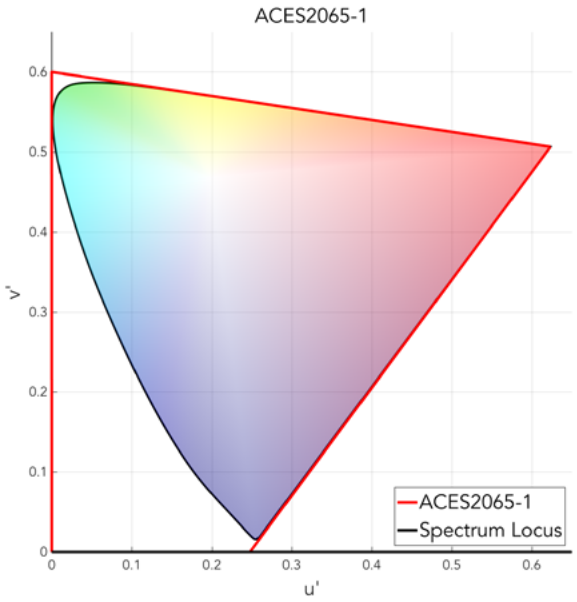
THE SHOOT

LIGHTS, CAMERA, ACTION!

A production doesn't begin with "lights, camera, action." It begins with a story idea that is crafted into a script, then cast with actors and prepped with sets, costumes, and more for its production and postproduction journey. And while a discussion of ACES during that ramp-up period is essential to establishing a successful workflow, the production stage is where ACES becomes a physical reality. It's also where giving it some extra attention can really pay off.

WHAT THE CAMERA SEES, ACES CAPTURES

The first duty of ACES is, of course, preserving the images captured by the camera. These images are transformed, or "mapped," to the ACES2065-1 color space, which covers all the colors that can be seen by the human eye. ACES2065-1 also has an exposure range of 30 stops of light, significantly greater than current cameras, which have about a 15-stop dynamic range.



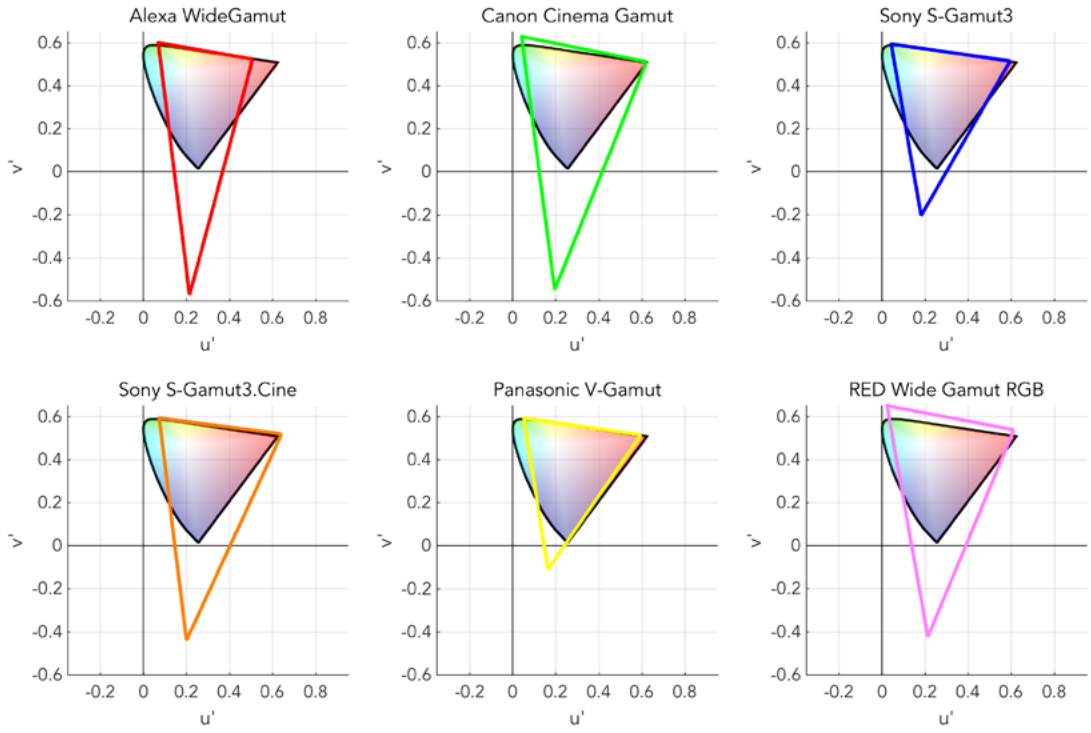
Furthermore, because ACES uses 16-bit linear encoding, more than 1,000 individual levels of luminance are captured for each stop of exposure. To put that into context, the best television image has only about 900 levels for the entire exposure range, from pure black to maximum white. This vast range of 1,000 luminance levels per stop ensures that ACES processing will not introduce any visual artifacts such as contouring.

