Introducing iccMAX – New Frontiers in Color Management

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Abstract

ICC has announced a preliminary specification for iccMAX, a next-generation color management system that expands upon the existing ICC profile format and architecture to overcome the limitation of the fixed colorimetric Profile Connection Space and supports a much wider range of functionality. New features introduced in iccMAX include spectral processing, material identification and visualization, BRDF, new data types, an improved gamut boundary descriptor and support for arbitrary and programmable transforms. The iccMAX preliminary specification is accompanied by a reference implementation, and is undergoing a period of public review before being finalized.

Introduction

One of the stated purposes of the ICC is to "promote the use and adoption of open, vender-neutral, cross-platform **color management** systems" with "color management being defined as the "*communication* of the associated *data* required for unambiguous interpretation of color content data, and application of color data *conversions*, as required, to produce the intended *reproductions*." In short, the ICC enables the "Communication of Color".

The ICC profile and associated color management architecture has been a part of the color imaging landscape since it was first introduced by the International Color Consortium in 1995. Owing to its interoperable format, unambiguous processing and open standardization, it is now widely used to connect color devices.

Since the first version was published, the ICC architecture and specification have undergone a number of incremental changes to resolve ambiguities in the specification and to address new requirements, primarily from the graphic arts, office, photography and motion picture market sectors[1]. The current version, ISO

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15076-1:2010[2] (hereafter referred to as ICC.1), represents an optimal solution for many existing workflows. However, some needs remain unmet, while at the same time new requirements continue to emerge.

Some areas where ICC.1 color management cannot be used successfully arise from failures to implement the specification and associated architecture. For example, on the web and mobile platforms, the color management framework is often weak or non-existent and devices are often connected on the basis of raw device values without honoring the profiles associated with the image or device. ICC cannot solve such failures by itself, but is working with the different communities in an attempt to address such issues.

In other areas there are challenges in "Communicating about Color" using ICC.1 based color management due to Real World complexities involved with color and color appearance. Such challenges include: differences in light sources, characteristics of surfaces, variations in observer, variation in lighting and/or viewing angles, modeling everything, handling variations in reproduction intent and keeping things reasonably simple. Thus the basic technology, including the underlying concept of connecting through a fixed, colorimetric connection space, is not capable of delivering solutions to more advanced requirements that have emerged, and will continue to emerge in the future. Some example use cases include:

Photography. One requirement in photography is to be able to define an encoding but not an associated transform, so that the choice of the particular flavor of an encoding can be deferred to a point in the workflow where connection to another encoding takes place. This would reduce the overhead associated with embedding a complete profile in an image, and enable smart selection of rendering parameters upon conversion.

Packaging. In package printing, increasing use is made of inks and substrates with complex and non-isotropic surfaces. Visualization, simulation and proofing of such materials is a challenge, and the assumed 0:45 measurement geometry in ICC.1 is not sufficient to communicate the optical properties of such materials.

Medical Imaging. Displays for primary reading of radiological images are calibrated to the DICOM Gray Scale Display Function (GSDF), and the emerging dRGB standard[3] permits different primaries to be associated with this tonal reproduction curve. Although it not yet clear how the desired behavior of both color and grayscale will be achieved, a single LUT-based transform may not be able to deliver the required conversion. Additionally, in some medical imaging modalities such as whole-slide imaging the purpose of imaging is to identify the relative amounts of biomarkers present, rather than solely generating a visualization of the slide contents.

Fine art. Recent research in fine art capture and reproduction has focused on multispectral and hyper-spectral imaging[4], and on multi-channel and multispectral printing[5]. Multi- and hyper-spectral imaging has many applications in research, education, display and conservation; one example which parallels the biomarker quantification in medical imaging being the identification of pigments and other materials present in an artwork. On the output side, it is desired to achieve a spectral match, rather than a metameric match, to an artwork in order to convey the artist's intentions under a range of different viewing conditions and possibly to different observers.

