INTERNATIONAL COLOR CONSORTIUM

Colorimetric and spectral matching

Prague, Czech republic
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Marc Mahy
Agfa Graphics

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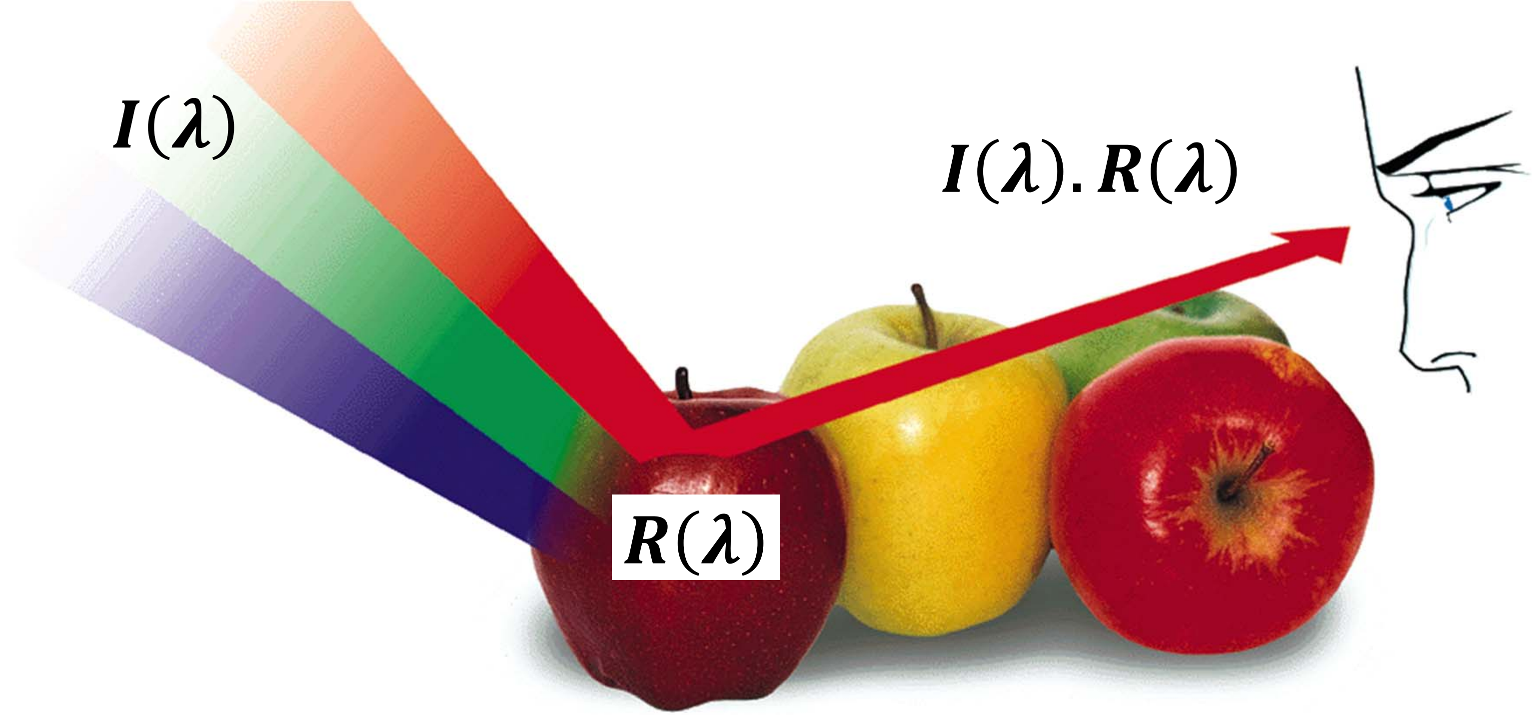
Overview

- **Modeling color**
- **Color matching**
- **Process control**
- **Profile based color transforms**
  - Visual effects
  - Light interactions
- **Color matching**
  - Colorimetric matching
  - Spectral matching
  - Metameric colors

