Introduction

Benefits of color management

- Vendor independent
- Consistency, Predictability, Reproducibility
- Accuracy
- Conformance to a standard
- Printing process workflows optimization

Problems of color management

- Requires knowledgeable resources…
- Takes time…
- Costs money: machine off-production, ink and substrate consumption…
- Limitations: substrates, viewing conditions, colors…
- Non-Flexible to print environment oscillations: machine, substrate, equipment, ink, environmental…

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The Challenge

- Characterization of the printing condition has been dominated by CIE Lab based ICC profiles
- To build an ICC profile one usually requires large set of measurements (Calibration + IT8)
- In order to print and measure an ICC profile target one needs dedicated print sessions
- This requires printing machine time, uses material resources (ink and paper), requires specialized measurement equipment (and trained personnel to perform the process.
- Therefore, many printers do not do it…

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Agenda

- We will evaluate the prediction power of spectral models and compare them with conventional prediction models.
- We will evaluate spectral prediction models accuracy and compare them with colorimetric models for CMYK and Multicolor ICC profiling including single ramps input data.
- We will evaluate the effect of spectral matching compared to colorimetric matching on metamerism.
- We will evaluate if spectral predictions could lead to various optimizations of the color management process making it easier, faster and more automated.
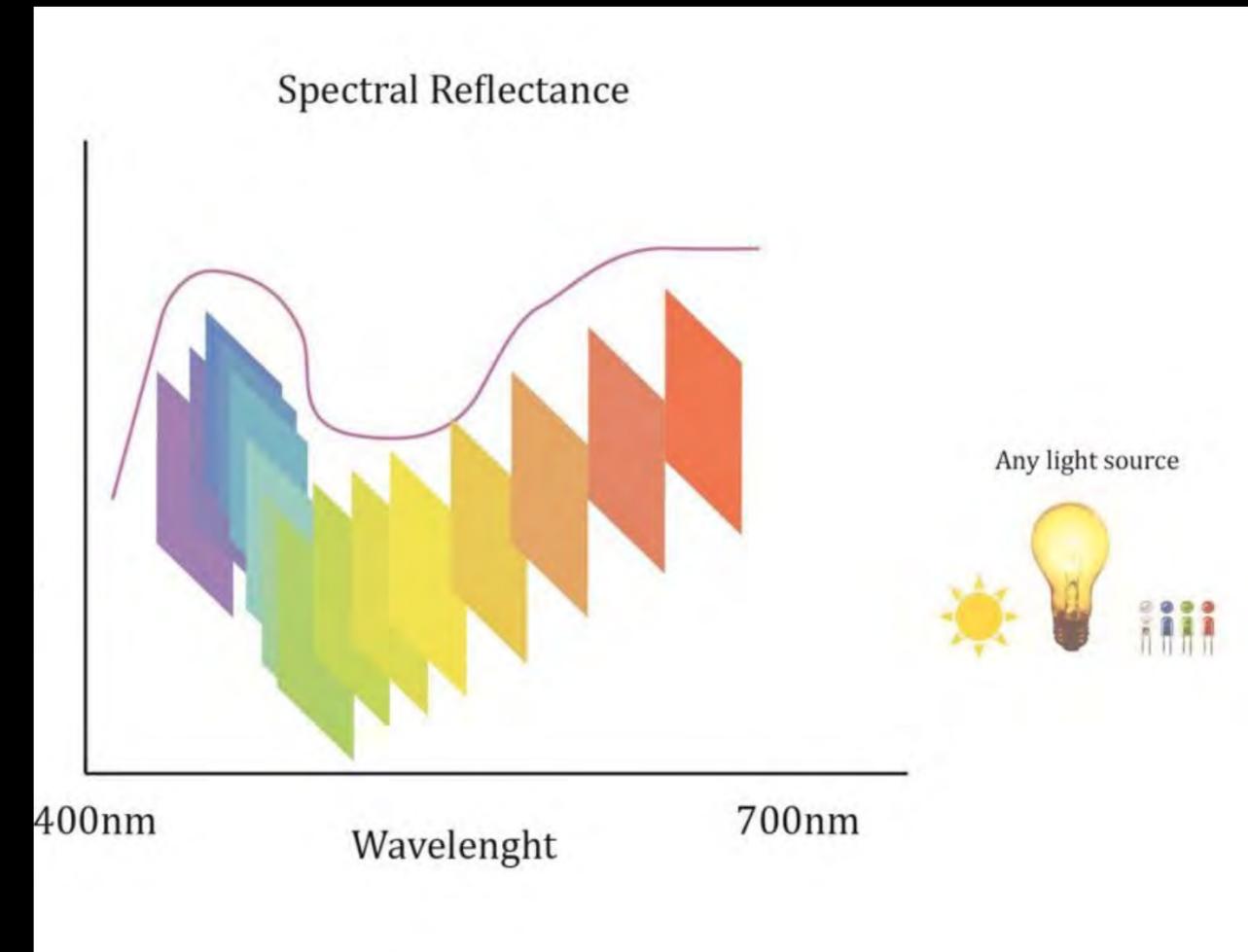
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Spectral Data Processing

