Hybrid Printer Output Profiles

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Abstract

The ICC profile specification provides a well-established framework for color management across a wide variety of printing and imaging workflows. However, as printing technology continues to advance, new use cases have emerged that go beyond the capabilities of the base ICC profile format. In particular, spectral color reproduction and overprint simulation of spot colors present significant challenges that cannot be addressed within a standard ICC profile alone.

This paper presents the concept of Hybrid Printer Output Profiles, in which an iccMAX sub-profile is embedded within a standard ICC profile. This hybrid approach extends the capabilities of existing ICC profiles without breaking backward compatibility: legacy systems continue to use the base ICC profile as usual, while extended systems can leverage the embedded iccMAX sub-profile for advanced workflows.

Two primary use cases are explored. First, a Hybrid Spectral Reflectance Output Profile enables spectral color reproduction for applications requiring illuminant-independent color matching, such as packaging and textile printing. By incorporating a spectral characterization transform in the iccMAX sub-profile, it becomes possible to search for device values that minimize an index of metamerism across multiple observing conditions, enabling improved spot color replacement workflows. Second, a Hybrid Overprint Simulation Output Profile allows for the preview and communication of overprint appearance involving spot colors that are not managed by the base ICC profile. Using the Spot Color Overprint (SCOP) modeling approach, an overprint simulation transform is encoded in the iccMAX sub-profile and can account for print order, background color, and the appearance of specialty inks such as white and metallic silver. Demonstrations using both raster and PDF-based workflows are presented, including an example of T-shirt print simulation with white and silver spot color channels over colored fabric.

The hybrid profile approach provides a path forward for extending color management capabilities in a standardized and interoperable manner, and

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Interoperability Conformance Specifications (ICS) documents are being developed to define and govern these extended profile sub-classes.

Introduction

ICC profiles have been the foundation of color management in the printing and imaging industry for decades. They provide standardized transforms between device color spaces and a Profile Connection Space (PCS), enabling consistent color reproduction across diverse output devices and software systems. However, modern printing applications increasingly require capabilities that go beyond what the base ICC profile format supports, including illuminant-independent spectral color matching and accurate preview of spot color overprints.

The iccMAX specification (ISO 20677) extends the ICC architecture with new profile types, color spaces, transforms, and processing elements that can address these advanced needs. The challenge, however, is how to introduce these capabilities into existing workflows without disrupting systems that rely on the established ICC v4 profile format.

Hybrid Printer Output Profiles offer a solution by embedding an iccMAX sub-profile inside a standard ICC v4 profile as a private tag, extending its capabilities without disrupting existing workflows.

This paper is organized around two major use cases for Hybrid Printer Output Profiles: spectral reflectance reproduction and overprint simulation. For each use case, the motivation, profile structure, implementation, and practical demonstration are discussed.

Hybrid ICC/iccMAX Profile Overview

A Hybrid ICC/iccMAX Profile is a standard ICC profile that contains an embedded iccMAX sub-profile in a dedicated tag. The iccMAX sub-profile extends the functionality of the containing ICC profile in the following ways:

- It can extend the device color space to include additional channels (e.g., spot color channels not managed by the base ICC profile).
- It can provide new or extended Profile Connection Spaces (PCS), including spectral PCS for reflectance-based color management.
- It can encode more powerful transform definitions using iccMAX processing elements such as multi-process element types and calc elements.
- It can carry additional metadata relevant to extended workflows, such as colorant order and spectral measurement data for ink formulation.

The iccMAX sub-profile is associated with an Interoperability Conformance Specification (ICS), which defines a sub-class and sub-class version that governs the encoding and usage scenarios for that hybrid profile type. Redundant tags that are already present in the containing ICC profile do not need to be repeated in the iccMAX sub-profile.

From a software perspective, legacy ICC color management systems (CMMs) simply ignore the iccMAX tag, treating it as an unrecognized private tag. They continue to apply the base ICC profile transforms as usual. New, iccMAX-capable systems can be configured to detect and utilize the iccMAX sub-profile for extended workflows when appropriate. This clean separation ensures that hybrid profiles are valid ICC profiles and can be used wherever printer profiles are used, regardless of whether the receiving system supports iccMAX. The hybrid profile structure is illustrated in Figure 1.