ICC is responding to these new requirements by expanding the ICC.1 architecture. The new iccMAX[6] functionality is a major step change that goes well beyond the previous incremental approach of adding and deleting tags from the specification. The most important conceptual changes in the new architecture revolve around linking material properties to the workflow and providing registered interoperability guides to insure that requirements of complex workflows can be identified prior to processing. The decision to go to a full spectral workflow enables the process to include physically relevant spectral illuminants, rather than hypothetical illuminants that may not be characteristic of the application of the workflow.

Some of the new features are: a spectral Profile Connection Space to connect spectral data; a spectral viewing conditions tag which permits arbitrary illuminants and observers to be defined; a Material Connection Space (MCS) that supports identification and visualization of material amounts in addition to color; support for bidirectional reflectance distribution functions and 3D rendering; support for processing of bi-spectral fluorescence data; and an extended named color profile that incorporates spectral, bi-spectral and BRDF processing. iccMAX also incorporates a flexible processing element that gives profile creators the ability to incorporate arbitrary transforms yet continue to benefit from unambiguous CMM processing.

It must be emphasized that iccMAX is an expansion of ICC.1 and not a replacement for it. Thus it provides a platform for defining workflow specific color management systems. For this reason the name iccMAX has been adopted rather than simply referring to the new specification as version 5. Version 2 of the ICC specification is still in widespread use, many vendors seeing no compelling reason to move to version 4. V4 is a significant improvement in clarity and functionality over v2, and addresses the great majority of color management requirements that exist today. iccMAX represents an optional expansion of v4 capabilities; vendors are not required to implement all of the iccMAX features, but just the sub-set defined by a given Interoperability Conformance Specification (ICS) for a particular use case.

Specification

Full details of iccMAX are given in the preliminary specification[7]. This is not a final document, but is being released by ICC as a preliminary specification while also initiated as a New Work Item in ISO TC 130. ICC welcomes evaluation, testing, implementation and comment on the draft as it finalizes the document.

The principal features introduced in the iccMAX specification are as follows:

Header. The iccMAX header is a fixed-length 128-byte header based on the ICC.1 specification, with the addition of fields to define Spectral and Material Connection spaces, in addition to the ICC.1 Colorimetric PCS.

Data types. iccMAX incorporates all the data types defined in ICC.1, with the addition of support for 16, 32 and 64-bit floating-point encodings, together with sparse matrix encodings to avoid redundancy when incorporating a Donaldson matrix in the profile to define fluorescent emission.

Tags and types. Several new tags and tag types are defined. These include:

- The spectralViewingConditionsType defines the reference colorimetric observer and the reference illuminant, to enable conversion between the D50 PCS and other PCSs.
- The customToStandardPCS and standardToCustomPCS tags provide the transforms needed to convert between the colorimetry defined by the observer and illuminant specified by the spectralViewingConditionsTag and that of the standard PCS utilizing a D50 illuminant with the standard 2-degree observer.
- The measurementType utilized by the measurementInfoTag defines measurement conditions for the colorimetric and/or spectral PCS as well as measurement parameters of the data encoding including observer, geometry, flare and illuminant, which enables conversion between standard and custom PCS.
- The namedColorTag provides a combination of PCS, spectral PCS and optional device representation for each named color in a list of named colors.
- The brdfAToBTag and brdfDToBTag define conversions from viewing angle, lighting angle, and Device or Color Encoding to colorimetric PCS and spectral PCS respectively.
- The brdfSpectralParameterTags defines a BRDF model and its parameters for conversion to spectral PCS.
- The surfaceMapTag allows a normal map (or height map) to be associated with surface characteristics.
- The gamutBoundaryDescription tag, which stores the vertices and faces of the encoding gamut for each rendering intent.
- The cxfTag encoding, which supports embedding of Cxf7 ref data and metadata.

