Interoperable Workflows Through IMF Output Profile Lists

By Arjun Ramamurthy and Raymond Yeung

Abstract

The SMPTE Interoperable Master Format (IMF) has, over the past couple of years, been adopted by content owners (studios and broadcasters) in numerous applications ranging from archival to distribution servicing. The key characteristics of variable composition (via Composition Playlists) and packaging provide proven economy in scaling of versions. An additional feature of the IMF framework is the Output Profile List (OPL), which provides the foundation of robust and interoperable workflows through the use of standardized media-processing macros (operators), ensuring identical output regardless of systems or facilities. This presentation details how standardized as well as customizable OPL operators can be applied to construct a universally portable processing pipeline for content servicing.

Keywords

Composition Playlist (CPL), content distribution, distribution servicing, file-based, Interoperable Master Format (IMF), media processing, Output Profile List (OPL), workflow automation

Introduction

The Interoperable Master Format (IMF) workflow is designed to replace a tape-based distribution servicing workflow by enabling the storage of one master set of file-based elements to be assembled for any downstream distribution using multiple Composition Playlists (CPLs) (Recipes). The broad concept of high-quality, uniform IMF is to lower costs, improve time to market, and increase interoperability of existing production processes and needs.

One of the main reasons for having an IMF is the ability to create many versions of a program without duplicating the common essence used for each version, and this is enabled by the CPL, which contains a composition timeline for the playback of the media. Similar to an editorial composition, the timeline references segments of the essence, including picture, sound, and data, or resources in general. Essence that is specific to the desired version is created and supplied along with a new CPL, which in conjunction with the common essence results in the desired version. The CPL defines the playback timeline for the composition and includes metadata applicable to the composition as a whole. It is a human-readable structure expressed using eXtensible Markup Language (XML)[1] and specified using XML Schema.[2,3] It includes multiple extension points supporting both backward and forward compatibility. The CPL is not designed to contain essence but rather references external track files that contain the actual essence. This allows multiple compositions to be managed and processed without duplicating the essence in common.

> **This presentation details how standardized as well as customizable OPL operators can be applied to construct a universally portable processing pipeline for content servicing.**

SMPTE has developed a suite of standards under ST 2067 that specifies the IMF for file-based media servicing workflow as proposed by content producers, and adoption has been continuously expanding since the initial publication in 2013. The core constraint defines the standardized packaging format, i.e., the Interoperable Master Package (IMP).

The companion track files in SMPTE Material Exchange Format (MXF) in the IMP contain essences referenced by one or more CPLs. The packaging design of the IMF supports the flexibility to include:

- one or more CPLs in a single IMP
- any number of track files.

The concept of partial IMP enables the delivery of supplemental or replacement materials for savings from replicating large essence track files. For the purpose of clarity, this paper refers to complete IMPs as shown in **Fig. 1**.

The Packing List[4] defines each IMP as a logical unit for delivery and ingest. The packing list contains system-level unique identifiers for each component or asset that includes all referenced essence track files.

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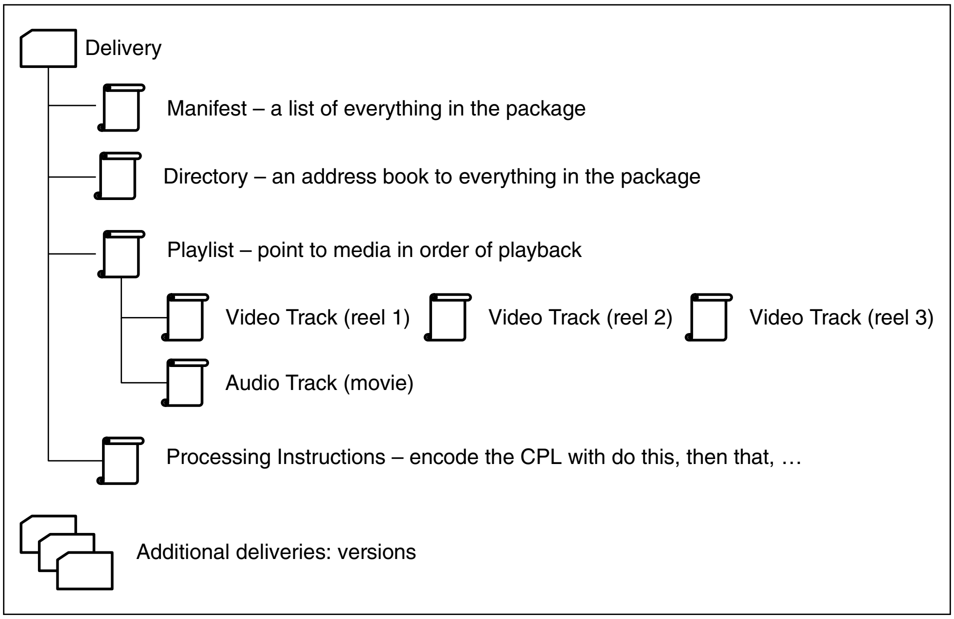

FIGURE 1. Delivery with IMP.

