Background and Objectives of AMPAS-IIF

The development of digital imaging technology allows more and more feature films to be made using the DI (Digital Intermediate) process, which means - whichever the input is (film or digital), whichever the output is (film or digital), any intermediate process including editing, visual effects, and color correction - all processes were carried out utilizing digital files. There were de-facto standard file format DPX and de-facto encoding procedures Cineon for DI, but Cineon is a very vague specification with no assurance of the same color for the same code value. As a result, every facility started to use different code values in various workflows, leading to tremendous inefficiency and quality loss in the process.

In response to this situation, AMPAS (the Academy of Motion Picture Arts and Sciences), started to discuss new standards for digital motion picture workflows in 2004. The goal was to create a new standard for the digital motion picture making procedures, which would include the clear definition of color spaces and specific procedure of image rendering. This new process was named the Image Interchange Framework (IIF).

The AMPAS committee announced that more than 30 companies would contribute to the development process. FUJIFILM joined this project in 2005 and contributed in the solution of one of the major technical issues: reference rendering transform. This transform needs to have “Film-look” reproduction, huge dynamic range coverage and very precise accuracy for its inversion. Completion of this transform enabled feasibility testing of this workflow. At this point, the workflow has a satisfactory quality and is effective enough to be implemented.

Basic Understanding of AMPAS-IIF

AMPAS-IIF is intended to achieve its various applications in diverse use cases. It consists of several encoding color spaces and transformations between these color spaces which are clearly defined for easy understanding of the pixel value meaning (Fig. 1).
2.1 Encoding Color Spaces

2.1.1 ACES

ACES stands for “Academy Color Encoding Specification”. It is a scene-referred color space and RGB primary (see Fig. 2) was selected to cover all of the spectrum locus. This means all of visible colors can be expressed in positive RGB values. ACES images are encoded in 16-bit float. This means it can express an unlimited range of colors, and can be saved in the OpenEXR file format which is the de-facto standard for saving floating point images.

ACES is the principal color space of AMPAS-IIF. ACES images are used for archiving. Camera film images are converted to ACES. Digital camera data are also converted to ACES. CGI (Computer Generated Imagery) is also rendered to ACES. ACES is a connecting color space and all of the editing should be done in ACES. Color correction will be done to ACES images.

ACES is defined as scene-referred color space, but it is not necessary to express very precise scene colors. Above all, ACES white point is set to D60 (CIE standard illuminant), and it would never match that of the actual scene. It can also include an input device characteristic as well as artistically controlled color reproduction.

Another important point is that the same ACES values must be rendered to the same color, making it possible to observe the same color in different output devices. This will be explained later.

![Fig. 2 Color spaces.](image)

2.1.2 APD/ADX

APD stands for “Academy Printing Density”. ADX (Academy Density Exchange Encoding) is the code values of APD, and their relationship is defined with one to one mathematical calculations.

APD is defined very clearly by its spectrum sensitivity (see the top left of Fig. 3). Given the spectrum transmittance of the OCN (Original Camera Negative), all facilities can get the same APD values. The spectrum density was determined to match the product of the spectrum sensitivity of print film and printer’s light. Fortunately, the spectrum sensitivity of Eastman Kodak’s positive film and FUJIFILM’s were very similar. By using the most popular printer’s light, we could decide the definition to a single set of spectrum sensitivities for APD.

2.1.3 OCES

OCES stands for “Output Color Encoding Specification”. This is the definition for the internal use in the IIF. No end-user ever handles OCES images directly. OCES is the output image color space targeted for the reference display device which would have a more than 1,000,000 to 1 dynamic range. OCES images can be acquired by rendering RRT (which will be explained later) to ACES images. Therefore, the same ACES images would be converted to the same OCES images every time.

2.2 Input Transform

2.2.1 Digital Camera to ACES: IDT (Input Device Transform)

The digital camera image would be transformed by IDT to ACES images. Usually, digital cameras have a function to encode colors according to its own data format. AMPAS-IIF requires image data which must be converted to scene-referred ACES images, so IDT’s role is to make an inverse transformation from the encoded image data through raw image data to ACES image data. The most important part of this transformation is a 3×3 matrix to convert digital camera spectrum sensitivity color space to ACES color space defined by ACES primaries.

2.2.2 APD/ADX to ACES and vice versa: Universal Unbuild and Universal Build

The role of OCN is simply to convert original scene colors (ACES) into OCN density (APD). We call this transformation a “Build” function. The inverse transformation from APD to ACES is called an “Unbuild”.