- The colorEncodingParamsTag defines encoding parameters for a three component color space, which can be used by a CMM to select a conversion between the color space and the PCS.
- The AToM tag provides transformation from device channel values to MCS channel values while the MToA, MToB and MToS tags provide transforms between MCS channel values and device channel values, colorimetric PCS values and spectral PCS values respectively. MCS connection utilizes the MCS subset requirements flag in the header along with the materialTypeArray tag (which defines MCS channels) and the materialDefaultValues tag. No direct conversion between MCS and PCS or device channels is defined by the iccMAX specification.

ICS documents specify the conformance requirements of a given profile sub-class, and it is envisaged that such documents will be developed in consultation with individual user communities and registered with ICC. This will ensure that for a given workflow requirement, the required profile content and connections are unambiguous and can be independently evaluated.

multiProcessElements

The multiProcessElementType provides the transform elements and the connections between encodings. multiProcessElementType tags are essential in all the main iccMAX features, including DToBx, BToDx, BRDF and Profile Connection Conditions, Material Connection Space AToMx, MToAx, MToBx, MToSx transforms. They are also optional in other tags, such as AToBx and BToAx.

A multiProcessElement tag completely defines the transformation from tag input to tag output. It supports a full range of data type precisions up to 64-bit floating point, and an arbitrary sequence of processing elements. The supported processing elements include:

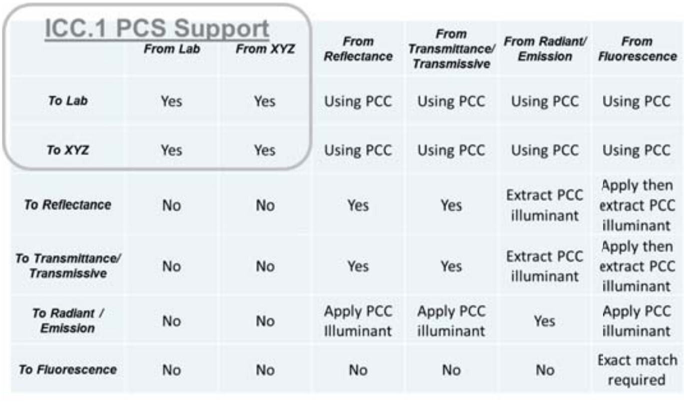
- Sets of 1-dimensional functions that are made up of parametric and sampled curve segments
- A 1-D to N-D transform
- An N x M linear matrix transform
- An N x M multi-dimensional lookup table
- A marker element that performs no operation on values
- A programmable Calculator element
- Elements to transform into and out of a modification of CIECAM02 which avoids the known mathematical instability of CIECAM02[8]
- Elements that provide for late binding of observer and/or illuminant to provide efficient custom colorimetric processing

Use of the multiProcessElement enables a wide range of functional conversions to be defined in place of the v2/v4 LUT-based conversions. Two Examples include:

multivariate polynomial regression on device and colorimetric coordinates; and implementation of a 7-colour LUT using the sector model[9].

The Calculator element provides a mechanism for encoding more complex device models. It avoids limitations of CLUT accuracy and storage requirements when many input channels are used. It defines a script based expression calculator, employing a PostScript-like stack-based language, to determine output channels from input channels. Finite memory storage is provided for temporary results, and nearly all operations are vector based (operating on multiple channels at the same time). Calculator element operators include: stack operations, input / output channel access, temporary memory access, math operators including arithmetic, exponential, log and trigonometric operators, inequalities (<, ≤, = ≥, >), logical and conditional operators, high-level matrix operators (transpose and linear matrix solver), polar – to - Cartesian conversion, and error handling. The Calculator element incorporates support for conversions between XYZ and CIELAB. The Calculator element also provides the ability to embed and invoke other processing sub-elements within the context of the Calculator element's script. This makes conversions to and from color appearance coordinates possible using CAM processing sub-elements.

The Calculator element provides secure deterministic behavior, since script validation is performed before processing begins, and all possible code paths are known for any arbitrary input. Branching can be achieved through conditional operators and inequality tests, and loops are not supported. This absence of loops means that a Calculator element cannot hang. Operations with undefined results giving NAN or INF on the data stack which can be tested for to perform error handling. The extent of all possible memory usage is known in advance for any arbitrary input, and the possibility of stack underflow/overflow is avoided. A Calculator element can only access input and output channels and temporary memory, thus avoiding potential security risks.