Cinematographers capturing images on film recognize that different film stocks have different color qualities. Similarly, each make and model of digital camera has subtle differences in the way it interprets the light it sees. ACES, along with its ADX film-style

encoding, is capable of capturing all the color nuances of any film stock as easily as it does all the color detail of digital image sensors.

At the end of the day, productions that have multiple units shooting with different cameras will undoubtedly collect footage with somewhat different looks. An additional complication is the number of processing steps that some shots will undergo on the way to the finishing suite. This is especially true for visual effects-heavy productions, which may process images through several different digital systems.

The graphic below shows some *chromaticities* of *camera encoding primaries* for popular cameras. Every one of these disparate results can be suitably transformed to the ACES2065-1 color space.



MOVING CAMERA DATA TO ACES

But how do the images get from the camera into the ACES color space? That job is handled by another transform that's part of the ACES system. The Input Transform, sometimes referred to as IDT (Input Device Transform), is designed to be unique and individual to each camera.

Many Input Transforms are actually developed by the ACES Logo Program camera manufacturers for their own devices. Every camera chip has unique properties researched and designed by the companies that manufacture them. Some aspects of the chips are proprietary intellectual property of the manufacturers. As such, the most accurate mapping of the chip color space into ACES2065-1 can best be achieved by the camera companies that fully understand their products.

NOTE: For cameras that do not have manufacturer-created Input Transforms, it is possible for users to create them. The computer code and specifications to do this can be found on Github. To share or search for existing custom transforms, there is a section within the ACES Central community to connect.

Many productions continue to use motion picture film instead of digital cinematography. With the introduction of digital visual effects in the 1990s, the process of scanning motion picture film into digital image files was developed. But early scanning methods, such as the Kodak-supplied Cineon file format, were never standardized, and they produced highly variable results.

In 2012, as part of the ACES family of color specifications, SMPTE standardized an improved format for scanned film images: *Academy Density eXchange (ADX)*. ADX ensures a smooth integration of film-original imagery in an ACES-based production pipeline.

VIEWING CAMERA IMAGES

One of the primary purposes of ACES is to provide for a consistent color look for all monitors that will be used during the production process. For on-set monitoring and video production, ACES works within the signal transport technology that relays images from the camera or DIT station to the monitors.

The most common signal transport is HD-SDI, or High Definition Serial Digital Interface. As this technology was designed to move video-formatted images between video devices, it neither has the bandwidth nor internal structure to directly handle images formatted to the large-as-life ACES2065-1 color space. Enter *ACESproxy*.

USING ACESProxy IMAGES

Within the ACES family of specifications, one is specifically designed to transport camera-generated images directly to monitoring devices: ACESproxy. Because this proxy format doesn't contain all of the color information of the original file, it is easier to transport over HD-SDI.

ACESproxy takes the rather large 16-bit linear data format from the ACES2065-1 space and converts it to a more efficient log-encoded video stream. This stream can then be presented on ACES-capable monitors that are designed and equipped to decode ACESproxy signals. ACESproxy can also be converted to conventional monitor and projection color spaces using small outboard processing devices.