An optional Asset map[5] can map each uniquely identified asset to the corresponding storage location on delivered media. This packaging mechanism for delivery and ingest utilizes the SMPTE Digital Cinema standards suite.

The design of IMF essence components recognizes that some flexibility is required in the formulation of the MXF to accommodate a range of use cases to which IMF architecture may be applicable. To limit the variety of formulations that a decoder must support (and to simplify the description of these variations), the IMF specification includes the concept of shim, which describes the variant aspects of IMF essences using keyword parameters (with constrained values) specific to each formulation. The goal of this is for engineers to develop IMF applications using the IMF essence component as a core component, knowing that allowable variations can be defined by the application. This allows IMF applications to satisfy their respective requirements (by taking advantage of IMF essence component's flexibility) while reusing the same core specification and retaining interoperability. Thus, based on the generic specification for packaging, the specialized use cases are realized by additional constraints, resulting in the IMF applications. For example, the mezzanine format for feature film and produced television in broadcast and online distribution is specified in Application #2[6] and Application #2E.[7] In addition, the use case for the film *Mezzanine* is specified in Application #4[8], and the use case for Archival in the Academy (AMPAS) ACES format is specified in Application #5.[9]

In addition to the standardization of packaging to facilitate consistent and automated delivery and ingest, the IMF proponents went a step further. The optional component of Output Profile List (OPL) as specified in Ref. 10 standardizes the processing of CPLs in a rigorous framework of step-by-step operations. The focus of this paper is to detail the features and the application of OPL for automated processing in media servicing and distribution. This discussion is centered on the use case of complete IMPs, which include all necessary assets to playback and process the CPLs in an IMP, as shown in **Fig. 1**. The same concepts apply equally to sets of partial IMPs, although the complexity increases in terms of asset management. In the latter use case, the cross referencing of multiple IMPs does not affect the concepts presented in this paper.

The OPL Primer

The IMF file-based workflow was designed to replace existing tape-based distribution servicing workflow. It stores one master set of file-based elements to be assembled for any downstream distribution using multiple CPLs. However, in a file-based workflow, an important requirement is to be able to deliver files in many different distribution formats that customers require. So, the challenge faced was how to do that—especially in a fashion that permits numerous different versions—as specified by the CPL.

The IMF OPL is part of the SMPTE IMF standards suite[11] intended to enable consistent and automated processing of IMF compositions (CPLs). The motivation for the OPL arose from the fact that, in generating each of the downstream distribution files, there should be a way of specifying the program independent of the mechanism of how to transform, i.e., transcode, such a program. In this way, one program specification (CPL) could generate multiple files at the desired raster, bit rate, codec, and so on.

The OPL would be used in conjunction with a CPL to specify particular content provider output operations. In a typical workflow, an OPL would point to a specific CPL within an IMP and instruct a transcoder or playout device to manipulate the content per those provider output sequences of operations. In doing so, it would also pass the content provider's preferences (if included) through to a downstream device to facilitate the execution of these preferences in the downstream device (i.e., automation). The CPL provides the program information, and any transformations that are required on the overall composition list are performed within the OPL.

An OPL consists of an ordered list of parameterized operations, called *Macros*, that are applied to the virtual tracks of the composition. Each macro has a name that is unique within the OPL instance and exposes a number of outputs. Macros can take many forms to address the wide range of essence kinds found in composition and support both low- and high-level processing, from image pixel operations to subtitle rendering.

OPL Processing Model

As specified in SMPTE ST 2067-100:2014—the SMPTE standard for the OPL—the OPL processing model is expressed in terms of an abstract macrostructure independent of the underlying essence kinds. This allows macros to be defined by other specifications, whether for private or standard use, by merely extending the structure. Essence or metadata available for processing within an OPL—whether originating from the composition, virtual media tracks, or the output of a macro—is assigned a unique name, called a *Handle*. Handles are used to tie the output of one macro to the input of another and by external processes such as an encoder. For convenience, Handles can also be aliased so that the same information, e.g., primary image output, can be referred to using a known Handle independently of its source.