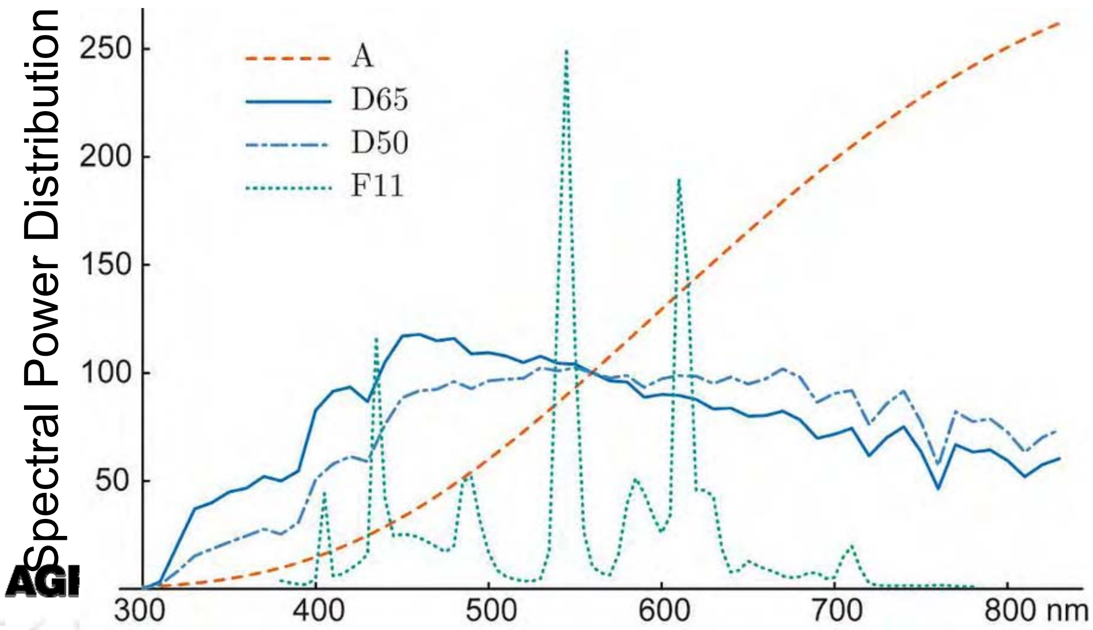
Modeling color

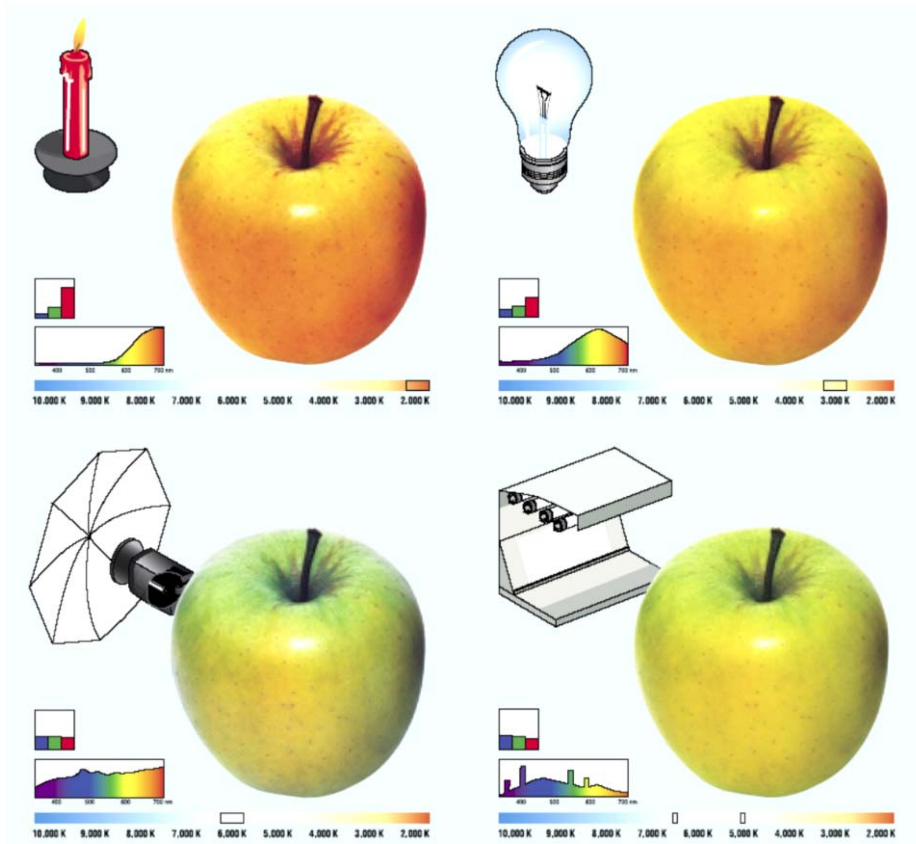
- **Object has the color of the "light" leaving its surface**
  - *Light source* $SPD: I(\lambda)$
  - *Object* $Reflectance: R(\lambda)$
  - *Human observer* $CMF: (X(\lambda), Y(\lambda), Z(\lambda))$



Modeling color

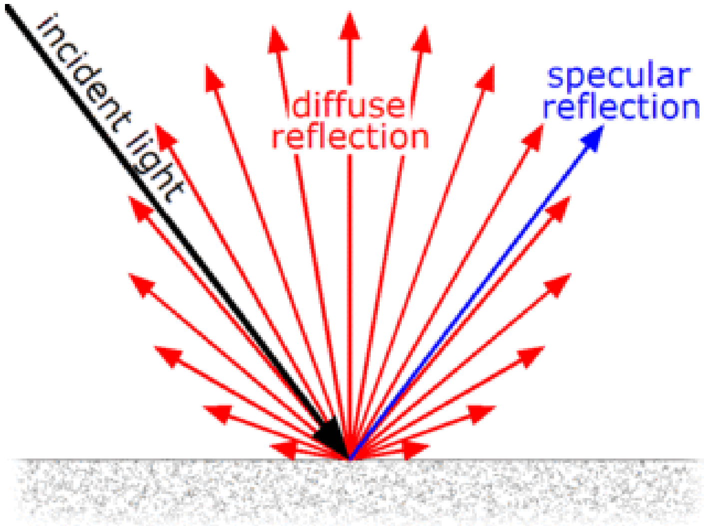
- **Light source**
  - Electro Magnetic Radiation (EMR)
    - Focus on wavelength range from 300 till 800 nm
  - Different standard illuminants
    - Illuminant E (equi-energy)
    - Illuminant A, D_{50}, D_{65}, F_{11}