1. Conventional: CIE Lab encoding and processing

2. New: Spectral encoding and data processing
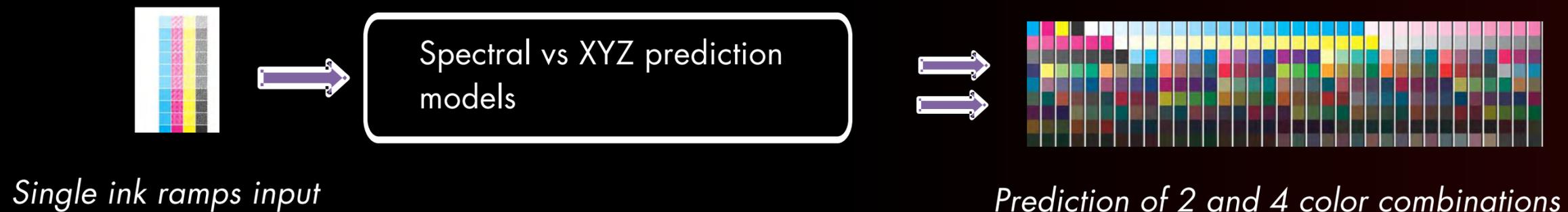

CIELab Color definition (D50)
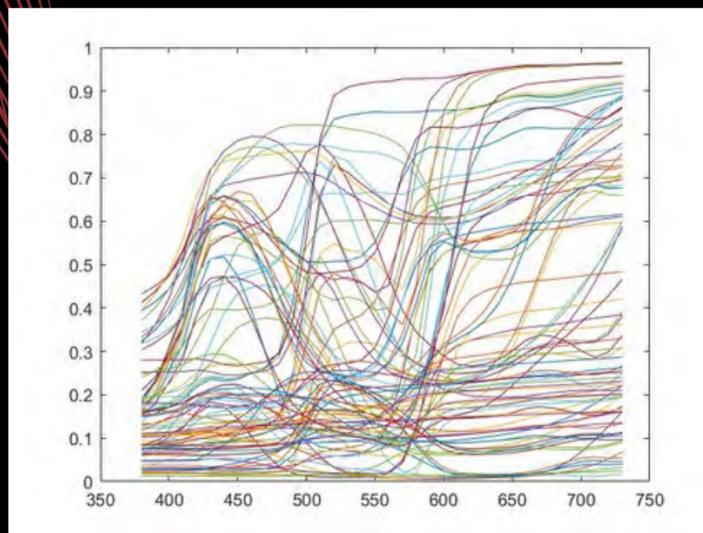

Spectral Color Definition

Accuracy of Spectral Prediction Models

Method of evaluation of the prediction accuracy of the spectral prediction models.

CMYK ramps: Direct prediction accuracy

Spectral vs XYZ prediction models

Single ink ramps input

Prediction of 2 and 4 color combinations

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Input Colors Dataset

- We selected 1121spectrally measured spot colors that are used in packaging material.

- The test Spot colors are selected to cover both spectral and color gamut uniformly.

- All Spots are first gamut - mapped to the target profile and then in-gamut color accuracy is reported.

- From the spectral measurements D50 ICC profiles have been built with Alwan's Hydra spectral processing framework.

- Separations are done with B2A table of the profile.

Spectrally measured spot colors

CIELab encoding

Gamut mapping to an ICC profile gamut

Separation to CMYK

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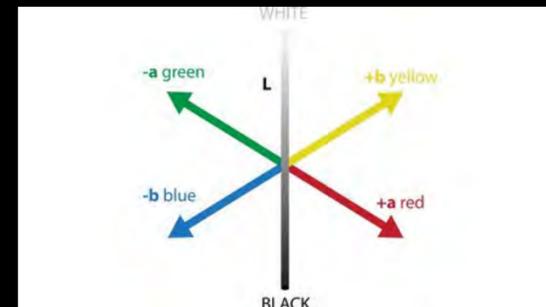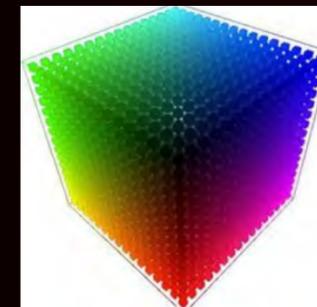
Spectral Prediction Accuracy Evaluation

- In Tables 1 to 4 ink mixing predictions are shown using Spectral and CIE XYZ prediction models.