For commonality across macros operating on images, a Reference Image is defined in the OPL specification. Implementations are expected to produce output substantially equivalent to what would have been produced by the operations against the reference image. A reference image sequence consists of an ordered sequence of reference images, and each reference image consists of a rectangular pixel array, with each pixel consisting of a 4-tuplet of 32-bit float (IEEE 754 binary 32) values. When mapping common image formats to reference images, the first triplet of the 4-tuplet corresponds to the color primary, while the last component corresponds to the alpha channel.

With a reference image, the OPL processing model defines a framework for defining a pixel color scheme and representing a pixel color value in such a pixel color scheme. This specification does not specify concrete pixel color schemes, which is left to other specifications; however, a macro definition can then use "`ColorEncodingType`" as the type of an XML element intended to represent a pixel color value in any pixel color scheme. An instance of such a macro can then use a concrete pixel color as the value of the element. For example, in a specific instance, `REC709-RGB-8-ColorEncodingType` uniquely identifies the pixel color scheme and the triplet (1, 255, 255) corresponds to a color in the pixel color scheme. Macros for decoding source pixels to the reference image and encoding from reference image pixels to encoded color pixels then permit the support of any color space desired by any current or future application.

OPL Structure

The OPL, an XML structure of processing recipe, consists of the following elements:

- a unique identifier of the OPL
- a unique identifier of the input CPL
- a set of optional descriptive information, including annotation, issue date, issuer, and creator
- a list of aliases, zero or more synonyms for references to input and output elements
- an optional extension properties for user-specific data or instructional elements and structures
- an optional ordered list of macros (Operators) that specifies a step-by-step procedure with input(s), output(s), processing model, and parameters.

The key features of the OPL are embodied in the Macro List, the ordered list of macros to be executed fully in the order of appearance. The standardized set of image-processing macros in Ref. 12 includes the following:

1) Pixel Decoder Macro
2) Pixel Encoder Macro
3) Image Crop Macro
4) Image Scale Macro.

The standardized audio processing macro in Ref. 13 is the Audio Routing Macro. The processing algorithm can be specified to operate on the reference image pixel representation as specified in Ref. 12 for certain macros, e.g., the Image Scale Macro. The Pixel Decoder Macro can convert from any supported input pixel representation to the reference image pixel representation on the input to the appropriate processing macros. The Pixel Encoder Macro can convert from the reference image pixel representation to any supported output pixel representation. The conversion between pixel representations is determined by the input and output pixel color schemes defined by each IMF applications. For example, all supported pixel color schemes for Application #2 and #2E are standardized in Ref. 14.

FIGURE 2. Example Preset Macro: IMP Lister in an OPL as XML.

In the simplest form, the simple OPL is an OPL that does not have a Macro List. Therefore, no processing is described, except for a reference to the target CPL. The purpose of the simple OPL is to playback the composition timeline as specified by the CPL.

The OPL standard[10] specifies a provision of the most flexible Preset Macro, which consists of a single reference to another specification document for intended operations, e.g., a file or a Uniform Resource Identifier (URI).[15] The Preset Macro is constrained to be the only macro in the Macro List when present.

Figure 2 presents an example OPL with a Preset Macro, the IMP-Lister by the 20th Century Fox, named *FOX-IMP-Lister*. The IMP-Lister Preset Macro references the URL http://www.fox.com/opl/impLister, which in turn provides instruction to list the elements in the OPL and the resource unique identifiers referenced by the target CPL. The Preset Macro IMP-Lister is the only macro that appears in the example OPL as required.

The Advantages of the OPL Framework

The IMF OPL structure prescribes a standardized mechanism for the processing of the CPL with assets within one or more IMPs. The CPL referenced by an OPL, in conjunction with the asset map present in the IMP, completely and unambiguously identifies all assets (resources) required to execute the prescribed operations in the OPL. The immediate advantage of the OPL processing can be characterized by the following:

1) The algorithmic validation of required assets referenced by the CPL is straightforward. This can be programmed as accessibility checks for the referenced resources using the asset map packaged with the OPL.
2) The operators listed in the OPL are required to be processed completely and entirely in order of appearance. This requirement guarantees the order of execution for each processing step.
3) Each operator is required to define the exact algorithm for the processing. Therefore, identical input(s) is assured to produce the same result in all compliant systems. Consistent and repeatable output from any OPL is expected independent of system, configuration, and infrastructure.

These OPL design objectives result in the natural development of automated workflows that are robust and predictable.

The macros/operators standardized in Ref. 12 are Image Crop and Image Scale, and Ref. 13 is Audio Routing. These documents normatively define the input(s), processing model, and output(s) of each operator. The Image Crop Macro specifies an input image sequence and produces an output image sequence in the same pixel representation. A crop of the input image is generated from a reference rectangle with an inset, and the cropped image is then padded with pixels of fill color in the output image, which are the input parameters. **Figures 3** and **4** show the structure and the processing model of the Image Crop Macro, respectively.