NOTE: ACESproxy images are designed only for real-time monitoring. While they carry all the color fidelity needed for on-set image evaluation, they do not preserve all the available image data and should never be recorded or used in postproduction.

CREATING COLOR LOOKS ON SET

The director and cinematographer generally want to see the ultimate appearance of a shot while they are lighting and composing the scene. If a production requires a special look, such as day-for-night or a Technicolor 3-strip "period" look, digital imaging technicians can apply preset looks, or modifications of those presets. They might also create something new, from scratch, to suit the scene's specific mood.


4

However, once the look is created and the scene is shot, it's a bit of a conundrum to communicate that look to the colorist in the color correction suite. ACES has a tool for just this task: the ACES Look Transform is part of the ACES metadata structure that communicates color information about the scene.

Because a Look Transform is not rendered, or "baked," into the captured images, it can be switched on and off for reference, modified, or used later in postproduction. And the images themselves remain exactly as they were photographed.

[4] *Photo courtesy of James Metcalfe, DIT*

SCREENING DAILIES IN THE ACES WORLD

When it's time to sit back and screen dailies, a set of image files for each scene must be created for the dailies viewing environment. This may be Rec. 709 files for HDTV monitors or tablet computers. Or digital cinema projection standard files for screening room use. Or both.

To create these file sets, original captured images with their applied creative looks must be rendered to the target display color space and format. This is done by choosing the appropriate ACES Output Transform as part of the render setup.

NOTE: Files created for dailies use will have the color space of the targeted display baked into the image. These files should never be used for finished work.

FUTURE-PROOFING THE SHOT

The benefit of incorporating ACES at the earliest stages of production is simple but powerful. ACES-based workflows not only accommodate the color capabilities of any current device, but also ensure that the captured images will be stored at their maximum fidelity, with all of their original image data intact. Looking ahead, the ACES2065-1 color space is large enough to accommodate future devices that may even approach the perceptual limits of the human eye.

CARRYING THE MESSAGE USING ACESclip

As ACES encoded images move through the production pipeline, they carry with them a combination of metadata files, LUTs and manual notes. This information must accompany each shot from the set, through the edit room and visual effects, and on to the *Digital Intermediate (DI)* and final mastering stage. To bring all these elements into a streamlined workflow, the Academy has created the ACES Clip-Level Metadata File—or *ACESclip*.

ACESclip files are written in XML (eXtensible Markup Language), a standard way of communicating data among computer programs. Each ACESclip file contains all the information necessary to configure visual effects and DI systems for image data to be presented correctly and consistently. The file contains notes about the Input Transform and Output Transform used, as well as about optional Look Transforms, *ASC CDL* values, and pointers to LUTs as necessary.

An ACESclip file is generated for each shot as the shot is created. The file then travels with the image data as it moves through the pipeline. During the DI stage, when visual effects are integrated and other image processing occurs, new metadata may be added to the file to show the "last viewed" state of the image.

CHAPTER SIX

VFX MARKS THE SPOT

NAVIGATING THE COMPLEXITIES OF VISUAL EFFECTS

If making movies is magical, then the visual effects department is where the pixie dust is kept. Digital compositing and computer-generated imagery have added incredible tools to the art of visual storytelling. But along with the artistry comes Tarzan's jungle of technical complexity. This is especially true in visual effects color management. And this is where ACES comes to the rescue.

CREATING AND EXCHANGING IMAGERY

The visual effects world has hundreds of vendors—from large facilities in major global production hubs to small boutiques just about anywhere. Often a motion picture finds its way to several of these facilities to complete its various effects shots. Or it adopts a one-stop-shop approach and enlists a single large company to handle the effects. Animated films are often completed this way, albeit by several in-house departments.

Large or small, near or far, each of these VFX scenarios have one thing in common—the need to exchange imagery and color information among the contributing VFX artists.

In traditional workflows, each visual element would be accompanied by LUTs, transforms and notes about how color was handled in previous processing. For the compositing stages of VFX, this may mean managing multiple color pipelines simultaneously, for individual elements in each shot. This is time consuming, error prone, and not at all "artistic."