- The predictions from single ink ramps is shown for 2 and 4 color ink mixes for Offset and Flexo processes.

- For spectral predictions we used Alwan's Hydra spectral prediction engine while for XYZ we used SCOP model.

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Spectral Prediction Accuracy Results

Table 1. Two color overprint (ink mixing) predictions for Offset printing technology shown for Spectral and XYZ model.

2 Color Overprint Offset	Avg ΔE00	95%	Max
XYZ model	3.4	10.8	13.6
Spectral Model	0.9	2.8	3.8

Table 2. Two color overprint predictions for Flexo printing technology shown for Spectral and XYZ model.

2 Color Overprint Flexo	Avg DE	95%	Max
XYZ model	3.1	7.7	12.2
Spectral Model	1.5	3.9	6.8

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Spectral Prediction Accuracy Results

Table 3. Four color overprint predictions for Offset printing technology shown for Spectral and XYZ model.

| 4 Color Overprint Offset	Avg ΔE	95%	Max
XYZ model	3.8	7.7	12.2
Spectral Model	1.5	3.9	6.8

Table 4. Four color overprint predictions for Flexo printing technology shown for Spectral and XYZ model.

4 Color Overprint Flexo	Avg ΔE	95%	Max
XYZ model	4.4	9.4	15.1
Spectral Model	1.4	3.4	4.9

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Spectral Prediction Accuracy Discussion

- From Tables 1 – 4 one can conclude that Spectral model outperforms predictions made with SCOP XYZ model.

- The results are consequent for both Offset and Flexo technologies and for two- and four-color overprints.

- The reason for the Spectral model better performance is that it includes much more physical and process metadata while XYZ model relies only on the ink opacity for predictions.

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CIE Lab vs Spectral Profiling
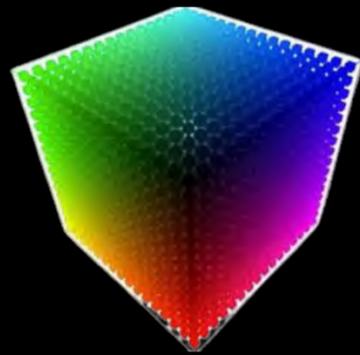
CIELab model

- **Requires a lot of data to perform accurately**
- Uses mathematical models
- Process agnostic
- No need for knowledge about process or print conditions specifics
- **Illuminant Dependent (D50)**

- **Requires a small number of patches**
- Uses light and colorant interaction physics, material and printing process knowledge
- Can be adapted to any printing process, substrate and colorant
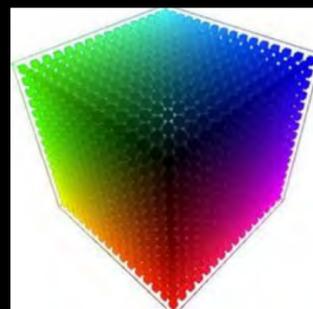- **Illuminant Independent**
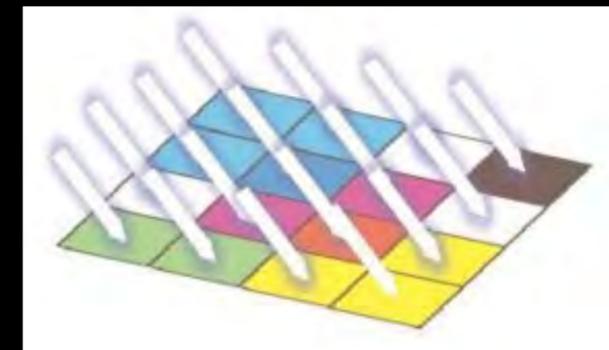
Light interactions spectral model

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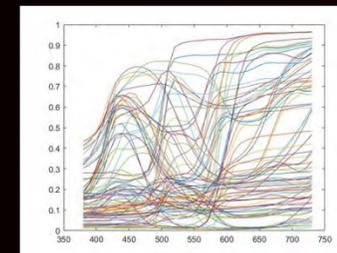
Spectral Profiling Evaluation

- How accurate is the ICC profile built from a small number of patches?