The Image Scale Macro specifies an input image sequence in the OPL reference image format and produces an output image sequence in the reference image format scaled to the parameters by width and height. Additional parameters specify the boundary condition handling and image filtering algorithm per the Lanczos or a custom filter. **Figures 5** and **6** show the structure and processing model for the Image Scale Macro, respectively.

The image scaling filter algorithm Lanczos filter is normatively specified in Ref. 12. In conjunction with a

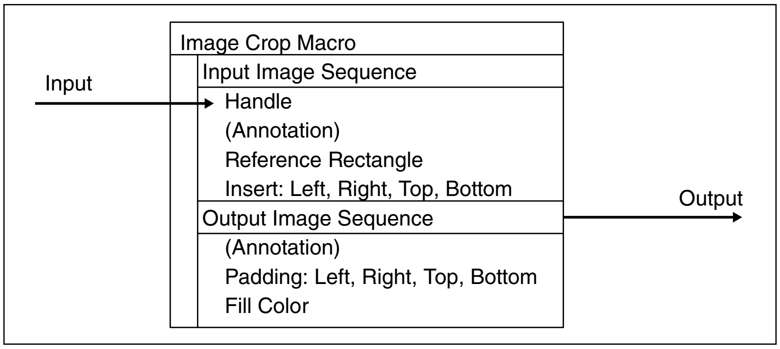

FIGURE 3. Image crop operator specification.

specified boundary condition, the precise mathematical equations define a deterministic process, up to numerical accuracy such as rounding, independent of the manufacturer, platform, and infrastructure.

By combining the standardized macros in an OPL, precise and predictable processing of the associated IMP can be achieved. A structural view of an example image crop-scale OPL is shown in **Fig.** 7.

Since the Image Scale Macro operates in the OPL reference image format while the Image Crop Macro does not, a Pixel Decoder Macro and a Pixel Encoder Macro are inserted before and after the Image Scale Macro, respectively. Alternatively, the Pixel Decoder Macro can be inserted before the Image Crop Macro since the cropping operation is independent of pixel representation. **Figure 8** shows the processing model for the example image crop-scale OPL.

For a more complex example, the processing of HDR imagery with Dynamic Metadata for Color Volume Transform (DMCVT)[16] can illustrate the potential of the OPL. A processing model is presented in **Fig.** 9. For each output image sequence element, the macro outputs a single image sequence. Each output image frame OI of the output image sequence is computed as

$$OI = T(II, M),$$

where

II = the corresponding image frame of the input image sequence

M = the corresponding metadata set of the input

T = the color transform algorithm.

This model features the processing of images in combination of a set of per-frame metadata as input parameters to the color transform (**Fig. 9**—Transform). Furthermore, this model also supports the selection (**Fig. 9**—Select) logic from the standardized DMCVT applications in the SMPTE ST 2094 suite.[17]

An example processing flow of the DMCVT algorithm is shown in **Fig. 10** for the specific use case of transforming HDR input images to SDR output images. The color processing algorithm based on DMCVT Application #1[18] is represented by the chain of boxes or macros/operators. The foundational macros have not yet been published at the time of writing.