ICC.1 PCS Support

	From Lab	From XYZ	From Reflectance	From Transmittance/ Transmissive	From Radiant/ Emission	From Fluorescence
To Lab	Yes	Yes	Using PCC	Using PCC	Using PCC	Using PCC
To XYZ	Yes	Yes	Using PCC	Using PCC	Using PCC	Using PCC
To Reflectance	No	No	Yes	Yes	Extract PCC illuminant	Apply then extract PCC illuminant
To Transmittance/ Transmissive	No	No	Yes	Yes	Extract PCC illuminant	Apply then extract PCC illuminant
To Radiant / Emission	No	No	Apply PCC Illuminant	Apply PCC illuminant	Yes	Apply PCC illuminant
To Fluorescence	No	No	No	No	No	Exact match required

Figure 1 – *Various PCS Connection options available using iccMAX with comparison to PCS support in ICC.1*

PCS Connections

Two colorimetric (XYZ, and CIELAB) and four spectral (Reflectance, Transmittance, Radiance, and Fluorescence) PCS types are defined in iccMAX. Supported connections have well specified conversions between them. Unsupported PCS connections include conversion from colorimetric to spectral, and any conversion to fluorescence.

Spectral and custom colorimetric PCS processing is performed using Profile Connection Conditions (PCC) which are made up of the spectral viewing conditions (defining the spectral characteristics of the observer and illuminant), as well as transform tags that convert between custom colorimetry and standard (ICC.1 compatible) colorimetry. PCC information can be provided by tags within a profile or can optionally be externally provided to the CMM top perform PCS transformation. One advantage of this approach is that it allows PCS data in profiles to use actual viewing conditions – thus obviating the need for the chromaticAdaptationTag defined in ICC.1. Data encodings for device channels can be connected to and from PCS encodings, depending on the transforms provided in the profile. The extent of PCS support provided by iccMAX is shown in Figure 1, and relationships between profiles, PCS transformation and PCC information is shown in Figure 2.

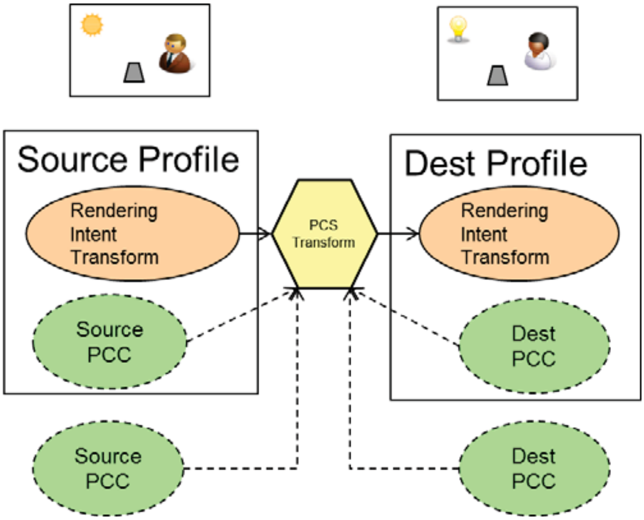


***Figure 2** – Profile, PCS, and PCC relationships*

Implementation

An iccMAX CMM will be backward-compatible and will recognize and correctly process v2 and v4 profiles. For example, Figure 3 provides an example of connecting a v4 input profile to an iccMAX output profile that uses a custom colorimetric PCS.