- How accurate is a profile built with ink ramps or CxF/X-4 data?
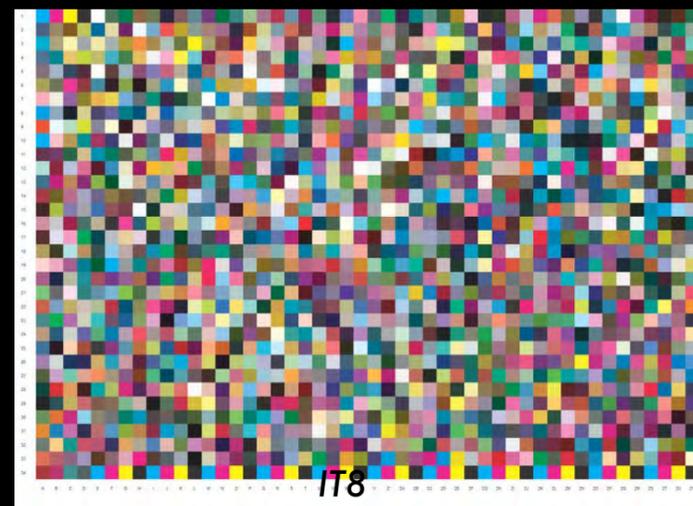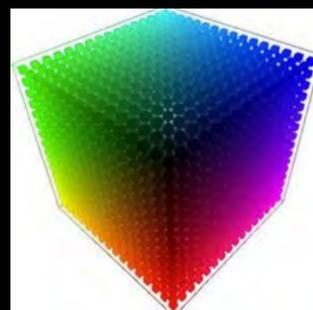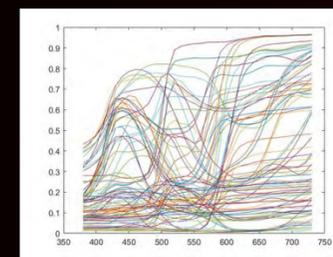

IT8 chart

Build ICC profile from IT8 data

Test Spots

Separation to CMYK

Hydra chart

Build ICC profile
from 40 – 80 patches

Test Spots

Separation to CMYK

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Spectral Profiling Evaluation

- We compare Spectral prediction engine with CIELab predictions in the case of Offset printing (40 patches), Flexo and Digital printing (80 patches).

- Evaluations is done on Spot color separations performed with B2A tables of ICC profiles built from single line of patches.

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Spectral Profiling Results

Table 5. Separation accuracy with CMYK profiles built from IT8 datasets, single line 80 patches for Digital and Flexo, and 40 patches single line for Offset.

Spot Color Reproduction	Avg ΔE	ΔE 95%	ΔE Max
IT8 Digital	0.5	0.9	2.2
80 Patches Digital CIELab	4.5	8.4	16.8
80 Patches Digital Spectral	1.1	2.6	4.8
IT8 Flexo	0.4	0.9	2
80 Patches Flexo CIELab	4.2	8.8	18.9
80 Patches Flexo Spectral	0.8	1.4	2.8
IT8 Offset	0.3	0.8	1.8
40 Patches Offset CIELab	3.6	8.2	14.8
40 Patches Offset Spectral	0.7	1.2	2.6

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Spectral Profiling Discussion

- In Table 5 we saw that it is possible to have a reasonable color accuracy from a profile built from a small number of measurements patches

- Although there is a (small) prediction error with Spectral prediction models, the results can be satisfying for brand owners and printing companies when productivity, efficiency and costs are equally or more important than absolute color accuracy.

- There are many practical benefits in Spectral profiling a CMYK process:
  - A single line of patches can be measured at the same time and with the same instrument used to measure calibration patches (TVI, Gray Balance).
  - High Ink Savings
  - Nice and smooth photo reproduction
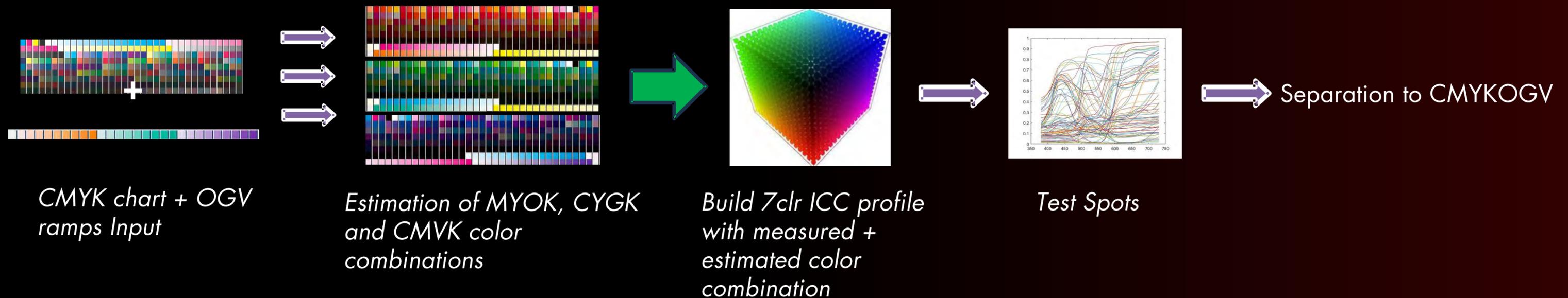
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Single Ink Ramps Profiling