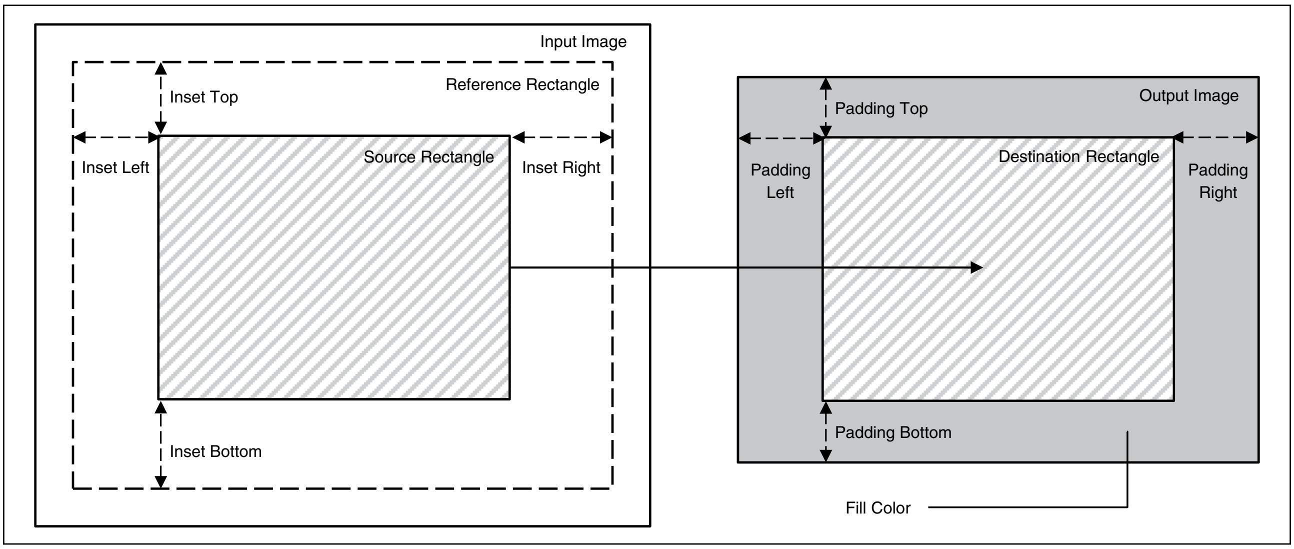

FIGURE 4. Image crop operator processing model[9].

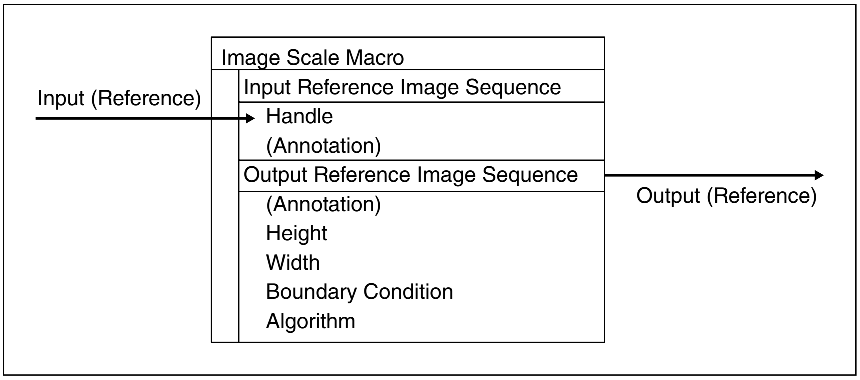

FIGURE 5. Image scale operator specification.

The Limitations of the Current OPL Framework

The previous example requires macros beyond the limited standardized set in the current OPL documents suite. The example also provides some of the leading candidates for development in the immediate term.

While the ordered list design of the OPL macros appears to limit the efficiency gain by parallel processing, the simplicity in implementation will result in very robust systems. The exclusion of branching and joining by the current design avoided the implementation of complex data flow parsing. This apparent disadvantage is easily overcome by using multiple OPLs that can be executed in parallel. Furthermore, there is no constraint for implementing parallelization at the algorithm level within a macro. The current design, therefore, offers both robustness and parallelization in the workflow.

In terms of image processing, the support of chroma-subsampled images is implicit in the OPL standards suite. The reference image format and all macros are standardized so that subsampling must be reversed. For example, a 4:2:2 YCbCr input image must be converted to 4:4:4 YCbCr or RGB for the first image processing macro. Also, a desired 4:2:2 YCbCr output image must also be obtained by converting the 4:4:4 YCbCr or RGB output of the final image processing macro. This aspect of the OPL specification is not optimal for many applications.

The recent publication[19] for Sidecar Composition Map standardized the packaging of sidecar assets. The inclusion of supporting documentation such as quality control (QC) reports and descriptive metadata in IMPs is anticipated to be common. Although the Sidecar Asset Map can reference the sidecar assets and their corresponding CPL, it is not yet included in the OPL in the same fashion as the CPL. The only possible referencing mechanism is the use of extension properties specified by the OPL schema. However, this method is *ad hoc* and lacks the necessary consistency in any robust standardized workflow.

Just as the construction of complex macros can be built on the fundamental operators, procedurally lengthy OPLs can be constructed from simpler ones. Such a mechanism will be crucial to the versatility of OPL workflows looking to the future.

