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White Paper

The Beauty of ACES with Nucoda Film Master

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This paper explains the theory and practice of using Nucoda Film Master with the workflow developed by the Science and Technology Council (STC) of the Academy of Motion Picture Arts & Sciences (AMPAS). Their aims are to:

- Improve and simplify post-production workflow
- Restore and preserve current motion picture assets
- Create a standard that is ready for future technologies.

Why is a new workflow needed?

Film and Telecine

In the past things were much easier. All film cameras exposed original camera negative (OCN), which could be printed to film, or transferred to video with a telecine. The choice of camera, film stock or telecine was subjective and not based on compatibility. There were choices of film and video formats and these standards were carefully documented, for example ITU rec 601 for standard definition and rec 709 for high definition. The display used to be considered a constant. Once calibrated a CRT broadcast monitor was never challenged.

"When things are ingested into a Rec. 709 workflow, you're constrained by the color gamut of Rec. 709, as well as by the dynamic range," explains cinematographer **Curtis Clark, ASC**. "With the ACES workflow, it enables the full dynamic range and full color space to be faithfully maintained within the post finishing process."

Television Standards

We have learned that the television programs that were once state of the art are now merely standard definition and often need expensive re-mastering to be of acceptable quality today. Re-mastering and restoration are possible for material shot on film because the source images had potentially better quality than the deliverable. However, since the programs were often made in systems that were limited to the rec 601 delivery format, conforming and effects need to be re-done to take advantage of the higher quality film source. At the time there was no choice because the technology either did not exist, or was prohibitively expensive. A workflow that is based around the delivery format is

known as ***output referred*** and is cost and performance effective because it reduces the data size early in the pipeline. The disadvantages are the consequent loss of quality, the difficulty in accommodating future standards and the lack of useful archival copies.

Digital Formats

Today, as a result of competition amongst digital camera manufacturers, display companies and software developers we have an overwhelming number of incompatible source formats, file formats, distribution formats and display formats. At some point in post-production all the sources need to be combined, and that is still usually done in a system that monitors and exports lower resolution, bit depth and dynamic range than the source material.

The problems are compounded because each facility has had to research a solution that matches the equipment it has invested in with the media that its clients bring in. Amongst the workflow challenges are the interchange of numerous image file formats and encodings, and limited exchange of meta-data between the systems. These challenges can be met, but there are further factors that reduce quality, early in the workflow. Film and many digital cameras have a potential dynamic range greater than the 10 bits most DI systems currently record to, and even cinema masters are output referred.

Archives

Similarly, for many years archivists have argued that restoration to anything less than the original source quality, whilst better than nothing, is nevertheless a short-term solution, since the process will need to be repeated at the next technology level. Repeating the restoration is inefficient, but the real problem is that original elements may have deteriorated or been lost since the first attempt.

Today we are less restricted by technology and cost, but we continue to employ unique complex workflows to manage all the cameras, file formats and distribution channels in use, as well as remaining compatible with our assets from the past. For a single standard to dominate it would have to be broad enough to accommodate all others past, present and future, and be adopted by all manufacturers without proprietary gain.

In summary, the ideal workflow would

- **A**ccommodate film, video and data material
- **C**onsider future standards and technologies
- **E**nable seamless interchange of high quality motion picture images whilst accurately maintaining high dynamic range and wide color gamut
- **S**hare intermediate stages of digital image post production including all meta data

The ACES workflow

Like so many good ideas the concept is simple enough, but ACES is special because it comes from the co-operation of all the major industry players including Adobe, Arri, Autodesk, Digital Vision, Dolby, FilmLight, Fujifilm, ILM, Kodak, Pixar, and Sony Electronics. In addition it is designed and built in the open with wide ranging input from all the interested parties.