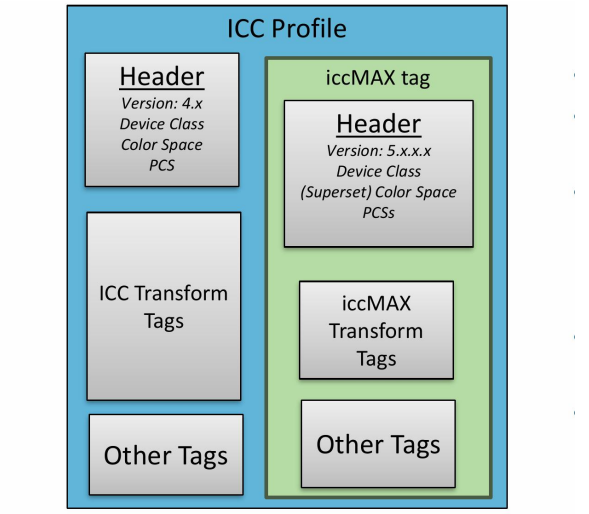


Figure 1 – Hybrid ICC/iccMAX Profile Structure

Hybrid Spectral Reflectance Output Profiles

Motivation

Accurate color reproduction for spot colors is critically important in industries such as textile printing and packaging, where brand colors must be reliably reproduced across different viewing conditions and lighting environments. The fundamental challenge is that standard colorimetric color management profiles are based on tristimulus values (such as CIELAB) computed under a specific illuminant. When a printed color is viewed under a different illuminant, its

appearance may change – a phenomenon known as metamerism – and the ICC color management system provides no mechanism to account for this.

Spectral matching offers a solution. A spectral match reproduces the same spectral reflectance as the target, ensuring that the color matches under any illuminant. Ink formulation is one approach to achieving spectral matching but applying it broadly within a color management workflow requires a spectral understanding of the printer's color reproduction capabilities and a method for finding spectral matches to target colors.

Standard ICC profile colorimetric color management for spot color replacement is only valid for the single viewing condition used in the profile. An ICCMAX spectral sub-profile, by contrast, enables the use of spectral transforms that can represent the printer's behavior across the full spectral range, enabling illuminant-independent colour reproduction.

Profile Structure

A Hybrid Spectral Reflectance Output Profile for an N-channel printer is defined as a Level 1 subclass in the ICS document currently under development. The structure consists of:

- A base ICC v4.3 profile with standard Device-to-PCS and PCS-to-Device colorimetric transform tags, providing the standard colorimetric workflow for legacy systems.
- An embedded iccMAX tag containing a spectral characterization of the printer. The iccMAX sub-profile has a shares the same Device color space and a spectral PCS of 'ref' (spectral reflectance). It contains a forward spectral transform (DToB3Tag) consisting of one or more curve elements, matrix elements, or N-dimensional CLUT elements that are used to map device values to spectral reflectance. A spectralViewingtConditionsTag identifies the spectral viewing conditions, and a spectralWhitePointTag defines the spectral reflectance for the white point.

The Level 1 sub-class is designed to minimize implementation overhead while enabling spectral reproduction. The key insight is that a forward spectral transform (device to reflectance, DToB3Tag) is much easier to create than an inverse spectral transform (reflectance to device), and the Level 1 approach avoids requiring a direct inverse spectral transform in the profile, instead leveraging a search-based implementation as described below. The profile structure for the Level 1 spectral hybrid profile is shown in Figure 2.

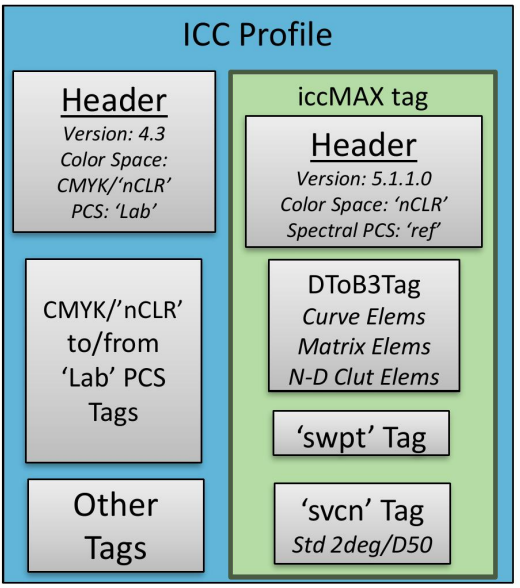


Figure 2 – Hybrid N-Color Spectral Printer Profile (Level 1 Sub-class)

Connection scenarios supported by this hybrid profile include: standard colorimetric printing using the base ICC profile (for legacy systems), proofing using the base ICC profile, custom-condition proofing using the iccMAX spectral sub-profile (for different observing conditions), and full spectral reproduction using the iccMAX spectral sub-profile.