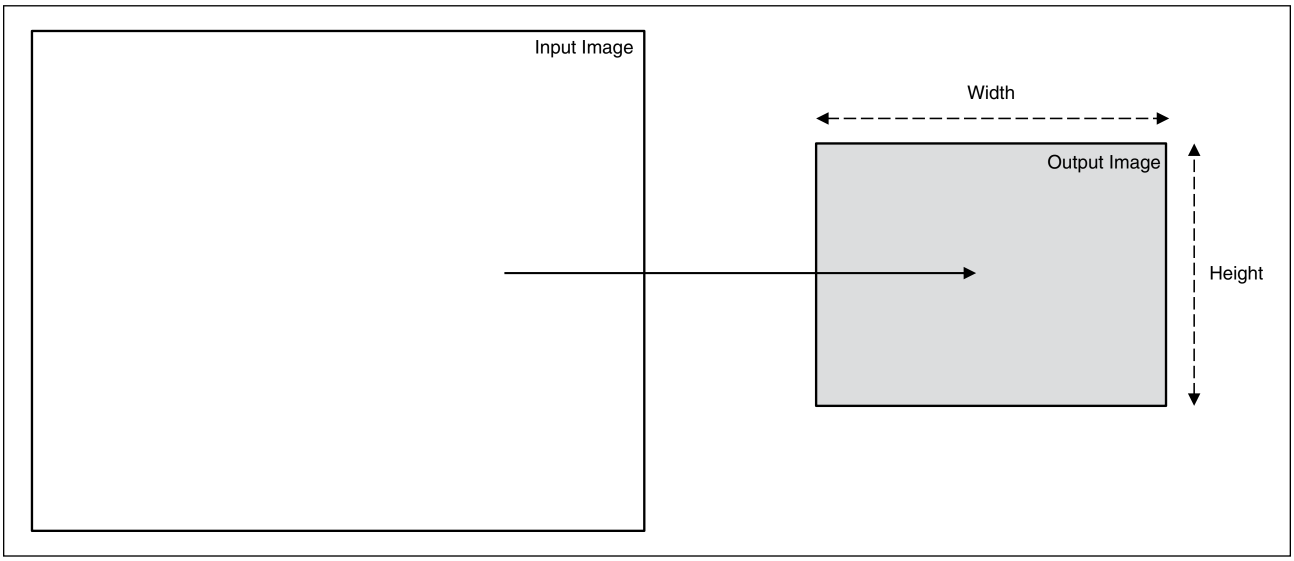

FIGURE 6. Image scale operator processing model[9].