Every OCN has its characteristic to achieve its own image reproduction. AMPAS has defined “Universal” transforms for both directions, “Universal” means that there is only one transform. As a result, a different OCN image results in a different ACES image even if the same scene was captured. In other words, “Universal Unbuild” was chosen for the typical OCN characteristic, and there remain different OCN characteristics in ACES image.

2.3 Output Transform

2.3.1 RRT (Reference Rendering Transform)

RRT is the only one transform from ACES to OCES. We will explain what was required for this and how we developed the ultimate RRT in a later section.
2.3.2 ODT (Output Device Transform)

ODT is the transform to convert OCES into an actual output device format which has a specific and limited dynamic range and limited color gamut. Usually, ODT is expressed by a simple 1D LUT (Look up Table) and one $3 \times 3$ matrix. The simplicity of the ODT is brought about by the definition of the OCES transformed by complex RRT. We can easily calculate proper ODT for many different output devices.

2.4 Use Cases

In this section, we will show the typical procedure based on AMPAS-IIF.

2.4.1 Film Capturing and Digital Projection

1) OCN is scanned into ADX through a film scanner.
2) ADX is transformed to ACES.
3) Editing and grading are accomplished using ACES images.
4) ACES images are rendered by RRT/ODT to a digital projector.

2.4.2 Digital Capturing Film Out

1) Digital camera raw images are transformed to ACES by it’s IDT.
2) Editing and grading is accomplished using ACES images.
3) ACES images are rendered by RRT/ODT and transformed by inverse print film functions to get ADX code values for film recording.
4) The internegative is recorded and printed on print film.

3. Requirements and Difficulties of RRT/ODT Design

There was a strong demand for Reference Rendering Transform (RRT) inheriting the characteristics of scene reproduction of the film. The major elements of AMPAS-IIF is RRT that converts scene-referred colorimetry image data (ACES) to output referred colorimetry image data (OCES), providing a “film-like” image in the theater viewing environment.

In the traditional film-based production, which has evolved for several decades through collaborative efforts between film manufacturers and cinematographers, an original scene was shot using color negative film, printed onto print film and projected on the screen. This film system has achieved an excellent scene reproduction cultivated over decades.

In order to satisfy the demand mentioned above, the AMPAS-IIF concept requires RRT to meet the following:

- RRT tone scale has luminance dynamic range more than $6.0 \log E$ or $1,000,000 : 1$.
- RRT maps all ACES data to OCES data.
- The tone reproduction and color rendering of the RRT when used with an ODT are similar to those of the film system.
- The ODT handles primarily luminance dynamic range mismatches between OCES and viewing device.
- The RRT is invertible to a reasonable level of precision.

ACES has no limitation of dynamic range and color gamut. OCES has a wide dynamic range. To design the “film-like” transform from ACES to OCES was very challenging. The difficulties in RRT/ODT design are as follows:

- The transform must cover a huge color space which has never been attempted before.
- The transform must have a high quality and reasonable architecture appropriate to be a future standard.
- There is no common understanding of the “film-like” reproduction design. RRT should reproduce scenes equivalent or greater level than film.

Many attempts have been made to develop RRT by many people, such as to describe output colors by using a viewing model of color science, or manipulation to expand the print film preview 3DLUT. All of them failed to satisfy all requirements at the same time.

4. RRT/ODT Design

4.1 Outline of the Design

After we started to seek for the solution, we also encountered a lot of difficulties. But we came up with a new idea of RRT/ODT design. It was to expand the mathematical model of a print film simulation.

First, we developed the very precise print film reproduction simulation in a mathematical model. We expanded its dynamic range by extending the tone curve and expanded the color gamut by the saturation control method.

4.2 Print Film Simulation (PFS)

Print film simulation in a mathematical model is the starting point of RRT development. FUJIFILM already had developed a color reproduction simulation method for the color paper. We applied this technology to motion picture print film and achieved ultimate accuracy.
The PFS consists of the following steps.
1) Calculation of printing density of color negatives by integrating the negative stock transmittance spectrum with the print film’s spectral sensitivity.
2) Acquisition of Analytical Dye Amount (ADA) by converting printing density by using the print film’s exposure versus dye amount curve (ADA curve). ADA curve is obtained by color ramp exposure and channel independent density calculation.
3) Addition of CMY dye spectrum corresponding to each ADA value to print film base transmittance, bringing an estimated print film transmittance spectrum.

The calculation flow of the PFS is shown in Fig. 3, and the accuracy of the simulation is shown in Fig. 4. The difference between this calculation and actual film color is less than 2.0 in average delta E.

Since this method is based on parameters like ADA tone curve, dye spectrum and base spectrum, it could be a good model for the expansion of the dynamic range and color gamut.