GLOSSARY OF TERMS

ACES 1)**The system**: a non-proprietary workflow based on the Academy Color Encoding Specification. The Academy has spent many years developing all the elements needed, obtained universal agreement and documented everything in great detail.
2) **Academy Color Encoding Specification** (smpte 2065-1)**:** A color space that includes the entire visible spectrum is the heart of the new workflow. ACES uses RGB values that are compatible with existing processing systems. The big change is that ACES images are 'scene referred' meaning that light is accurately recorded as it existed at the camera focal plane, regardless of how that might look when viewed in its raw state or indeed independent of any output format or display device.
3) The **file format** smpte (2065-4)**:** ACES files are frame based and a proposed replacement for the .dpx format. ACES is derived from Open EXR, developed by ILM and is a half float format that shares the extension .exr. However, ACES files contain a metadata flag that identifies them. All ACES files are .exr, but not all .exr files are ACES.

IDT **Input Device Transform:** A calculation to convert a camera, scanner or other image sources to the Academy Color Encoding Specification, at which point the image will be ***scene referred*** and in an RGB floating-point format. Each device will need its own IDT, and scene referred means that even exposure affects the transform.

ADX **Academy Density Exchange Encoding**: A way of outputting film scans to ACES based on print density. ADX recommends a 16-bit integer format to handle the full dynamic range available but also defines a 10-bit encoding for compatibility.

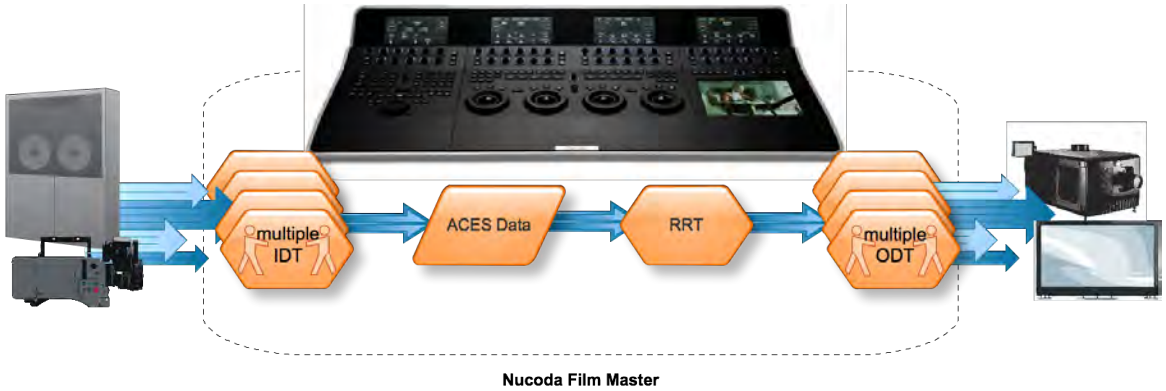
RRT **Reference Rendering Transform:** A single transform that is universally accepted as the standard, and which converts from ACES to OCES. The ACES image is scene referred and does not look right to the eye, so the RRT converts the image to output referred. The RRT is hugely important to the success of the workflow and is a necessary part of making an image

aesthetically pleasing. In practice the RRT and the ODT are compounded into one calculation.

OCES **Output Color Encoding Specification:** The output referred color space created by applying the RRT to ACES. It is still an idealized color space, and needs an ODT to look correct on any real world display.

ODT **Output Device Transform:** Maps the image from the high dynamic range of OCES to an ideal display format such as rec 709. Each display standard will need its own ODT. Real world displays will still need calibration to exactly match the ideal color space of each ODT.

The Workflow.



Ingest

To work in ACES all sources, whether film video or data, must first be transformed to the Academy Color Encoding Specification. The main purpose of this is to remove any capture characteristics that relate to the camera, lens, sensor, or recording method and as accurately as possible reproduce the physical light of the scene. This is referred to as linear light and has lots to do with the physics of light and little to do with the way we see. Values stored as linear light are directly proportional to the light in the scene rather than how the human eye perceives light. It is more important that the transform is repeatable than strictly accurate. The result is that all media is not just in the same file format, but it also has a real world relationship regardless of exposure, lens and other mechanical factors. This is a great starting point for a colorist and a major benefit of the workflow.