Spectral Reproduction Using Search

Because the iccMAX sub-profile only provides a forward spectral transform (device values to spectral reflectance) rather than a direct inverse spectral transform, spectral reproduction can be implemented as an optimization search. The goal is to find printer device values that minimize an index of metamerism across a set of defined observing conditions.

The search process proceeds as follows:

- Initialization: for a target spectral reflectance, the target colorimetry is computed for each of several observing conditions, defined by Profile Connection Condition (PCC) profiles. Initial device values are determined using the base ICC profile's PCS-to-Device transform with the PCS values for the target spectral reflectance for one of the observing conditions.

- Cost function evaluation: the current device values are applied to the printer's forward spectral transform (DToB3Tag) to obtain a predicted spectral reflectance. This reflectance is converted to colorimetry for each observing condition using the PCC profiles, and compared to the target colorimetry for those conditions. A weighted average of the color difference across all observing conditions defines the cost (index of metamerism).
- Optimization: device values are iteratively adjusted to minimize the cost, until either the cost falls below a threshold or the improvement per iteration becomes negligible.

This search-based approach is now implemented in the iccDEV project by the CIccCmmSearch class in IccProfLib, and as the command-line tool iccApplySearchCmm. The Tools/hybrid folder in IccDEV contains a round-trip example that demonstrates the approach: starting CMYK values (e.g., 50C 40M 40Y 0K and 0C 0M 0Y 50K) are first converted to spectral reflectance using iccApplyNamedCmm, and then the search tool recovers CMYK values (49.28C 39.34M 39.40Y 1.31K and 0.16C 0.13M 0.20Y 49.87K) that closely reproduce those spectral reflectances, with only minor rounding-level differences. The search algorithm is illustrated in Figure 3, and a round-trip example is shown in Figure 4.

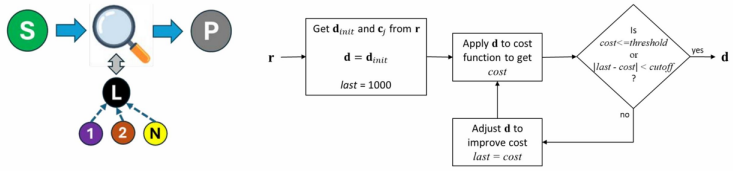
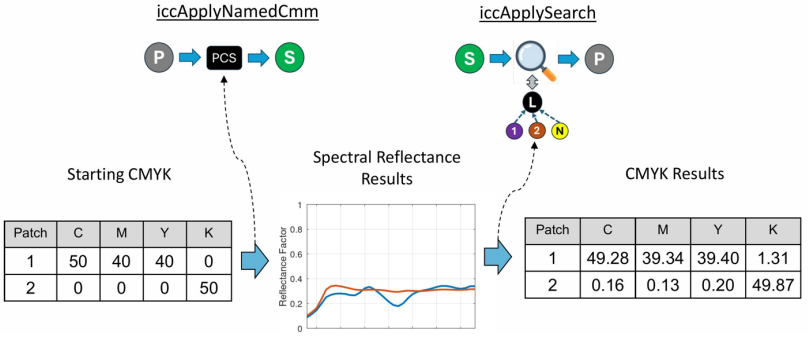


Figure 3 – Spectral Reproduction Using Search (iccApplySearchCmm)



Patch	C	M	Y	K
1	50	40	40	0
2	0	0	0	50

Patch	C	M	Y	K
1	49.28	39.34	39.40	1.31
2	0.16	0.13	0.20	49.87

Figure 4 – Round-Trip Example: CMYK → Spectral Reflectance → CMYK

Use Case: Spot Color Replacement

A significant practical application of spectral reproduction is illuminant-robust spot color replacement. The workflow proceeds as follows:

- Spectral reflectances for spot colors are either extracted from a PDF document using its CxF (Color Exchange Format) information, or taken from known reference spectral data.
- An instance of the iccApplySearchCmm is used to find printer device values that spectrally reproduce each spot color.
- The resulting device values are then used as spot color replacements when processing the PDF file.

In this case, determining the spot color replacements is performed as a step before ripping the file and therefore doesn't require a change to the PDF rendering that already provides the ability to replace spot colors with known output device tone values.