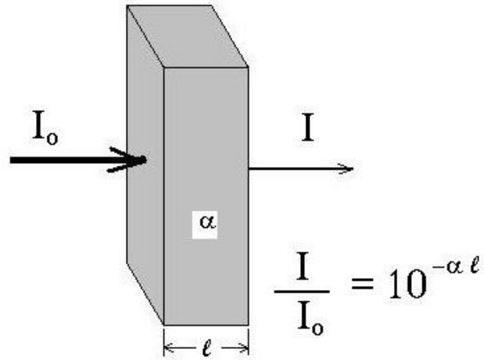


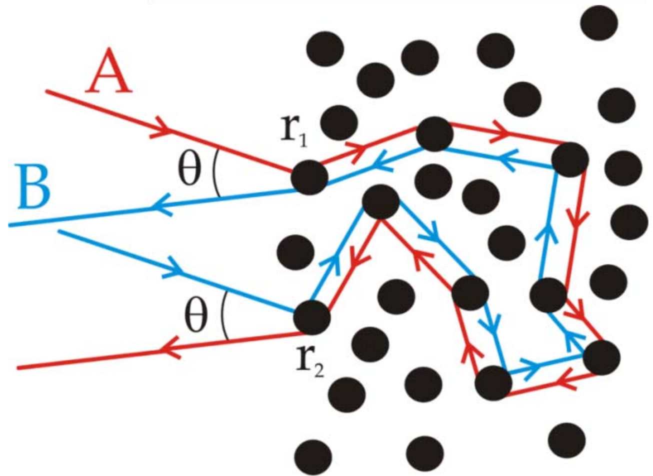


Modeling color

- **Object colors: Classes object types**
  - Opaque objects
    - Diffuse reflection: Lambertian reflector
    - Specular reflection: mirror
    - Most objects: diffuse and specular reflection
  - Transparent objects
    - Absorption, no scattering: plexi, glass, …
  - Translucent objects
    - Absorption and scattering: backlit
  - Special effects
    - Fluorescence: substrates
    - Metallic surfaces: (in plane) BRDF

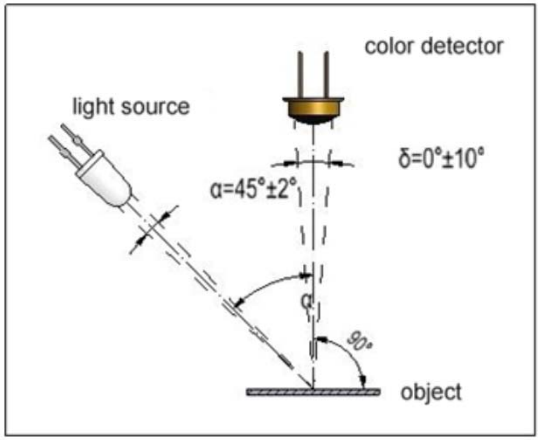




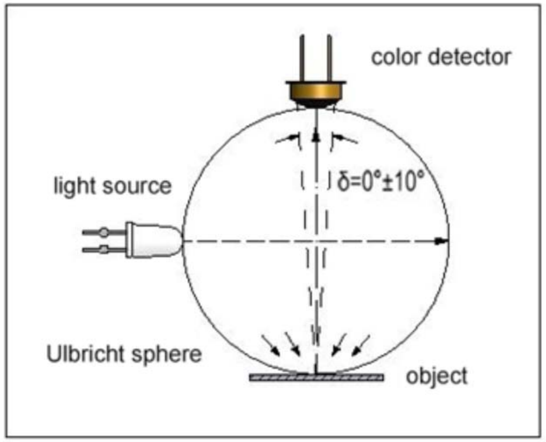


Modeling color

- **Object colors: Characterizing object types**
  - Opaque objects
    - Measurement geometry: 45°:0° or 0°:45°
    - Colorimetric or reflectance spectra
  - Transparent objects
    - Measurement geometry: d:0° or 0°:d
    - Colorimetric or transmission spectra
  - Translucent objects
    - In reflection or transmission mode
    - For reflection mode: White backing, black backing or self backing
  - Special effects
    - Fluorescent substrates: colorimetric data or bi-spectral reflectance
    - Metallic surfaces: BRDF based on colorimetric or reflectance data