Remember that any information that has not been recorded, or has been lost in compression will not be represented. Footage shot with a Canon EOS 5D Mark II is compressed by the H.264 codec and lacks much of the information that was present in the original scene. Using ACES cannot put back what is not there, it is logical not magical!

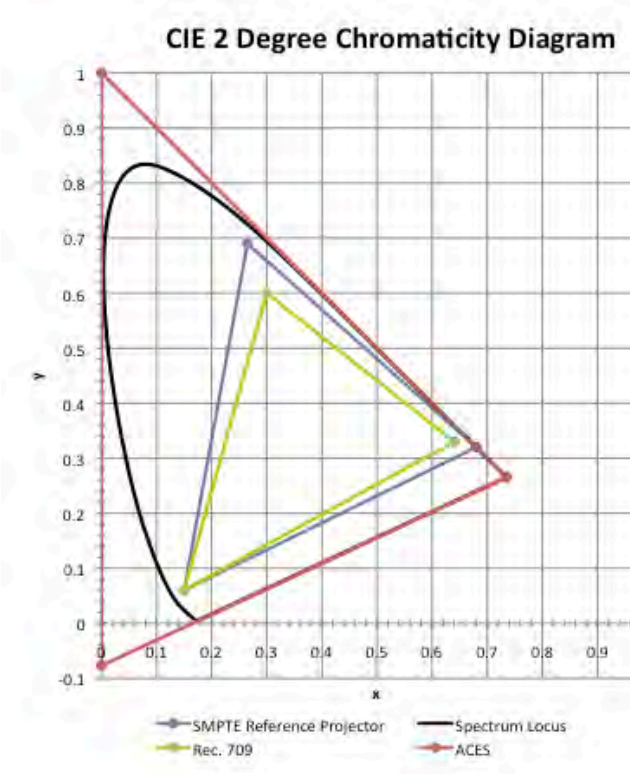
IDT

The Input Device Transform (IDT) maps the source image to ACES. Each device needs its own IDT, which is provided by the manufacturer and based on a very precise understanding of the device. In time most cameras will probably have the IDT built in and have an ACES output setting. Rec 709 and other non-ACES material can also be transformed and used in an ACES project by using the appropriate IDT.

The IDT is an essential part of the workflow and has two very significant benefits. When cameras record images in a display referred color space, such as Rec709, the sensor data must be distorted or clipped. The **A**cademy **C**olor **E**ncoding **S**pecification ensures that the full range of the source sensor is recorded and available to the colorist. Secondly the IDT maps media captured by cameras with different primaries and sensitivities to uniform linear light values, which minimizes color differences between cameras and makes them much easier to mix and match. ACES does not extend the dynamic range of a camera, but neither does it need to scale or fit the dynamic range to avoid clipping since it is a high dynamic range format.

ACES

Once media has been through the IDT it is much easier for a colorist to work with. Technically the image is now RGB 16 bit floating-point data. This sounds quite ordinary, but is actually very exciting. The RGB primaries for ACES are positioned so that they form a triangle that encompasses the entire spectrum of visible light. This makes it completely future proof since it can accommodate every color we can see. In the diagram the curved black line shows human vision as defined by the CIE chromaticity chart, and the red triangle represents the ACES color gamut.



The RGB values in ACES respond well to conventional color tools, making them more practical than XYZ formats. RGB values are also more easily recognized by humans. Mid gray, or 18% gray has the ACES triple 0.1800, 0.1800, 0.1800, whereas the CIE XYZ equivalent is 0.1715, 0.1800, 0.1816. The floating-point values are more precise than conventional 10, 12 or even 16-bit integer systems and can handle more than 25 stops of dynamic range. A 10-bit system uses 1024 digital steps to cover a dynamic range of about 12 stops of exposure. ACES however, uses 1024 steps for each and every stop of exposure across a dynamic range of 30 stops. This greater precision and range protect the source information, even within the final grade.