With this approach, the result is that spot color replacements have minimal color difference under different illuminants, since the reproduced spectral reflectances match the target reflectances rather than merely matching colorimetry under a single illuminant. Additionally, since the determination is separate from ripping, this approach can use a different CMM to find the spot color replacement than the one used for image and document color management, providing flexibility in workflow implementation.

Hybrid Overprint Simulation Output Profiles

Motivation

Modern print jobs frequently combine process color channels (managed by an ICC profile) with spot color channels (not managed by the ICC profile). When process and spot inks are printed together, the combined overprinted appearance must be previewed accurately in a soft-proof or preflight workflow – but standard ICC profiles have no mechanism for communicating how the spot colors interact with process colors or with each other.

Several challenges arise in this context:

- The combined process and spot channels are printed together, but the ICC profile only describes the process color channels. The preview of the combined output does not match the final printed result.
- Overprint simulation behavior varies by software implementer, leading to inconsistencies across workflows.

- There is no standardized way to communicate print order, spectral measurements of spot inks (needed for ink formulation), or viewing/lighting angle effects within color management workflows.
- It would be helpful if the solution works for both raster image data and vector PDF workflows.

A Hybrid Overprint Simulation Output Profile addresses all of these challenges by encoding the overprint simulation model directly within the iccMAX sub-profile, where it can be applied consistently by any conforming implementation.

Profile Structure

A Hybrid Overprint Simulation Output Profile consists of:

- A base ICC v4 profile describing the process color channels (e.g., CMYK), with standard colorimetric transforms for printing and proofing process color data.
- An embedded iccMAX sub-profile whose color space includes ALL channels (both process and spot). The sub-profile is identified by a DeviceSubClass of 'osim' (overprint simulation). It contains an overprint simulation transform encoded as an AToBxTag using a MultiProcessingElementsType with a calc element. Optionally, it can include: a print order specification (colorant order tag), spectral measurements of spot color tints for ink formulation (in a named color tag using a tagArrayType of namedColorArray), and selective channel connection via MCS (Multiplex Color Space) to support images with subsets of channels.

Shared transforms between AToB and MToB tags allow the same overprint simulation model to be applied whether the image uses all channels (AToB) or a subset via MCS connection (MToB).

Spot Color Overprint (SCOP) Modeling

An example overprint simulation model that was used in this work is based on the Spot Color Overprint (SCOP) modeling approach developed by Kiran Deshpande.[1] The SCOP model represents the XYZ appearance of overprinted inks as a combination of a foreground color scaled by a tint-dependent factor, added to a background color also scaled by a complementary factor. This captures the key optical behavior of semi-transparent ink layers.

Deshpande defines two SCOP model variants (Figure 5), of which the linear model is used in this work:

- Linear model (used in this work): the foreground and background contributions are combined with linear tint-based scaling.
- Power model (an alternative for ink systems with more nonlinear behavior): a power-law nonlinearity is applied to the tint values before scaling.

The scale and offset scalars are pre-computed from measurements over three backgrounds (media white, gray, and black) and stored in lookup tables, as described in detail in the following section.

The overprint simulation for a multi-channel image is then computed by the calc element in the iccMAX sub-profile, proceeding in print order through the channel stack: starting from an initial background XYZ (which may be provided as a CMM environment variable, enabling flexible preview over different substrate colors), applying each ink layer's SCOP transform in sequence to update the accumulated XYZ appearance. This repeated SCOP application for N-color overprinting is illustrated in Figure 6.

- **Linear**

$$X_r = j_x(X_b X_f) + k_x$$
$$Y_r = j_y(Y_b Y_f) + k_y$$
$$Z_r = j_z(Z_b Z_f) + k_z$$

$$j_{f,x} = j_x X_f$$
$$j_{f,y} = j_y Y_f$$
$$j_{f,z} = j_z Z_f$$

Resulting in :

$$X_r = j_{f,x} X_b + k_x$$
$$Y_r = j_{f,y} Y_b + k_y$$
$$Z_r = j_{f,z} Z_b + k_z$$

Scale XYZ $j_{f,x}, j_{f,x}, j_{f,x}$

Offset XYZ k_x, k_y, k_z

- **Power**

$$X_r = j_x(X_b X_f)^{k_x}$$
$$Y_r = j_y(Y_b Y_f)^{k_y}$$
$$Z_r = j_z(Z_b Z_f)^{k_z}$$

or

$$\ln(X_r) = \ln(j_x) + k_x \ln(X_b X_f)$$
$$\ln(Y_r) = \ln(j_y) + k_y \ln(Y_b Y_f)$$
$$\ln(Z_r) = \ln(j_z) + k_z \ln(Z_b Z_f)$$