ACES steps into this jungle and provides a common color space that can connect all the VFX contributors—removing the tedious tracking of myriad color references from artists' to-do lists.

ACES IN THE BOUTIQUE

Small effects boutiques may consist of just a few very talented artists who specialize in a subset of the broad VFX universe. Without a full-time color scientist on staff, however, it can be daunting for these artists to handle technical specifications and disparate elements across a number of different color spaces and file formats. Incorrect or imprecise handling of an image-processing step can lead to redos that threaten a project's delivery (and the artists' reputations).

In an ACES-based workflow, small boutiques can contribute easily and confidently within a compatible, well-defined color space. They can get right to work without having to deal with proprietary or "one-off" color processing steps. If images arrive in camera-native color spaces, the simple application of the appropriate Input Transform moves the material into an ACES "working" color space, matching the materials already in the pipeline. When it comes time to hand off the work, outputting the files in ACES2065-1 provides the same advantages for the next team.

ACES IN THE BIG HOUSE

Unlike the small boutiques, large VFX facilities often have in-house color science experts—many of whom, in fact, contributed to the design of ACES. Core pieces of ACES technology are built on the open source software these experts developed and still use. Within large facilities, however, motion picture materials still have to be exchanged among multiple departments and the artists within them. Connecting their work through a common color space enables this exchange to occur seamlessly. Artists spend less time managing color and more time on the creative aspects of visual effects.

In addition, larger shops build libraries of textures, objects, characters and other design elements. By creating and saving them with ACES2065-1 color encoding, these elements can be more easily repurposed in new productions without having to figure out or find notes about their respective color spaces.

ACES IN ANIMATION

Animation studios also use CGI tools to create shorts and feature films. For compatibility with these tools—which are capable of creating any color the human eye can see—ACES incorporates a specialized working color space, *ACEScg*. With ACEScg, animators can use their existing CGI tools to their full capability. They can easily convert their creative works to the standardized ACES2065-1 color space, for both long-term archiving and future use.

ADAPTING WORKFLOWS

VFX color management workflows are different for each project. They're designed according to the project's needs, and they expand with the various legacy elements involved. Researching and customizing color pipelines project by project can be a significant expense. In contrast, a single, standardized color management system can streamline the process, reducing costs and even amortizing them across multiple projects.

ACES enables the design of workflows that are vendor agnostic, presenting the greatest opportunity for color images from all sources to "play nice together." ACES is able to do this because it's based on the same color science used by most CGI tools: the *Tristimulus Color Model*.

REFLECTIONS ON A VIRTUAL WORLD

Color science in general is based on the way the human eye responds to light. This human perceptual model is referred to as tristimulus response. ACES color science is based on this model.

Computer-generated imagery (CGI) has an interestingly different characteristic when it comes to handling the red, green and blue (RGB) components that make up the displayed image. The basic values of RGB represent only a percentage of light reflected from objects in the scene. Early work with the ACES2065-1 encoding found that existing CGI tools had difficulties working in this vast color space, and produced undesirable distortions in rendered images.

The CGI-specific ACES working space—ACEScg—mentioned earlier, was created to be more CGI-friendly, so existing tools would yield more accurate results. ACEScg has a color gamut that is only slightly larger than Rec. 2020, the color space of the newly introduced UHDTV television standard. It still encompasses all the colors of DCI-P3 and Rec. 709. As with all ACES working spaces, images created or enhanced in ACEScg are returned to ACES2065-1 for storage or transport through the production pipeline. All CGI-generated image data is thus preserved.

CHAPTER SEVEN

EDITING THE STORY

SITTING AROUND THE CAMPFIRE

The edit room is the modern replacement for Tarzan's campfire. Motion picture creators gather in edit rooms to share and refine their tales. Story is the real focus. Technical details are best left at the door, mere distractions to the creative process of cutting and crafting the unique story they want to tell.

At first glance, this might seem an odd setting to be discussing something as technical as ACES color science. But even in the artistic enclave of the edit room, ACES can make a significant contribution.