RRT

Because of its extended dynamic range, an ACES image appears very contrasty with black and white clipping if shown uncorrected on a rec 709 display. ACES images are therefore always viewed through the RRT and an ODT in the same way that log images are monitored with a viewing LUT. The ACES transforms are complex compound algorithms and require great accuracy. The Dolby PRM-4200 reference monitor uses a huge 65 cube LUT specifically for the ACES transforms when viewing on set or during early stages of post-production. The grading system will always need to render and embed the transforms in order to create distribution masters.

> "I'm actually really glad that Digital Vision contacted you about this – we've been trying to get more manufacturer support for ACES, so having them come to you is awesome. The one thing about ACES is that it solves a HUGE issue we have with our Digital Intermediates – we are currently stuck with secret sauce color from EACH DI house. ACES would level the playing field and finally give us a known good *standardized* archive."
>
> - ***Annie Chang*** *- VP of post-production technology at Walt Disney Studios*

The Reference Rendering Transform (RRT) is a standard transform that is added to the scene referred image so that it will be aesthetically pleasing on a display. In other words an ACES image is scene referred until the RRT is applied. There is a nice film analogy, since original camera negative (OCN) does not "look" right until it is printed, so we can think of the raw ACES image as a digital negative and the RRT as the print stock. The IIF project committee based the RRT on 70 years of film print development and more than 15 years of Digital Intermediate experience and then spent 5 years refining it. Early versions were tried in 2011, and a release candidate is expected in 2012.

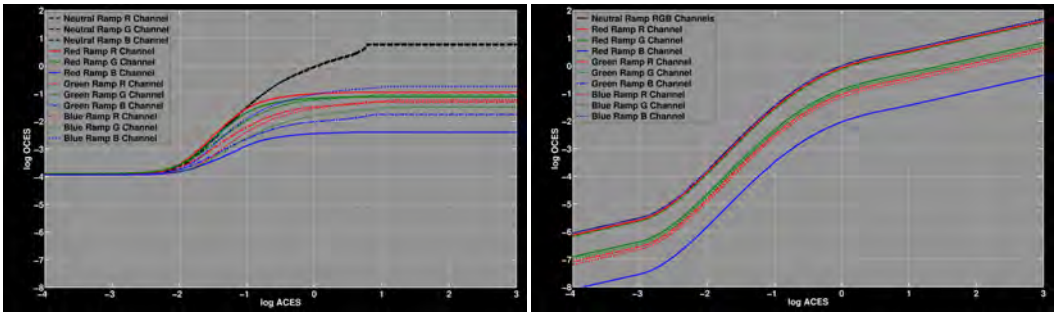
Image courtesy of Walden Media

Source image at normal exposure

Same image graded down in rec 709

Same image graded down in ACES

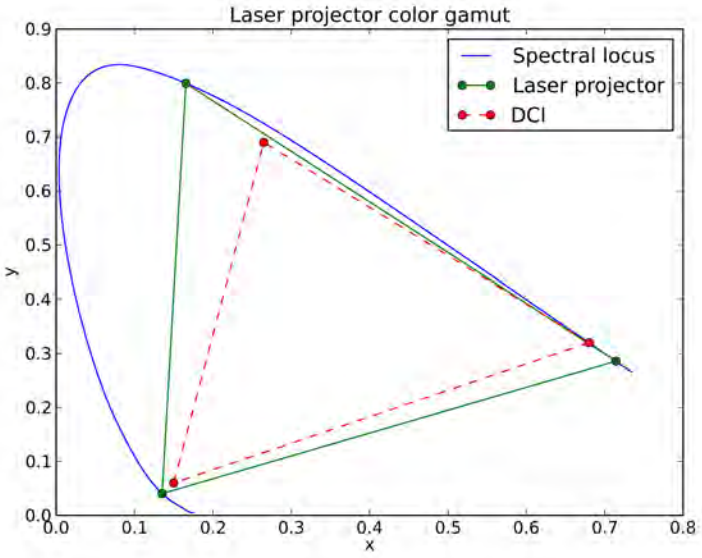
There are many benefits of the RRT over rec709 or a print LUT. It will become a new standard, and remove the need for a custom print LUT, making the film-out process more predictable. The RRT has a dynamic range of about 25 stops, which is far greater than film or any of the digital displays in use today. ACES masters can therefore take advantage of better dynamic range in future displays. However, whilst the RRT is a carefully calculated starting point, it does not replace the need for color grading, and is not a film "look".