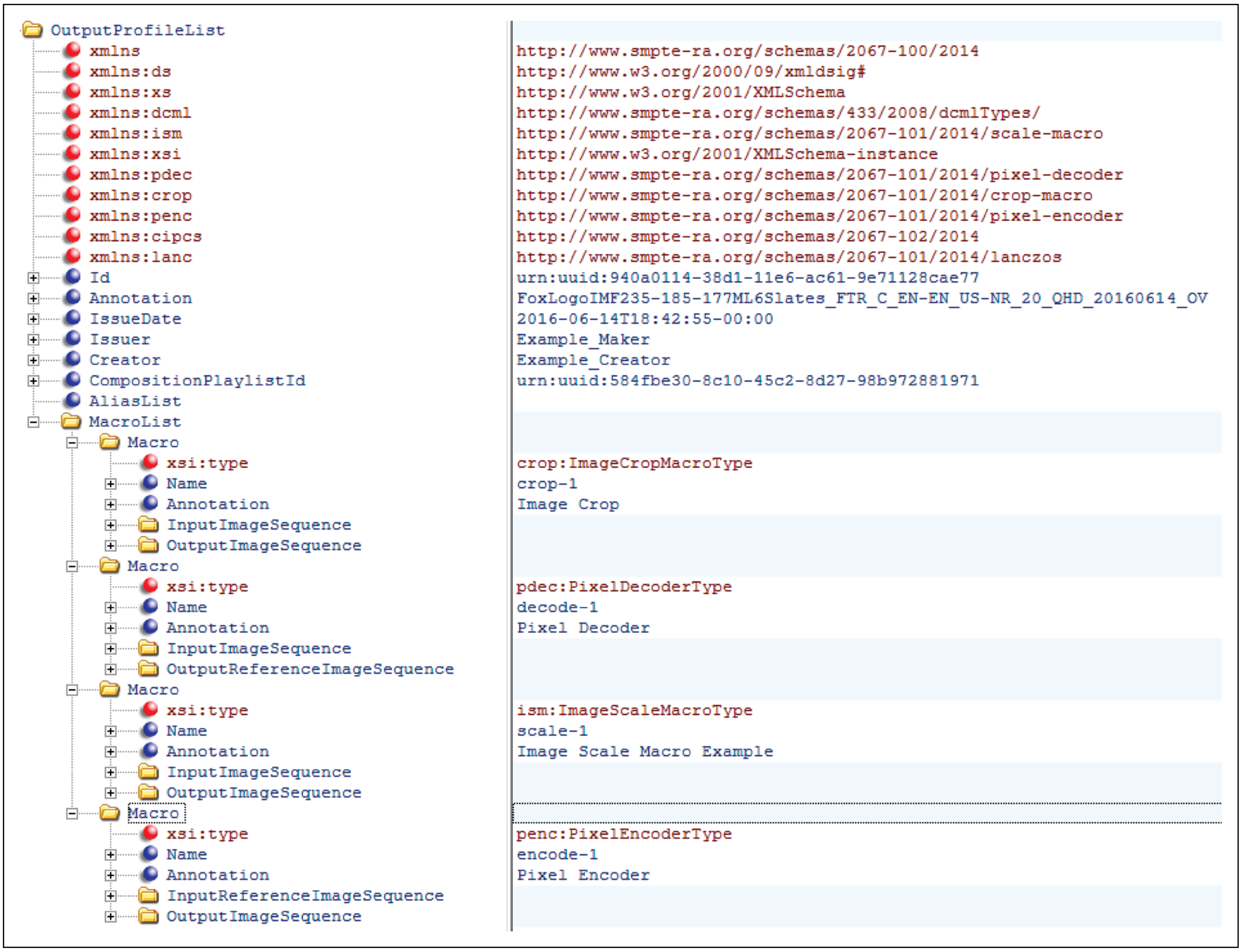

FIGURE 7. Example image crop-scale OPL as XML.

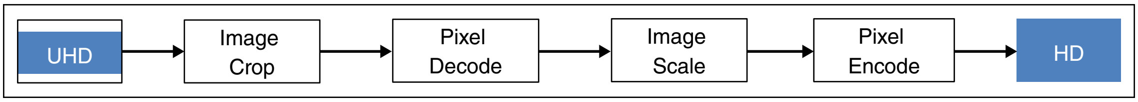

FIGURE 8. Example image crop-scale OPL processing model.

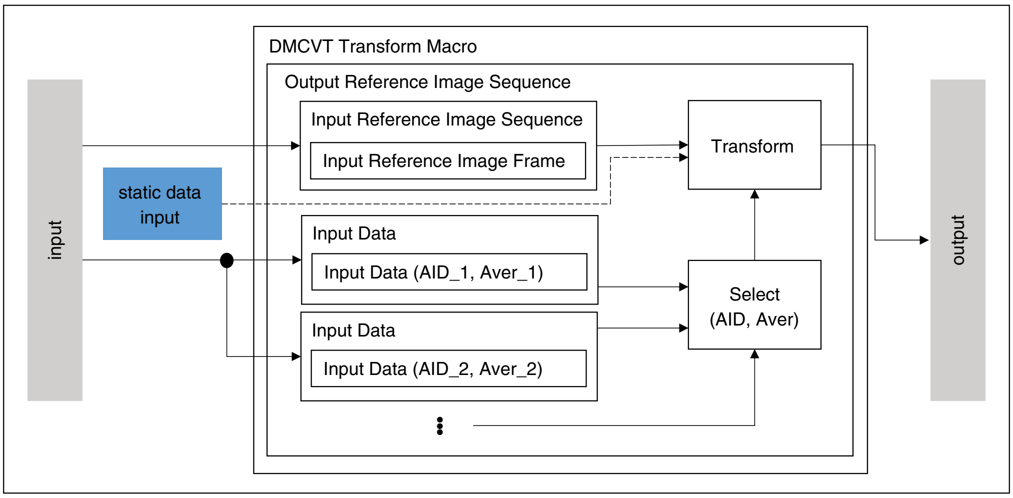

FIGURE 9. DMCVT processing macro (AID: Application Identifier; Aver: Application Version).

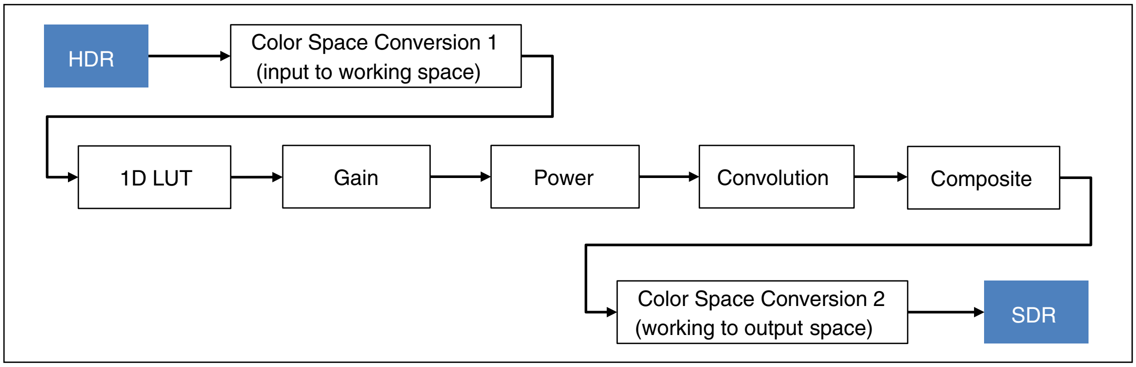

FIGURE 10. Example DMCVT processing flow.