Figure 5 – SCOP Linear and Power Model Equations

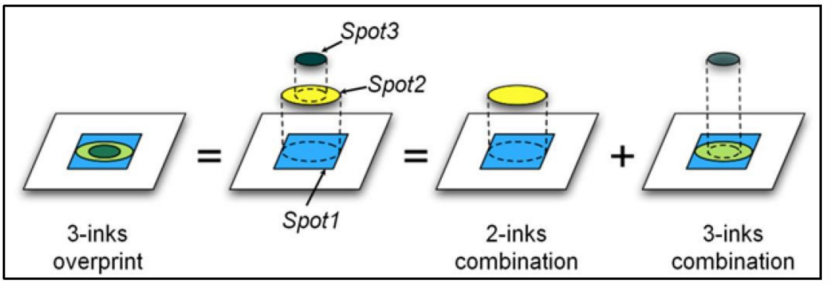


Figure 6 – Repeated SCOP Application for N-Color Overprinting

Note: Although the SCOP model is presented here as an example for overprint simulation it is not the only overprint model that can be encoded by an overprint simulation profile. The flexibility of encoding transforms in iccMAX allows for the model to be determined by the profile creator.

SCOP A2BxTag Creation and Implementation

Creation of the SCOP-based AToBxTag involves both measurement and pre-computation steps. The process for creating the AToBxTag for CMYK and spot color channels is as follows:

- Measure CMYK combinations over the media (white), a solid gray, and black backgrounds.
- Create shaper (tone) curves from the CMYK measurements.
- Pre-compute the SCOP scale (j) and offset (k) scalars for each CMYK combination from the three background measurements and store them in a CLUT.
- Measure tints of each spot color ink over the same three backgrounds (media, gray, and black).
- Pre-compute the SCOP scale and offset scalars for each spot color tint value from those measurements, using interpolation for intermediate tint values, and store them in tint tables.
- Create tint tables for the spot color scalars.

The calc element within the AToBxTag then implements the overprint simulation using these pre-computed tables by executing the following steps in order:

- Initialize the current XYZ to the background XYZ value (which may be supplied via CMM environment variables bkgX, bkgY, and bkgZ to allow flexible substrate color selection at render time, defaulting to the D50 relative white point).
- For each background spot color (if any), in overprint order: apply the SCOP model using the spot color's tint-based scalars (from the tint tables) to update the current XYZ.
- Apply the CMYK shaper curves to linearize the CMYK channel values.
- Apply the SCOP model using the CMYK tint-based scalars (from the CLUT) to update the current XYZ.
- For each foreground spot color in overprint order: apply the SCOP model using the spot color's tint-based scalars (from the tint tables) to update the current XYZ.
- Output the resulting XYZ as the colorimetric PCS value.

Handling Gloss and Metallic Inks

Gloss and metallic inks present an additional complexity: their appearance changes significantly as the viewing and lighting angles change. Accurately simulating their appearance likely requires a three-dimensional view of the printed surface with the ability to manipulate viewing and lighting angles interactively. Prior work by Tanzima Habib demonstrated an approach using additional parameters passed into the calculator element for viewing and lighting angles. Further work on integrating angle-dependent overprint simulation into the hybrid profile framework remains an area of ongoing research.

Using Fewer Channels with MCS

A practical challenge in overprint simulation is that a source image may contain only a subset of the channels defined in the overprint simulation profile. For example, a grayscale image with a single spot color channel does not have data for all of the CMYK process channels. The Multiplex Color Space (MCS) connection mechanism in iccMAX addresses this directly.

An MCS identification profile specifies which channels are present, and the CMM uses MCS connection to select those channels from the profile's MToB transform, using zero defaults for absent channels.

Demonstration: T-Shirt Overprint Simulation

A practical demonstration was developed to illustrate the overprint simulation capabilities of the hybrid profile. The scenario involves printing on colored fabric with CMYK process inks and two spot channels: white ink and silver metallic ink.

Profile creation proceeded as follows:

- Following the A2BxTag process described above, tint and CMYK measurements over white, gray, and black backgrounds were used to determine the SCOP scalars and tone curves for the white and silver channels.
- The base CMYK ICC profile was converted to XML using iccToXml, and an iccEmbeddedV5Tag entry was added encoding the overprint simulation model. The modified XML was converted back to an ICC profile (CMYK_W_Overprint.icc) using iccFromXml.