- A multicolor (7 clr) extension of the spectral ink mixing prediction is shown in Table 7.

- Single ink Orange, Green and Violet ramps (CxF/X-4 data) are added to CMYK chart to build multicolor ICC profile.

- Results are compared with CMYKOGV and CMYK chart based profiles.

- The reason to compare with CMYK profile is to show that any gamut extension has benefits for spot color reproduction.

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Single Ink Ramps Profiling Evaluation

Method of evaluation of the prediction accuracy of the spectral prediction model

Indirect prediction accuracy via separation (Spectral only)

CMYK chart + OGV ramps Input

Estimation of MYOK, CYGK and CMVK color combinations

Build 7clr ICC profile with measured + estimated color combination

Test Spots

Separation to CMYKOGV

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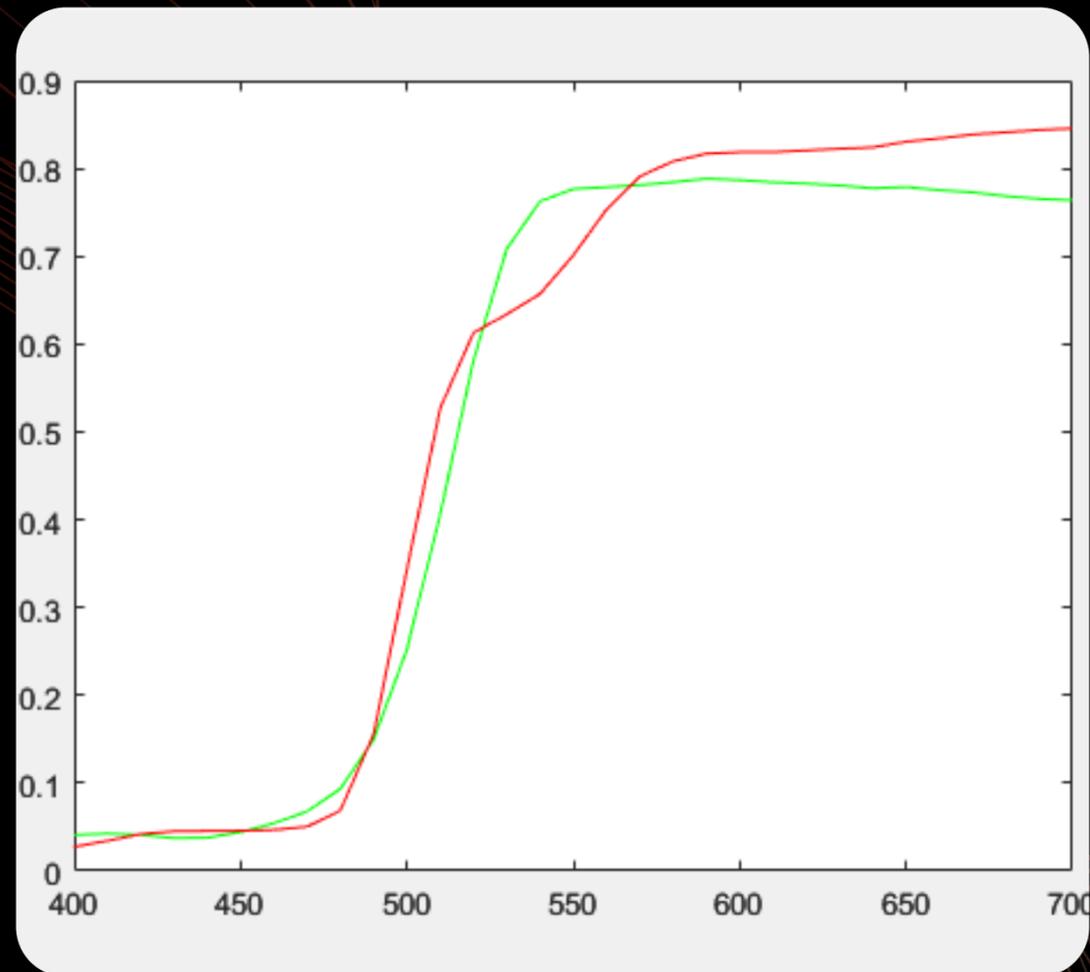Color Expertise