PROXY WORKFLOWS

In large-scale digital productions, editors and their assistants do not work with camera originals, because this master-quality material comes with high image-processing and file-management demands. In a workflow reminiscent of workprint and negative cutting, the editing team works with reduced-fidelity digital copies appropriate to their equipment. This material, often called "proxy files," may be the same files used for reviewing dailies, or they might be specifically prepared for the editorial process.

ACES-BASED EDITORIAL WORKFLOWS

ACES involvement in editorial workflows begins as these proxy files are prepared. Camera-original files are first transformed into the ACES2065-1 color space, using an Input Transform specific to the digital camera that captured the image, or the scanner that scanned the film negative.

Once the source images are in the common ACES2065-1 color space, they are transformed again to proxy files appropriate to the particular edit system (these two transformations are usually combined into a single operation). Most common are QuickTime movie files in the Rec. 709 color space, as the majority of editing work is accomplished using common LCD monitors. Any scene-specific looks are encoded or "baked" in as the proxy files are made.

In an ACES-based workflow, the images that reach the edit room from various sources should look identical to what was viewed on-set and in VFX, and what will be seen at the final color grading stage. Editors and their assistants won't have to adjust colors or apply looks, via proprietary LUTs, to any shots. Obviously, time not spent making those adjustments can be spent honing the story.

At this point, editors may not even be aware of the ACES process that was used to create the proxies that they receive. What they will notice is how easily the images cut together with a consistent look. This will be a huge bonus when the complete edit is readied for a test screening with an audience.

Typically a motion picture needs several days of work in a Digital Intermediate suite to color-balance the shots before an audience sees the cut. That means editing work must be halted days before the screening.

In an ACES-based workflow, however, the colors are consistent enough that the amount of time spent in the DI suite may be greatly reduced. In some cases, editors

might be able to output directly from their editing systems, skipping the DI step completely. Editorial changes can often be made right up to the day of the screening.

As with the traditional offline/online editing model, the final edits made on proxies are ultimately transferred to the digital master.

FINISHING IN THE EDIT SUITE

While conforming edited proxies to camera-original materials in the DI step is common in motion picture production, the step itself is not always part of project workflows. Television shows, industrials and marketing materials, for example, may be finished in the edit room.

To accommodate such projects, some editing system manufacturers are including ACES profiles in their products. This makes ACES an attractive option for 4K and UHDTV workflows, offering an easy path to HDR outputs.

CHAPTER EIGHT

DIGITAL INTERMEDIATE

LOOKING GOOD


5

The last stage of the creative process for a moving image project takes it into the finishing room for its final color grading. This Digital Intermediate (DI) process is where all the visual departments' creative work comes together and is finalized for presentation.

Some of this work is technical, balancing the look of all the elements regardless of the various paths they took to get to this stage. However, the primary purpose of final color grading is for a colorist to help the director and the cinematographer to fully realize their artistic vision.

SAVING TIME IN PRE-GRADE AND VERSIONING

Traditionally, the first part of the DI process is a pre-grade pass that is intended to bring all the shots to consistent exposure, contrast and white balance. In an ACES-based production pipeline, which may include one or more VFX vendors, this process can be much less tedious and time consuming. All the materials, through the Input Transforms,

[5] *DI Studio photo courtesy of Digital Intermediate Ltd. and Roundtable Films Ltd.*

will already be in the same color space and more closely balanced. This lets the colorist spend more time in the final color grading session creatively enhancing the images rather than making basic technical adjustments.

Once the look has been finalized, the motion picture must be output in several versions and formats for the various distribution platforms (see Chapter 3). Some time is required for separate trim passes for each format. However, in the ACES paradigm, this work can also be less burdensome, as ACES provides precise transforms for any display format. Trim passes are more likely to be quick and efficient. Once again, time saved here can be applied to experimentation and fine tuning in the final color grading session.

THE "FEEL" OF ACES IN DI

ACES2065-1 is a linear color space with an enormous range of exposure and color. DI systems have traditionally been designed to work with log color spaces and more constrained color and dynamic ranges. As a result, color correcting directly on ACES2065-1 images felt unfamiliar to colorists—the trackballs, knobs and rings were programmed to work on those older, legacy encodings.