45°/0° measurement geometry

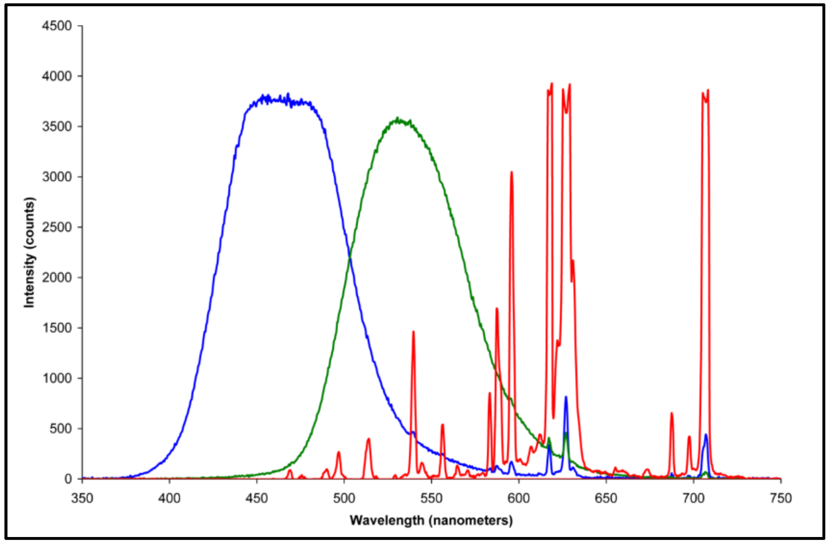


d/0° measurement geometry

Modeling color

- **Self luminous colors**
  - Displays
    - Additive color mixing based on Red, Green and Blue phosphors

- **Characterizing self luminous colors**
  - Displays: colorimetric data or radiant emission spectra

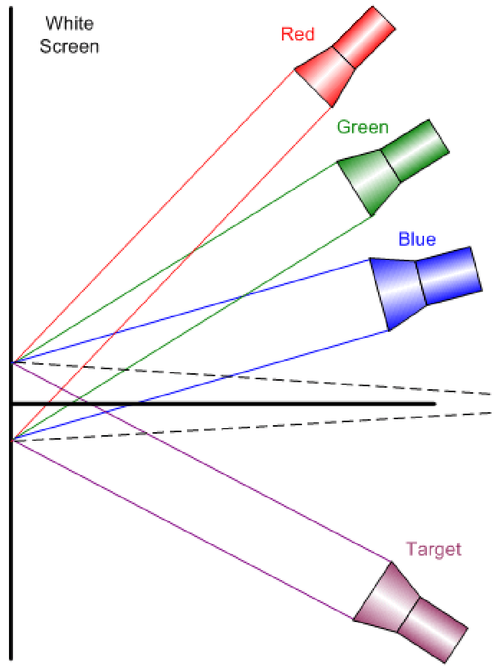


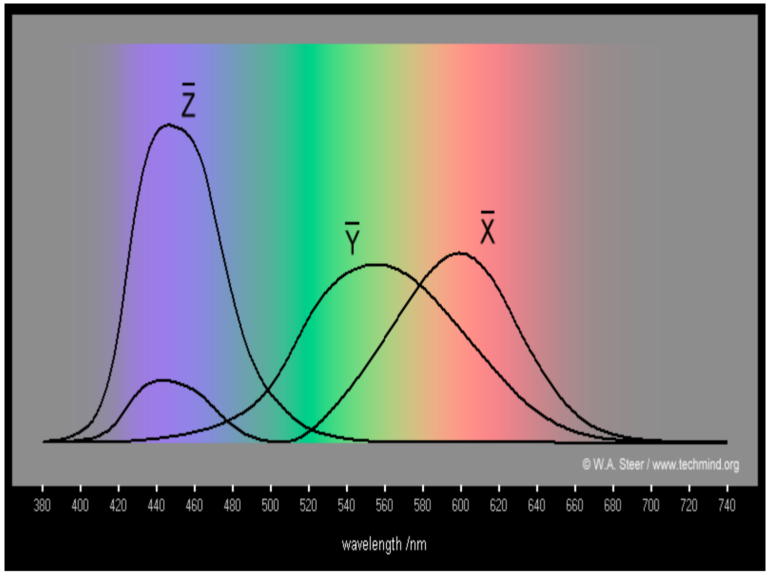
Modeling color

- **Human observer**
  - —Color vision: three types of cones
  - —Sensitive to EMR from 360 till 830 nm
- **Tristimulus color spaces**
  - —Based on color matching experiments
  - —Grassman's laws (additivity)
  - ⇒Color Matching Functions (CMF's)
- **Tristimulus values opaque objects**

$$X = \frac{\int_{360}^{830} R(\lambda)X(\lambda)\, I(\lambda)}{\int_{360}^{830} Y(\lambda)\, I(\lambda)} \qquad Z = \frac{\int_{360}^{830} R(\lambda)Z(\lambda)\, I(\lambda)}{\int_{360}^{830} Y(\lambda)\, I(\lambda)}$$