4.3 Dynamic Range Expansion

Since the print film’s dynamic range is about 3.0 or 1,000 : 1, we needed to expand it to more than 60. We tried to extend the tone curve straightforward toward negative dye amount (Fig. 5 (a)). However, the large negative value of ADA caused extremely highly-saturated colors and unbalanced high saturation in different colors of hue, therefore a big hue shift was observed in saturation-increased colors (Fig. 5 (b)).

After several trials with ADA tone curves, we found that the expansion of ADA tone curve in subtractive color space brought about a tremendous drawback. What we finally concluded was that the expansion in the ADA tone curve should be limited to a minimum, and that the main expansion would be applied in additive color space. It means that once we obtain XYZ values from calculated transmittance spectrum and RGB values expressed in ACES primary definition form linear combination of XYZ, we only need to apply the tone curve expansion in order to achieve a high dynamic range in additive color space containing those values in principle. This expansion method worked very well. The results are shown in Fig. 6, and this method had basically none of the drawbacks that the previous method had.
4.4 Color Gamut Expansion

Following to the expansion of dynamic range (4.3), there are requirements for better color reproduction in bright colors. For ODT, when the dynamic range is compressed from 6.0 to about 3.0 that of a real output device, colors close to highlight suffer not only tone scale compression but also saturation reduction. It seems to indicate that RRT and ODT rendering is not an improvement from print film reproduction.

We attempted to expand the bright color gamut by developing “saturation-preserving tone compression” and applying it in the RRT. This is a combination of the RGB LUTs and YCC (or L’a*b*) LUTs. The first step expansion of the tone curve is applied in ACES primary by RGB LUTs. The next step is the half compression of gamma also in ACES primary. The final compression was processed after converting to YCC and only Y channel undergoes gamma compression to targeted dynamic range of 6.0. This final process preserves the saturation of colors in this region. As a result, compared to the previous method of which compression is done in the entire RGB color space, bright color saturation is increased and coverage of color gamut is expanded. Fig. 7 (b) shows the color gamut of this method.

4.5 Design for the Ideal Gray Tone

The final problem in the RRT and ODT design is the gray tone scale issues.

Print film has a yellowish tinted highlight for better reproduction of skin tones. In other words, it sacrifices neutral grays for better skin tone reproduction. However, for an ideal color reproduction system, the gray tone scale should be neutral from the beginning to end for easy understanding and customization.

There was a controversy insisting that gray tone scale may work better for AMPAS-IIF standard. We made a couple of system gray tone scale examples and made evaluation of them.

Finally, we found that both proper skin tone color reproduction and neutral gray tone scale could be achieved by optimizing saturation control (4.4). AMPAS members agreed with our proposal, and the system gray tone scale was set to neutral and white point set to D60. It contributed to simple system design, easy implementation and customization of AMPAS-IIF.

4.6 Inverse Calculation Accuracy

The last requirement we had to meet was to achieve invertibility. Fig. 8 (a) is the RRT calculation diagram. Our RRT calculation includes conversion from multi spectral data (eg. 81ch) into 3ch (RGB) data by integral calculation. Analytically, this conversion is difficult to calculate the inverse conversion. Therefore we transformed the inverse function to the combination of 1D LUTs and 3D LUT. However, simple application of non-linear 3D LUT by linear interpolation results in unacceptable errors in inversion. 3D LUT is very non-linear and applying this 3D LUT by linear interpolation results in unacceptable errors.

To reduce the errors, we introduced a shaper matrix for the 3D LUT. The shaper matrix is designed to make the shape of RRT’s 3D LUTs close to ideal cubic. The shapes of 3D LUTs are shown in Fig. 8 (b). By this method, we achieved the roundtrip error 0.14 in average deltaE. Its accuracy was more than required and the difference between before and after roundtrip images was unrecognizable.
5. Conclusion

FUJIFILM’s dynamic range expanded print film simulation technology enables film-like reproduction from digital camera and CGI through wide scene color space. Furthermore, FUJIFILM’s color gamut expansion technology enables maximum use of the color gamut of the digital projector. Contributions of RRT and ODT enabled us to use AMPAS-IIF in real projects. Currently, a lot of projects are testing the use of RRT and ODT, and all of the projects are achieving positive results.

Several issues remain in AMPAS-IIF. FUJIFILM continues to contribute to the AMPAS-IIF standardization and to the development of the motion picture industry.

References

1) Academy of Motion Picture Arts and Sciences (AMPAS) Specification S-2008-001: Academy Color Encoding Specification (ACES).
2) Academy of Motion Picture Arts and Sciences (AMPAS) Specification S-2008-002: Academy Density Exchange Encoding (ADX) and the Spectral Responsivity Defining Academy Printing Density (APD).