As color-corrector manufacturers update their software for ACES2065-1, ACES provides additional "working" color spaces to accommodate colorists. These color spaces are referred to as *ACEScc* and its close cousin, *ACEScct*. They can be thought of as correction-friendly color spaces, designed to be compatible with traditional color-correction controls.

ACEScc is a log encoding of ACES2065-1 files that uses a different set of primaries and somewhat smaller color gamut. ACEScct is similar to ACEScc but also brings along familiar shadow detail characteristics of Cineon and other legacy working spaces. For those working in either of these color spaces, the physical controls return to more familiar "feels."

The ACEScc and ACEScct working spaces are not meant for storing, saving or interchanging images. That's the job of ACES2065-1. In most color-correction systems, transforms between ACES2065-1 and the working spaces are provided, often automatically.

APPLYING LOOK TRANSFORMS

Another useful ACES technology that appears in the DI suite is the Look Transform. When the cinematographer and digital imaging technician are working on set or on location, they quite often develop and set overall looks for a scene. This information, usually in the form of an American Society of Cinematographers Color Decision List (ASC CDL) or a LUT (preferably in the ACES-specified Common LUT format), is bundled into the metadata for each shot.

The colorist may use these looks as part of the viewing pipeline and finished shots, or may re-create them in the final color grading stage. Look Transforms are applied just prior to Output Transforms so that together, they produce a correct and viewable image on a monitor or projector. Unlike "power window" grades that may be confined to parts of an image, Look Transforms are applied uniformly to the entire frame for better integration with the visual effects and DI processes.

ACES color management works behind the scenes to make precise color-space matching as automatic as possible. This often results in reduced time in the DI suite for technical tweaks, and more time to develop each scene's creative look.

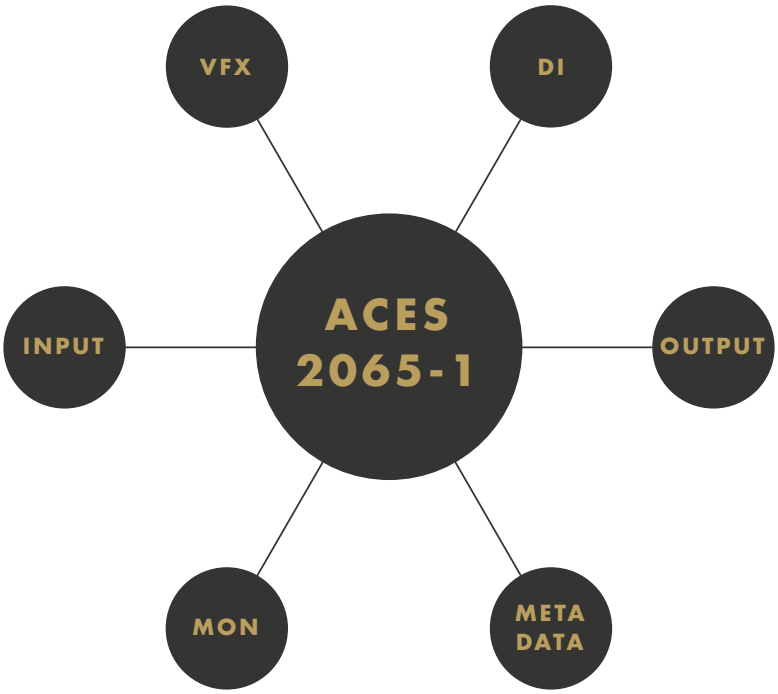
[6] *DI Studio photo courtesy of Terrassen Post. NYC Skyline photo courtesy of cinematographer Johan Palm.*

CHAPTER NINE

SHIFTING THE PARADIGM

FROM START TO FINISH

Tarzan can use a combination of tree branches and vines to swing through the jungle and arrive at his destination. Likewise, ACES provides "grab points" through common transforms and color spaces for any given workflow, making color pipelines easier to navigate.