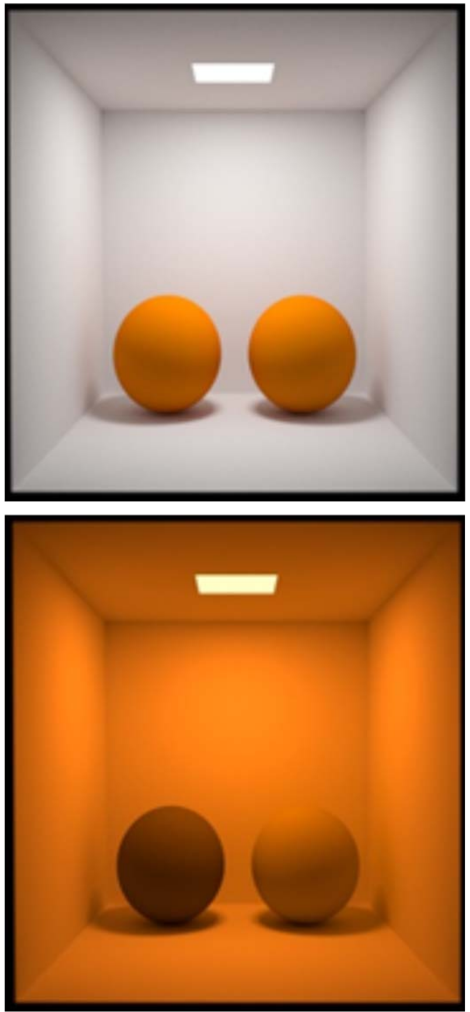
$$Y = \frac{\int_{360}^{830} R(\lambda)Y(\lambda)\, I(\lambda)}{\int_{360}^{830} Y(\lambda)\, I(\lambda)}$$





Color matching

- **Colorimetric matching**
  - Two colors (test and reference sample)
    - under the same viewing conditions
    - under different viewing conditions
  - Condition colorimetric match opaque colors
    - Same viewing conditions: $XYZ_1 = XYZ_2$
    - Different viewing conditions: $Jab_1 = Jab_2$
- **Examples**
  - Contract proofing for a given illuminant
  - Conversion from display (D_{65}) to graphic arts (D_{50})
- **Issues**
  - No match for changes in illumination
  - No match for observers with different CMF's



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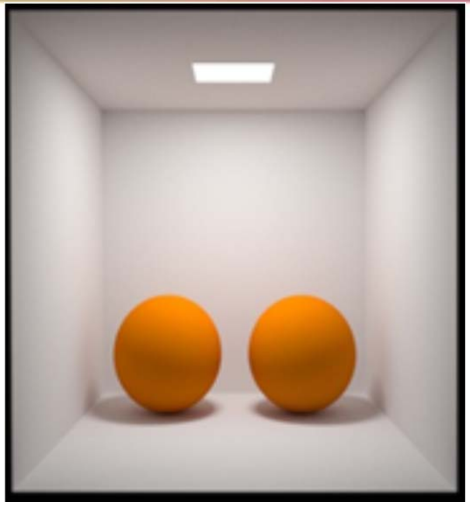
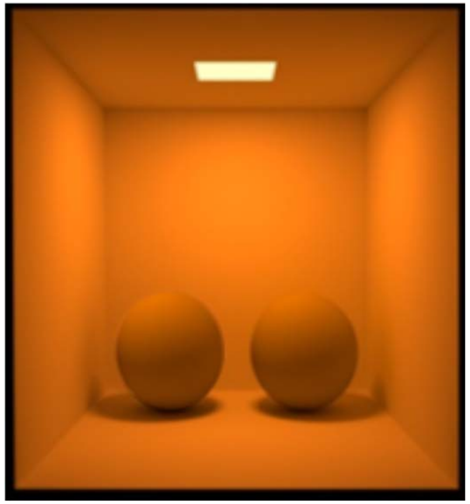
Color matching





- **Spectral matching**
  - Two colors (test and reference sample)
    - evaluated simultaneously for different illuminants
  - Too strict condition spectral match opaque colors:

$$SPD_1(\lambda) = SPD_2(\lambda)$$
$$I(\lambda)R_1(\lambda) = I(\lambda)R_2(\lambda)$$
$$R_1(\lambda) = R_2(\lambda)$$

- **Examples**
  - Conventional proofing systems
    - Spectral color matching between proof and press
    - Accurately simulating screening effects
- **Issues**
  - Not possible to get a spectral match between display and hard copy
  - Only supported for object colors