Single Ink Ramps Profiling Results

Table 6. Color reproduction accuracy with profiles built from CMYK, CMYKOGV and CMYK + OGV ramps data

Profiling data	Mean – 95%	% < 1	% < 2
Offset – Hydra CMYKOGV chart (875patches)	0.3 – 0.7	99	100
Offset – Hydra CMYK chart (377patches) + OGV ramps (30 patches)	0.8 – 1.6	88`	96
Offset – Hydra CMYK chart (377patches)	1.2 – 4.1	66	82
Flexo – Hydra CMYKOGV chart (875patches)	0.3 – 0.8	98	99
Flexo – Hydra CMYK chart (377patches) + OGV ramps (30 patches)	0.7 – 1.5	91	97
Flexo – Hydra CMYK chart (377patches)	1.1 – 3.3	71	86

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Single Ink Ramps Profiling Discussion

- It is shown in Table 6 that although there is a prediction error with Spectral models used to predict ink mixing from single ramps, the results can be satisfying for brand owners and printing companies when productivity, efficiency and costs are equally or more important than absolute color accuracy.

- There is always a benefit in adding more inks to CMYK processes for Spot colors. Gamut extension (overweights Spectral models prediction accuracy shortcomings.

- There are many practical benefits in Spectral profiling a CMYKOGV process:
  - Find minimum number of inks needed for a particular job: Orange juice box CMYKO...
  - Change of ink sequence without re-printing charts and reprofiling: overprint, ink opacity...
  - Changing process inks for a specific print job: Meat box BMYK...

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Spot Color Reproduction Metamerism

Original Spot (in green) and reproduced CMYK (in red):

ΔE2000 (D50) = 0.8 ; ΔE 2000 (A) = 4.1.

- Different printing systems can produce colors that are perceived as identical under one standard illuminant such as D50.

- The visual match will however fail in other illuminations if the spectral properties of the inks differs.

- This phenomena is called metamerism.

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Input Colors Dataset (reminder)
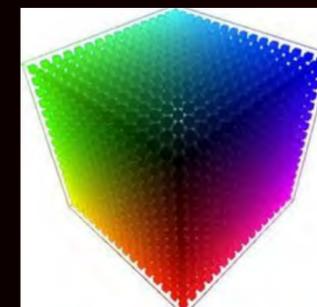
- We selected 1121spectrally measured spot colors that are used in packaging material.

- The test Spot colors are selected to cover both spectral and color gamut uniformly.

- All Spots are first gamut - mapped to the target profile and then in-gamut color accuracy is reported.

- From the spectral measurements D50 ICC profiles have been built with Alwan Hydra spectral processing framework.
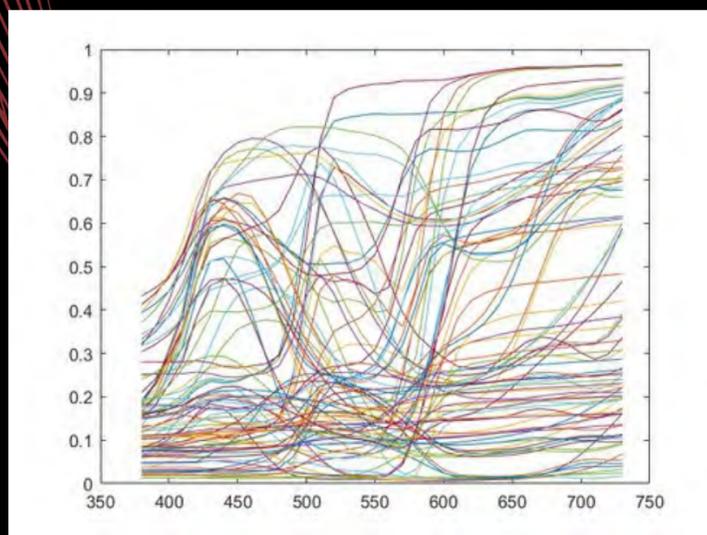
- Separations are done with B2A table of the profile.