Print Film Emulation **RRT release candidate (Feb 2012)**

ODT

The RRT is fixed and not optimized for any one display or output standard. The final part of the process is to ensure that the perceptual intent of the RRT is correctly displayed, and the Output Device Transform or ODT does that. The ODT does for the display what the IDT does for the camera. It maps the high dynamic range, wide color gamut OCES RGB values to a smaller range and color space that is appropriate for the display, so that the colors are always the same to the eye. Having an ODT in the system removes the assumption that a given set of RGB values will produce the same color on two different displays. Future



The Barco prototype DLP laser projector color gamut exceeds P3 and rec 709 displays.

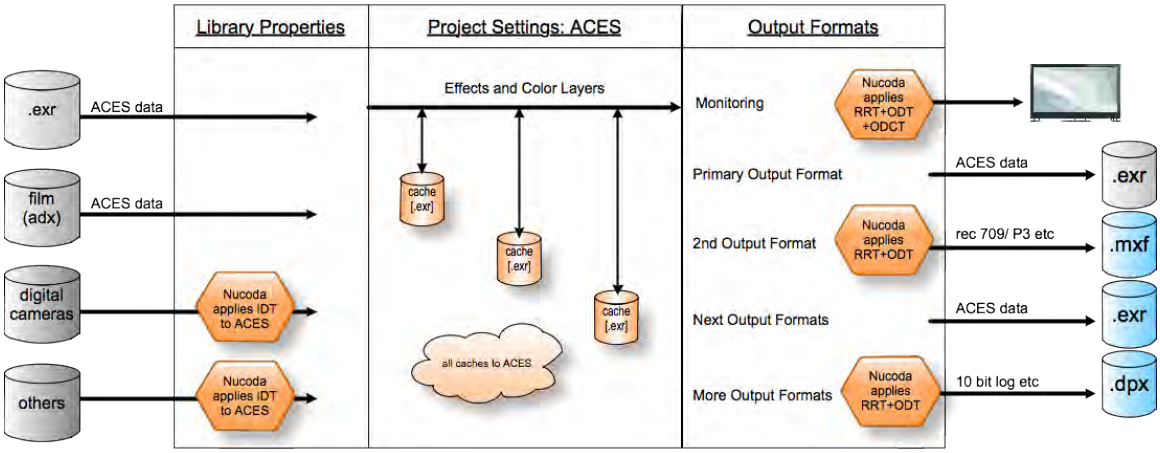
displays, such as the Barco laser projector, can benefit from an ODT designed to maximize their improved technology.

Burning in the appropriate ODT creates a distribution master and exporting the files without the RRT or ODT creates an ACES master.

ACES masters are ideal for film recorders, which have their own calibrated ODT. They are also perfect for restoration and archiving, since all of the source detail is preserved and future deliverables can be made by applying a different ODT.

Using ACES with Nucoda Film Master.