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Process control

- **Normal distribution**
  - Continuous probability distribution

$$\varphi(\mu,\sigma) = \frac{e^{-\frac{1}{2}x^2}}{\sqrt{2\pi}}$$

with x: variable

μ : average

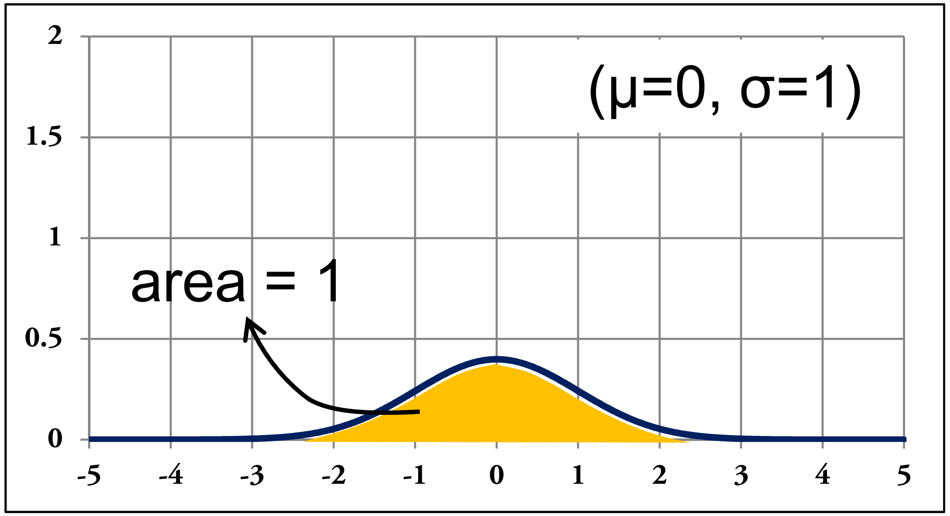
σ : standard deviation

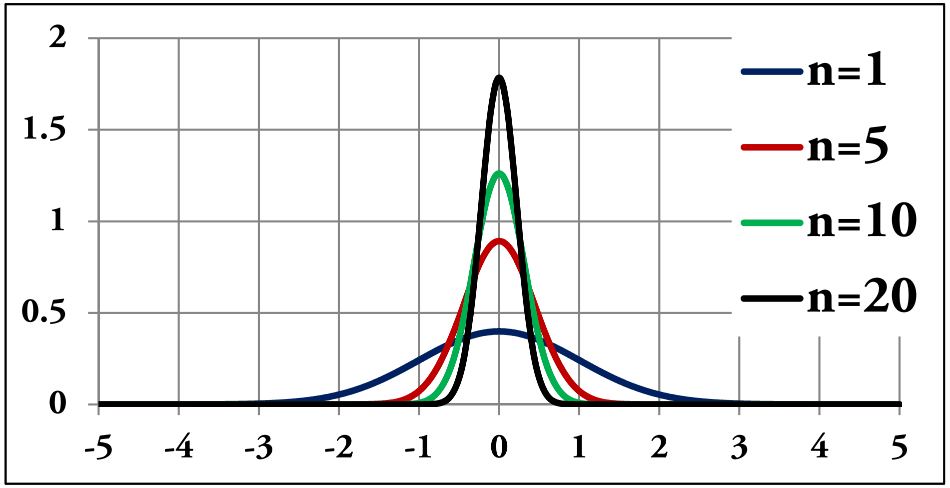
  - Properties

x normal distribution $\varphi(\mu,\sigma)$

=> $\bar{x}_n$ normal distribution $\varphi(\mu,\sigma/\sqrt{n})$

=> Reducing uncertainty & increasing accuracy





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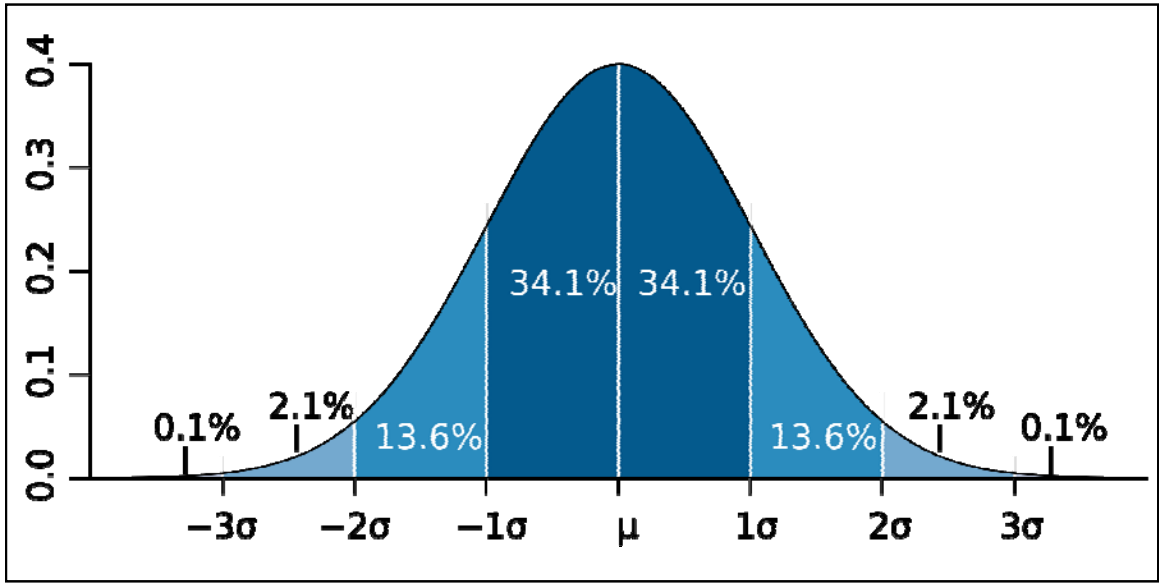
Process control

- **Normal distribution (cont'd)**
  - Confidence intervals
    - +/- 1σ: 68.3 %   3170 errors per 10,000 measurements
    - +/- 2σ: 95.5 %   460 errors per 10,000 measurements
    - +/- 3σ: 99.7 %   27 errors per 10,000 measurements