Spectrally measured spot colors
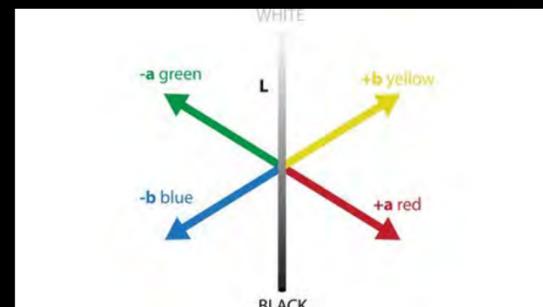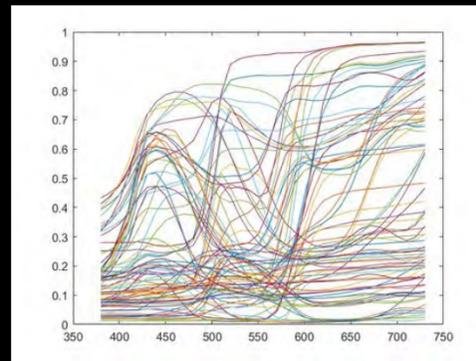
CIELab encoding

Gamut mapping to an ICC profile gamut
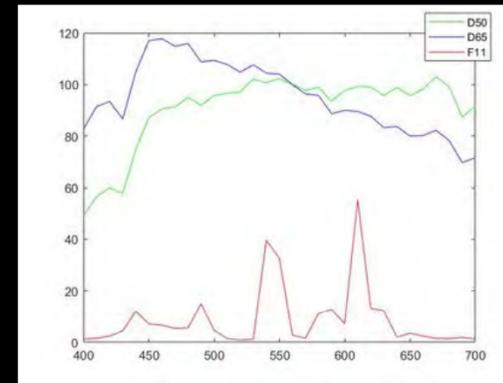
Separation to CMYK

Spot Color Reproduction Evaluation

Metamerism is evaluated by:

1. Conversion of the spectrally measured Spot colors to D50, D65 and F11 CIELab using spectrally defined Illuminants.

2. Conversions of the spots to D50 CIELab and then chromatic adaptation to D65 or F11.
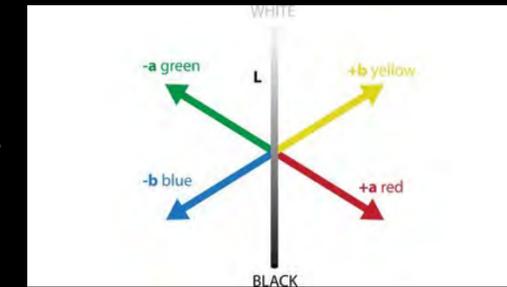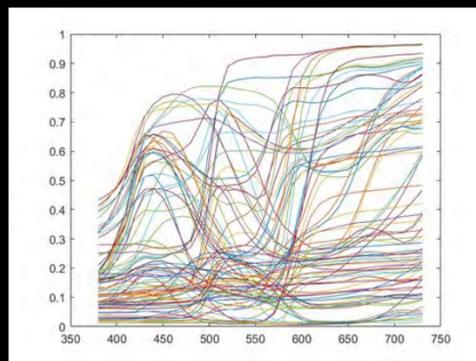
1.

Spec. Spots

Spec. Illuminants D50, D65 and F11

CIELab D50,D65 and F11 Spots

CIELab D65 and F11 Spots

2.

Spec. Spots
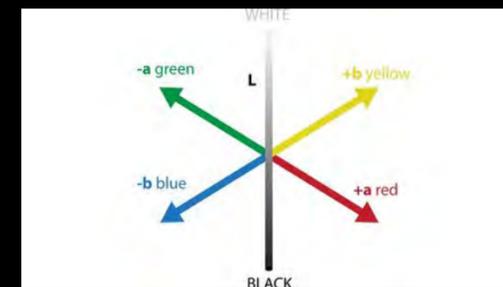
CIELab D50 Spots

Chromatic adaptation from D50 to D65 and F11

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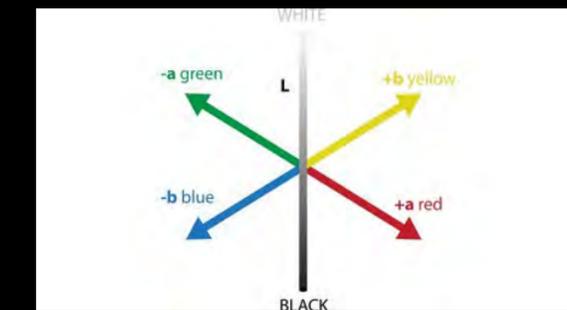
Spot Color Reproduction Evaluation

- Metamerism is evaluated using spots transformed spectrally to D50, D65, F11 CIELab and then separated to device values ("Spec" in Tables 1 & 2).