The iccMAX sub-profile contains a data color space of 'nc0005' (5 channels: CMYK + White), XYZ PCS, DeviceSubClass 'osim', and MCS 'mc0005'. The calc element encodes the overprint simulation model with the white spot channel applied either under or over the CMYK inks, depending on the print order. An

additional profile variant was created with silver ink rather than white, allowing comparison of silver-under and silver-over configurations.

The white ink SCOP model showed approximately 90% opacity and 60% illumination reflectance, while the silver ink showed approximately 50% opacity and 30% illumination reflectance, consistent with the optical characteristics of these specialty inks. The scale and offset curves for both inks are compared in Figure 7.

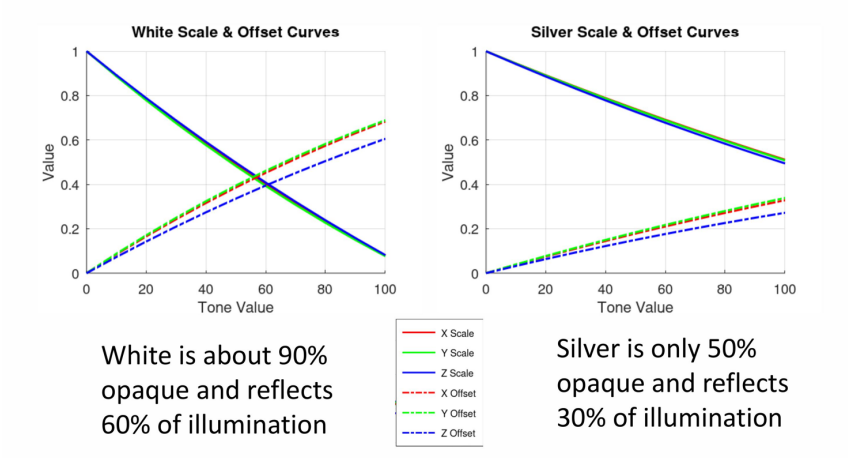


Figure 7 – Comparison of White and Silver Scale & Offset Curves

Image creation used an AI-generated RGB logo, which was converted in Adobe Photoshop to CMYK + spot channel format associated with the hybrid overprint profile, and saved as a TIFF image with the embedded hybrid profile. A 5-channel TIFF image (CMYK + White) was created for the full overprint workflow, and a 2-channel TIFF image (Magenta + Silver) was created to demonstrate MCS-based subset channel selection.

Overprint simulations were generated using the iccApplyProfiles tool with different background XYZ values corresponding to different fabric colors (white, red, black, blue, green), and with three different overprint profile configurations (White Under, Silver Under, Silver Over). The resulting simulations demonstrated visually distinct overprint appearances depending on both the substrate color and the ink ordering, confirming the utility of the background XYZ environment variable approach for substrate color flexibility. The resulting simulations are shown in Figure 8.



Figure 8 – T-Shirt Overprint Simulations
(rows: White Under, Silver Under, Silver Over; columns: different fabric colors)

Conclusions

Hybrid Printer Output Profiles, created by embedding an iccMAX sub-profile within a standard ICC profile, provide a practical and backward-compatible path for extending color management capabilities to address advanced printing workflows.

Two major use cases have been demonstrated. Hybrid Spectral Reflectance Output Profiles enable spectral reproduction of spot colors by providing a forward spectral transform in the iccMAX sub-profile and using a search-based optimization to find device values that minimize metamerism across multiple observing conditions. This approach supports illuminant-independent spot color replacement workflows, with practical application to spectral PDF spot color replacement using CxF color data.

Hybrid Overprint Simulation Output Profiles address the challenge of previewing spot color overprints in a standardized and consistent way across workflows. By encoding an overprint model (such as the SCOP overprint model) directly in the iccMAX sub-profile calc element, overprint simulation becomes part of the profile itself, ensuring consistent results across conforming implementations. The presented approach supports variable substrate colors via CMM environment variables, multiple ink orderings, MCS-based subset channel selection, and optional spectral measurement data for ink formulation.

ICS documents are being developed by the ICC to formally specify the requirements for creating and applying these hybrid profile sub-classes, providing a standardized basis for interoperable implementation across the industry.

References

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3. ISO 20677, Image technology colour management – Extensions to architecture, profile format and data structure (iccMAX).

4. ICC iccDEV Project, IccProfLib and iccApplySearchCmm source code. Available at: https://github.com/InternationalColorConsortium/DemoIccMAX