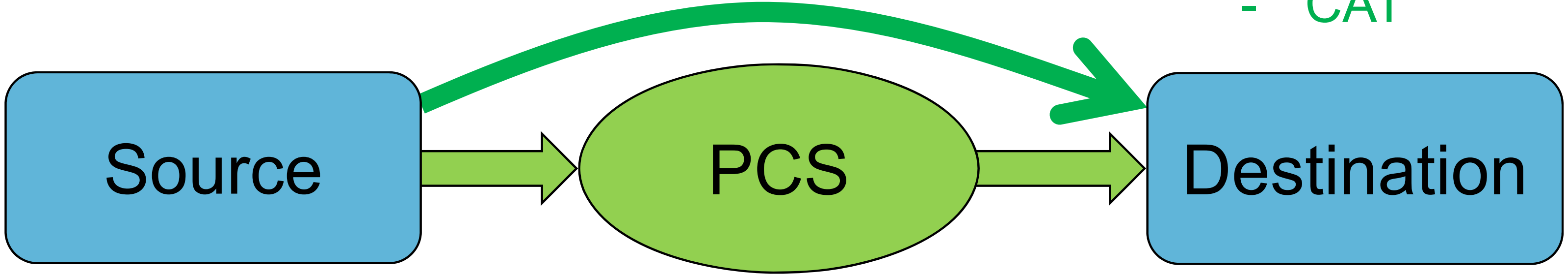
Profile based transforms

Profile connection spaces
- XYZ, Lab

Viewing conditions
- D_{50}, 2° observer
- CAT

- **ICC.1 approach**

Exchange color data:
Colorimetric only

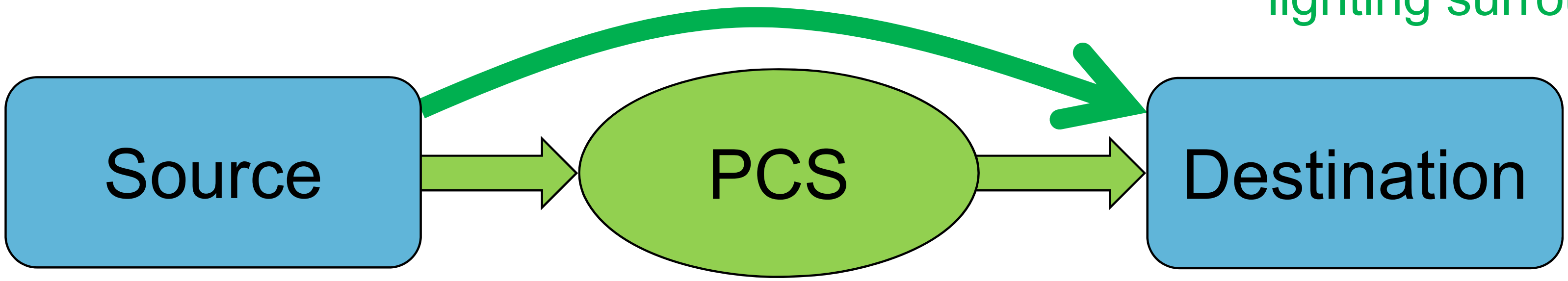


- **ICC.2 approach (iccMAX)**

Exchange color data:
Both Colorimetric and spectral

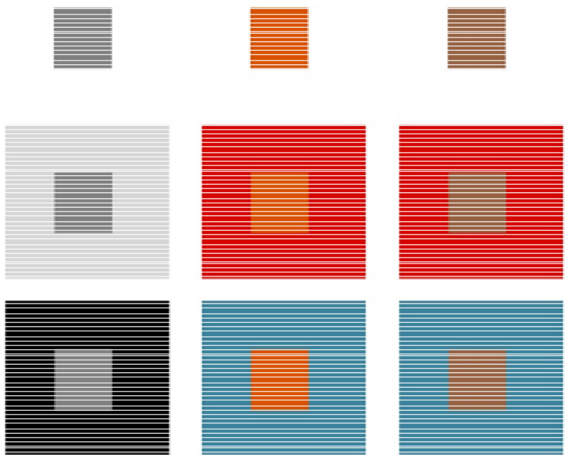
Profile connection spaces
- XYZ, Lab or spectral

Viewing conditions (PCC):
- Illuminant, observer and lighting surround



Profile based transforms: Visual effects

- **Visual effects**
  - Appearance based color matching
    - Needed if viewing conditions source and destination are different
      - For ICC.1: CAT's are used
      - For ICC.2: Support provided by modified CIECAM02
  - Local effects such as lightness and color induction, crispening, ...
    - Not simulated as they are present in the image



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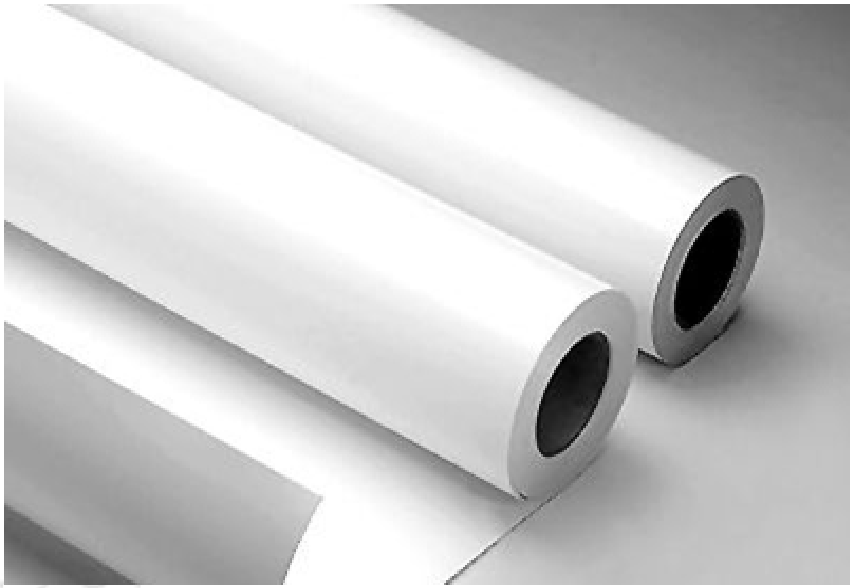
Profile based transforms: Light interactions