- and compared with the spots transformed to CIELab D50, then chromatically adapted to CIELab D65 and CIELab F11 and then separated to device values ("Lab" in Tables 1 & 2).

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D50/D65 Metamerism

Table 7. D50 to D65 Illuminant change with shown mean and 95%-tile ΔE2000 accuracy of the separation of the input Spots. Also, % bellow 1 and 2 ΔE2000 has been shown.

Print Device	mean	95%	< 1 DE	< 2 DE
KM-1 – Lab	0.7	1.6	77	99
KM-1 – Spec	0.4	0.8	97	99.7
EPSON 5000 – Lab	0.9	1.7	66	98
EPSON 5000 – Spec	0.4	1.1	94	99.5
Flexo Coat - Lab	0.9	1.8	68	96
Flexo Coat – Spec	0.4	1.2	93	99
Offset Coat – Lab	0.8	1.6	78	99
Offset Coat – Spec	0.1	0.7	97	100
HP Indigo CMYKOGV - Lab	1	1.9	65	96
HP Indigo CMYKOGV – Spec	0.5	1.5	90	97

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D50/F11 Metamerism

Table 8. D50 to F11 Illuminant change with shown mean and 95%-tile ΔE2000 accuracy of the separation of the input Spots. Also, % bellow 1 and 2 ΔE2000 has been shown.

Print Device	mean	95%	< 1 DE	< 2 DE
KM 1 - Lab	1.8	4.4	22	72
KM 1 - Spec	0.4	0.9	97	99.7
Ep 5000 - Lab	2	5	19	67
Ep 5000 - Spec	0.4	1	96	99.8
Flexo Coat - Lab	1.7	4	20	73
Flexo Coat - Spec	0.4	1.2	93	99
Offset Coat – Lab	1.7	4	93	74
Offset Coat - Spec	0.1	0.8	96	99.9
HP Indigo CMYKOGV - Lab	2	4.5	20	69
HP Indigo CMYKOGV - Spec	0.5	1.4	90	97

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Spot Color Reproduction Discussion

- It is clear from the Table 7 and Table 8 that having spectrally defined spots offer much more accurate transition from one illuminant to another.

- If the Spot is defined with CIELab values, one must perform a prior chromatic adaptation before separation, which induce unnecessary prediction error.

- Although transformation from CIE D50 to CIE D65 illuminant does not produce significant error, transformation to F11 illuminant produces much higher error.

- Illuminants such as CIE F11 correspond to the fluorescent lamps used in stores and markets where usually packaged products are displayed.

- This is one of the reasons to have Spot colors defined in CxF/X-4 standard encoding.

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Agenda (reminder)

- We evaluated the prediction power of spectral models and compare them with conventional prediction models.
- We evaluated spectral prediction models accuracy and compare them with colorimetric models for CMYK and Multicolor ICC profiling including single ramps input data.
- We evaluated the effect of spectral matching compared to colorimetric matching on metamerism.
- **We will evaluate if spectral predictions could lead to various optimizations of the color management process making it easier, faster and more automated.**

Color Management Automation?

- **At this stage, we can conclude the following**

  - CIELab prediction models can not provide acceptable accuracy from a small number of patches to build, edit or update ICC profiles, Spectral models can.

  - CIELab prediction models do not provide acceptable accuracy for spot color reproduction under non D50 viewing conditions, Spectral models can.

  Can Spectral models be used to automatize Color Management?...

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Conclusion

The conclusion of this work is that Spectral encoding and processing can lead to the Automation of Color management and decision-making, with many practical benefits such as:
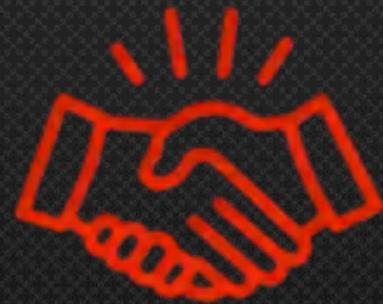
- No need for a special printing session to profile a print device: Cost saving…
- Profile building, editing or update do not take more than few minutes: Time saving…
- Can lead to automatic decision making: Easier color management.

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Thank you!

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