TRANSFORMING THE JUNGLE

Most transforms in ACES are designed to be used in multiple places throughout the production process. One way to imagine these roles is diagrammed in the image above.

Output Transforms appear in every place that images are displayed. Input Transforms are important for making dailies and edit proxies, but will also be used when *camera raw data* for editors' selected scenes is prepared for VFX or DI.

On-set or on location, an ACES-based workflow will include Input Transforms, ACESproxy for monitoring, ACEScc or ACEScct for the DIT cart, ACESclip metadata and Look Transforms to be sent downstream to VFX and DI, and Output Transforms for making dailies and edit proxies. Look Transforms may be used to test and apply overall looks for monitoring and will be passed on to the finishing artists.

The editing team will work with proxies created using the correct Output Transform for viewing on the monitors in the edit room.

At the mastering stage, the Input Transform will move the camera raw data into ACEScc or ACEScct for manipulation by the grading system. Look Transforms from the set may be referenced or employed in grading.

VFX departments and companies using ACES may bring camera-original material into their systems via Input Transforms. Most VFX pipelines will employ ACEScg for their image processing steps. And, of course, the transport to various monitors will use the correct Output Transform for the type of display and viewing environment the artists are using.

Mastering facilities will produce the "fully baked" ACES2065-1 master files packaged for delivery as Interoperable Master Format (IMF) packages to the content owners for distribution and archiving.

Distribution will take those IMF packages and use Output Transforms matching each type of display being used to deliver content to audiences.

Archivists will take those IMF packages and deposit them in their long-term archive.

The most important idea is that ACES serves the goal of bringing all image data to a single, unified color space—ACES2065-1—which is larger than even Tarzan's keen eye can see.

IT'S A WRAP

The entire process of creating theatrical motion picture, television, video game and immersive storytelling content—from the scene to the screen—was considered when designing ACES. After more than a decade of development by hundreds of experts and dozens of companies, as well as years of practical field experience on all manner of moving images, ACES is now the most comprehensive system for color management and image interchange available.

Taking advantage of ACES color science to streamline workflows is both easy and free. And using ACES standards throughout the production process will clear a path through the complex jungle of image encoding for the entire production team.

GETTING STARTED WITH ACES

We hope this Primer has answered some of your questions and encouraged you to incorporate an ACES-based workflow on your next project. The following resources and contacts are available to help you along the way.

ACES Contacts

- ACESCentral.com – This is your first stop to get in touch with anyone in the ACES Community. Sign up, read the "Getting Started with ACES" thread and get started!
- Contact information for the ACES Team can be found in the FAQ on ACES Central.

PRIMER GLOSSARY

ACES (system) The acronym for the Academy Color Encoding System, a free, open, device-independent color management and image interchange framework. ACES enables complete, standardized color management for moving images, from image capture through postproduction, presentation and long-term archiving.

ACES Reference Input Capture Device A mathematical model of a hypothetical reference camera with the ability to see every color visible to the human eye.

ACES2065-1 Shorthand for color space 2065-1, found in the SMPTE ST 2065-1 Academy Color Encoding Specification. This defines the ACES core color encoding from which all other encodings derive. This color space is capable of encoding every color visible to the human eye.

ACEScc The logarithmic color encoding that optimizes ACES for color correctors and other color grading tools. It is intended to be a transient working space, internal to software/hardware systems only. It is not recommended to be stored in files or interchanged.

ACEScct The quasi-logarithmic color encoding that optimizes ACES for color correctors and other color grading tools. It is intended to be a transient working space, internal to software/hardware systems only. ACEScct is similar to ACEScc but with the addition of a "toe" resulting in a more distinct "milking" or "fogging" of shadows when a lift operation is applied during color grading. It is not recommended to be stored in files or interchanged.

ACEScg The linear color encoding that optimizes ACES for computer graphics rendering and compositing tools. It is not intended to be an interchange working space. Before file interchange, care should be taken to transform ACEScg images to ACES2065-1.

ACESclip A "sidecar" XML file that assists in configuring an ACES-based workflow and enables portability of ACES pipeline configuration information throughout a production.