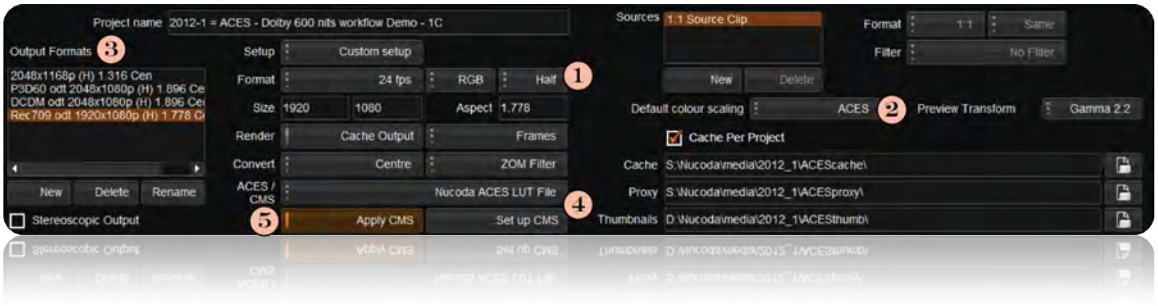
Nucoda working to ACES



In Film Master an ACES project is very similar to any other project and colorists are encouraged to try the workflow as soon as the possibility arises.

Project Settings

Understanding ACES makes the Film Master setup straightforward and obvious. When an ACES project is created the bit depth should set to "half", which is the standard for all .exr files and switches the system to expect a floating-point workflow. Once the "half" setting is active ACES becomes available as a working color space and should also be selected. Remember the ACES color space can only exist in a half float project. In an ACES project all Nucoda Film Master caches are ACES encoded.



ACES project settings

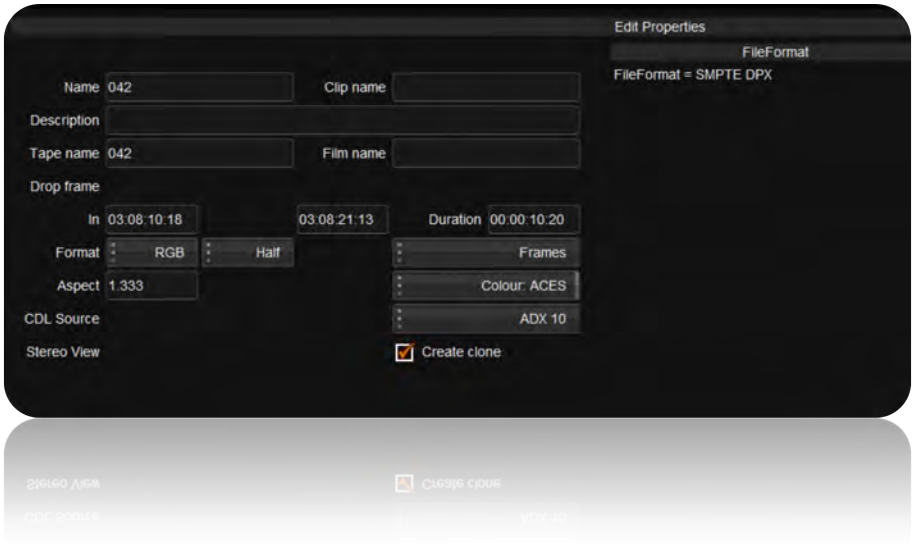
1. Set bit depth to HALF
2. Set color scaling to ACES
3. Configure output formats
4. Select ODT for each output format from ACES/ CMS
5. Apply ODT for output formats that need the ODT embedded

Each output format now needs the RRT and an ODT for monitoring and in most cases export. In an ACES project the CMS dialog displays a choice of ODTs, which are already combined with the RRT. Select the appropriate ODT for each output format and enable the "Apply ODT" button if the transforms should be burned in on export. This is similar behavior to a non-ACES project, which remembers the CMS for each output format and has the option to burn it in. Nucoda Film Master version 2012.1 allows the colorist to rename each output format to make it easier to identify. Note that the primary output format can have an ODT for monitoring but not for export.