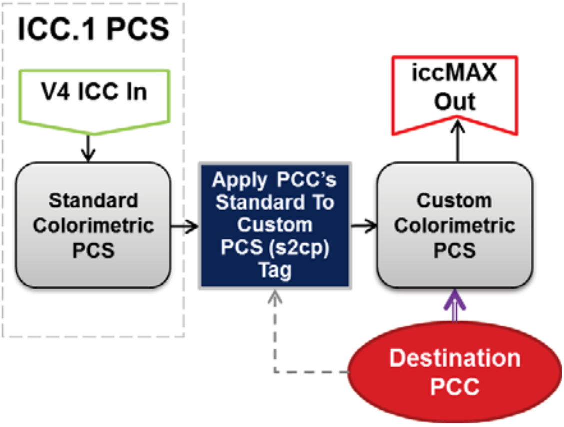


***Figure 3** – PCC processing provides conversion transforms for compatibility with legacy profiles*

However, iccMAX profiles are not expected to be compatible with v4 CMMs. ICC is providing a reference CMM implementation9 in the form of open source code, which will aid developers and researchers who wish to adopt iccMAX. An iccMAX application is not required to support all the new features but just the sub-set appropriate to a particular workflow domain.

Associated with the reference implementation are tools to convert between the binary file format of an ICC profile and an xml representation. This greatly simplifies the profile generation process, since a profile creator can edit an xml representation which is both machine-readable and human-readable before converting the xml representation to a binary profile. The IccXml tools also work with v2 and v4 profile versions.

The reference implementation is also accompanied by a test suite, which includes sample profiles, their xml representations, and images which demonstrate aspects of the iccMAX specification; and tools that can be used to apply profiles and test their conformance with the specification.

As with ICC.1, ICC does not specify the content of an iccMAX profile but provides a well-defined framework for constructing and applying profiles. Guidance and conformance documents will be provided by each ICS as it is developed, and the ICC user forum can be used to raise questions and share experiences.

iccMAX and Packaging ICS

The following discussion is provided as a means of understanding iccMAX for the specific color workflow related to packaging. Packaging has significant challenges as it relates to communicating about color. It crosses multiple output production and manufacturing processes and providers, and color plays a critically important role in packaging where variations in color can easily be interpreted by potential product purchasers as a defect in the product thus providing incentive to make an alternate purchasing decision.

Each of the different processes makes or reproduces color differently, yet everyone needs to agree on color description. The use of ICC.1 to communicate about color is limited by the fact that "simple appearance" as provided by CIELAB is inadequate as appearance changes under different lighting/viewing conditions and the final lighting condition varies and is unknown. Specialty colors involving metallics, fluorescence, and gloss do not have a colorimetric basis. ICC.1 named color profiles only communicate "simple appearance" for 100% solid tint colors. The communication of color overprints when 8 or more colorants are involved also challenges ICC.1 due to the nature of having to use N-dimensional lookup tables (LUTs) that grow exponentially with each additional colorant channel.

A packaging ICS is still in the process of development within the ICC, however the preliminary concepts include the following profile classes and extensions.

First, the use of the completely re-architected named color profile class within iccMAX can be utilized to define named color profiles that define each color spectrally for multiple tints with information about each tint over white and black to enable overprint characteristics of the colorants to be determined. Additionally, goniochromatic aspects (which provide information relationships between lighting and viewing angles) can also optionally be provided, as well as bi-spectral measurements can be used instead of spectral reflectance to provide information about fluorescence. Such information can be used for both ink formulation as well as better visualization.

Second, profile classes related to packaging can utilize a Material Connection Space to define ink channels utilized by a document (using a Material Identification profile class) as well as a visualization of overprint results for a specific inking order (using a material visualization or material link profile class). Visualization is made possible through the use of multiProcessElement tags that utilize a calculator element to algorithmically define the overprint visualization. Thus large numbers of channels can be handled without requiring enormous quantities of memory, and the overprint relationships can be defined and communicated within the profiles without the Application or CMM having to be intimately involved in understanding the overprint algorithms.

Conclusions

Although ICC.1 addresses many common color management problems, color in the "Real World" is much more complex than what can be communicated using ICC v2/v4 profiles. iccMAX provides the ability to communicate answers to many color questions including: What is it? How does it interact with light? And what does it look like under various specific conditions? Thus iccMAX provides a flexible platform for modeling and defining color workflows by encompassing the complexities of color in the "Real World" thus enabling new frontiers in color management.

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