ACESproxy The logarithmic color encoding designed to work within the limits of video transport media, such as HD-SDI cabling, to move video images between video devices. It is an integer, range-limited version of ACEScc.

ADX (Academy Density eXchange) A densitometric encoding for scanning photographic negative film. It enables filmed images to be brought into the ACES2065-1 color space, and incorporated into an ACES-based workflow.

ASC CDL (Color Decision List) is a framework developed by the American Society of Cinematographer's Technology Committee that allows the interchange of basic RGB color-correction information between equipment and software made by different manufacturers.

Camera Encoding Primaries A set of red, green, blue and white chromaticity coordinates used in the transformation of camera code values to various color encodings.

Camera Raw Data Proprietary and generally unprocessed image data captured by a digital camera, also referred to as "camera-native" image data. Specialized software is required to convert camera raw data into viewable images.

CGI (Computer-Generated Imagery) A process that utilizes imaging software/ hardware systems to create still or animated visual content.

Chromaticity Coordinates The ratio of the amount of one primary color to the total amount of all three necessary to reproduce a given color.

Color Gamut The range of colors that can be reproduced by an output or display device such as a monitor, projector or printer.

Color Management In digital imaging systems, the process of ensuring that color information is transmitted and presented accurately across a variety of media and devices.

CTL (Color Transformation Language) A portable, platform-independent scripting language used to create and implement ACES transforms. It is designed to be used in pixel-based imaging environments.

DCI-P3 The color space for digital cinema projection, which is larger than those specified in the sRGB and Rec. 709 standards.

DI (Digital Intermediate) The color grading, finishing and versioning steps during the postproduction phase of a motion picture project.
Display-Referred Color Color encodings defined by colorimetric values and a viewing environment associated with projectors, monitors and other display devices in a production pipeline.

HDR (High Dynamic Range) Displays Display devices and their associated technologies that can accommodate substantially greater dynamic range (i.e., "blacker blacks" and more brightness) than standard devices.

IMP A media package consisting of an asset list, essence, and metadata conforming to the interoperable mastering format (IMF) specifications

LUT (Lookup Table) A viewable, indexed array of input and output values used to represent and apply color transforms.

Rec. 709 The standardized format for high definition television (HDTV) that includes a 16:9 (widescreen) aspect ratio, 8- or 10-bit color encodings, a reference set of display color primaries, an image resolution of 1,280 or 1,920 pixels per horizontal display line, and other technical specifications.

Rec. 2020 The standardized format for ultra-high definition television (UHDTV) that includes a 16:9 (widescreen) aspect ratio, 10- or 12-bit color encodings, a reference set of display color primaries, an image resolution of 3,840 or 7,680 pixels per horizontal display line, and other technical specifications.

Scene-Referred Color Color encodings defined by colorimetric values and a viewing environment associated with objects as they exist in the real world.

SMPTE (Society of Motion Picture and Television Engineers) An international professional organization that develops standards, guidelines and recommended practices for moving-image industries. It has more than 7,000 members worldwide.

Spectrum Locus On a chromaticity diagram, the horseshoe-shaped line connecting the points representing the chromaticities of the spectrum colors. This represents all colors visible to the human eye.

sRGB (standard Red Green Blue) A color encoding standardized in 1999 for use with monitors, printers and the Internet.

Transform The process that translates or modifies image data for a specific display device or image processing operation in a color imaging system.

Tristimulus Color Model One of many systems of color representation, most often associated with the representation of color in the human visual system, where three component color values are used to represent stimuli generated from the cones in the eye. Examples of tristimulus color models include LMS, CIEXYZ, etc.

UHDTV (Ultra-High Definition Television) A video format with an array of technical specifications, including an image resolution of 3,840 or 7,680 pixels per horizontal display line. These resolutions are similar to the 4K and 8K formats, respectively, that are used in the motion picture industry.

ACKNOWLEDGMENTS

This Primer was produced by RevUpTech.com
and written by Diana Weynand and Vance Piccin.