Library Properties

Now the project is ready for opening and media is imported in the usual way. All .exr files are treated as ACES by default, but an IDT can be applied from the Library Properties dialog. All .r3d images bought into an ACES project are automatically set to half bit depth, ACES color space, and Linear Gamma. All other sources need the correct IDT to bring them into ACES space. The IDTs for each source are included in the Nucoda Film Master software, or an SDK controlled by it. The correct IDT can be set up as a default in clip preferences, or it can be done clip-by-clip using Library Properties.

"ACES is important" says **Mike Smollin**, senior DI colorist at Walden Media. "Digital Vision has worked with us every step of the way to get us everything we needed to create our first ACES workflow feature, 'Won't Back Down'. They're just the best at doing this kind of development." Mike is now using ACES on Film Master to grade "Of Men and Mavericks" starring Gerard Butler.

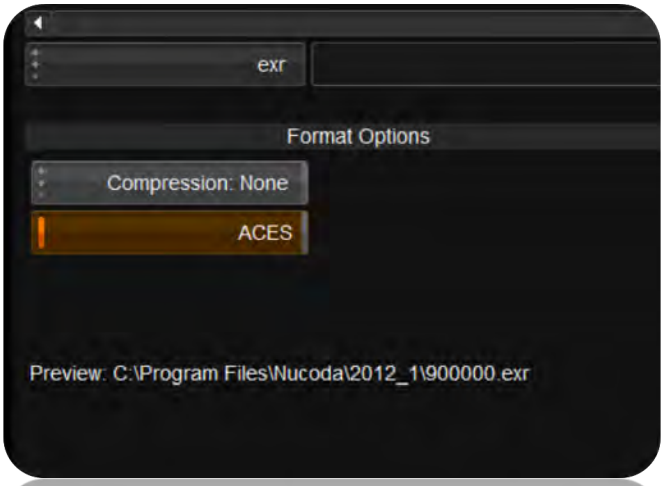


Library Properties in an ACES project

Grading remains exactly the same as it always was, although colorists will immediately feel the benefits of the increased range. Remember, that the primary output and any other output format that does not have "Apply ODT" selected, must have the ODT enabled from the panel or the GUI. If "Apply ODT" is selected in the project preferences the ODT is always enabled. Use of the ODT is very similar to CMS in conventional projects. In version 2012.1 compositions remember their output format, so switching the composition can also switch the output format and monitoring.

Export

When it is time to export, an ACES archive can be exported in its .exr format. All other deliverables should have "Apply ODT" selected in the project preferences. Senior colorist Mike Smollin was one of the first to adopt ACES with Film Master on "Won't Back Down" (2012). He passed his DI grade to E-Film as ACES and says that the resultant film prints were the very best digital intermediate that he'd ever seen.



ACES export

ODTs in Nucoda Film Master

DCDM ODT	produces X'Y'Z' encoded values for DCPs
P3DCI ODT	produces P3 RGB encoded values where R=G=B represents white with a chromaticity of x=.314 y=.351 according to DCI specification
P3D60 ODT	produces P3 RGB encoded Code values where R=G=B represents white with a chromaticity matching the ACES white specification (about D60)
Dolby PRM ODT	maps ACES to the full range of the Dolby reference monitor at 600 cd/m^2, so that a colorist can see detail that is clipped, or color errors in the ACES file that are masked when the dynamic range is reduced to Rec709.
Rec 709 ODT	maps ACES to the standard for HDTV space
sRGB ODT	maps ACES to the standard for computer displays

NOTE: All references to Nucoda Film Master assume software 2012.1

Kevin has been a colorist since 1985, and works all over the world grading feature films, commercials and TV shows. He has been teaching colorists for over 15 years, created the da Vinci Academy in 1998, and founded the International Colorist Academy in 2009 (www.icolorist.com). Some of his recent credits include “Streetdance 3D” , “Monsters” and “180”

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