Finally, an extensive set of macros is the key to the future of OPL as illustrated in the previous example for DMCVT image processing. A registry will be essential and beneficial to manage and support the eventual large collection of OPL macros, including standardized, *ad hoc*, and experimental ones. Some initial example macros are Image Composite, Color Space Conversion, 1D look-up table (LUT), 3 × 3 Matrix, 3D LUT, and Image Filtering.

The Development of Automated Workflow

Based on the IMF standards suite, the user community of OPL-based workflow has been proactive. Members of the SMPTE Technology Committee, the IMF User Group, and other practitioners have been planning a series of interoperability tests. No doubt being in its infancy, the natural application is in media encoding. The initial objective will be to exercise the Preset Macro and to build on the experience for a Named Parameter Macro as a dedicated interface to encoding profiles.

Since standards are best developed based on working systems, the prototyping of custom workflows can produce practical proposals to complete the intended collection of OPL macros. The very specialized but greatly effective use cases can also advance the feature set. For example, the previously mentioned OPL reuse and a public macro registry can be developed initially by the implementers. At this point, it is most important to have the user community from all parts of the media ecosystem, including content owners, equipment manufacturer, system integrators, technology developers, and servicing organization and distributors to engage in this process.

Conclusion

The SMPTE ST 2067 IMF standards suite provides a solid and flexible foundation for the OPL. The system consists of a basic but clearly defined processing pipeline. When combined with the standardized set of fundamental operators, the system is expected to be interoperable and consistent. Systematic testing is ongoing with extensions in the SMPTE IMF standards community, as well as experimental development with the OPL Drafting Group. The final results will be robust, repeatable, and interoperable automated content servicing workflows.

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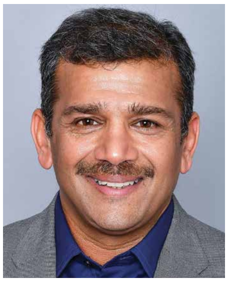
Glossary

Composition	A timeline in an editorial project in which segments of picture and sound contents are sequenced for playback. Composition consists of a Composition Playlist along with the essence track files that define the work.
CPL	Composition Playlist—the definitive playlist for specifying how a composition is played and what track files are required.
Essence	Picture, sound, subtitles, or any content that is presented to a human being in a presentation.
IMF	Interoperable Master Format—a SMPTE standard file-based media packaging, interchange, and processing framework.
KLV	Key Length Value—used by the MXF to parse binary data.
Metadata	Data about data or data describing other data. Information that is considered ancillary to or otherwise directly complementary to the essence. Information that is useful or of value when associated with the essence being provided.
MXF	Material eXchange Format.
OPL	Output Profile List—the standardized processing prescription to transform a single IMF composition in an IMF Package into deliverables tailored to one or more downstream distribution channels.
Package	The collection of files delivered to a content processor or distributor as defined by a governing specification. A package can contain pieces of a composition or several compositions, a complete composition, replacement/update files, etc.
Packing List	A list describing the files and providing a means for authentication of the files as delivered in a package.
PlayList	Conceptually, the format and structure of the various lists used to define the playback of content.
Reel	A conceptual period of time having a specific duration of generally 10–20 min. Used primarily in feature film production.
Track File	The smallest element of a package that can be managed or replaced as a distinct asset. A track file may contain essence and/or Metadata, and its duration matches an associated reel.
XML	eXtensible Markup Language.

About the Authors



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Raymond Yeung is a senior member of the engineering staff with the Imaging Research Group, Dolby Laboratories, Los Angeles, CA. He received a PhD in high energy physics from the University of California at Los Angeles, Los Angeles, CA, in 1987. After working on high-performance computing, with a specialization in large-scale simulation, he has spent 25 years in the field of entertainment technology. He started in digital imaging with Cinesite, Los Angeles, CA, the digital film center of Eastman Kodak, followed by several years of leadership in visual effects (VFX) technology research and development. For the last decade, Yeung has been engaged in the technical and production advancement of digital mastering for feature films and television, from digital intermediates to theatrical and home distribution. He joined Dolby Laboratories in 2012 to focus on HDR content creation and distribution. In the SMPTE standards community, Yeung is a document editor for the Interoperable Master Format (IMF)—Output Profile List (OPL) suite.

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