- **Print substrates**
  - Large variety of substrates used in ink jet applications
    - Plastics, backlit, plexi, glass, wood, …
    - Special light objects interactions
    - ⇒ Not always easily to measure

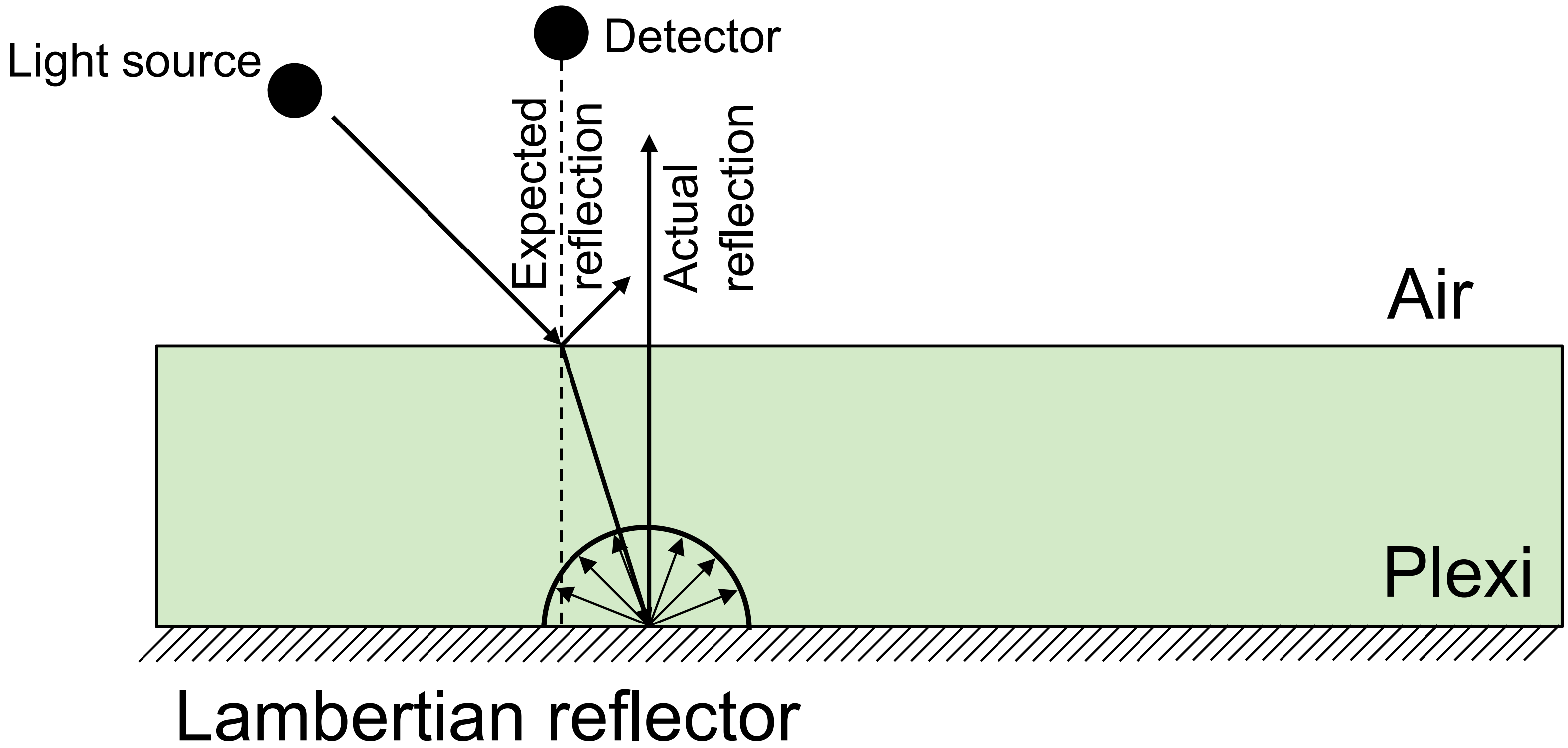


Profile based transforms: Light interactions

- **Measurement instruments**
  - Both available for reflectance and transmittance
  - Support M0, M1 and M2 measurement conditions for reflectance
    - M1 either for D_{50} or a custom illuminant
  - Typical characteristics
    - Different apertures to measure local non-uniformities
    - Spectral data provided
    - Black and white backing available

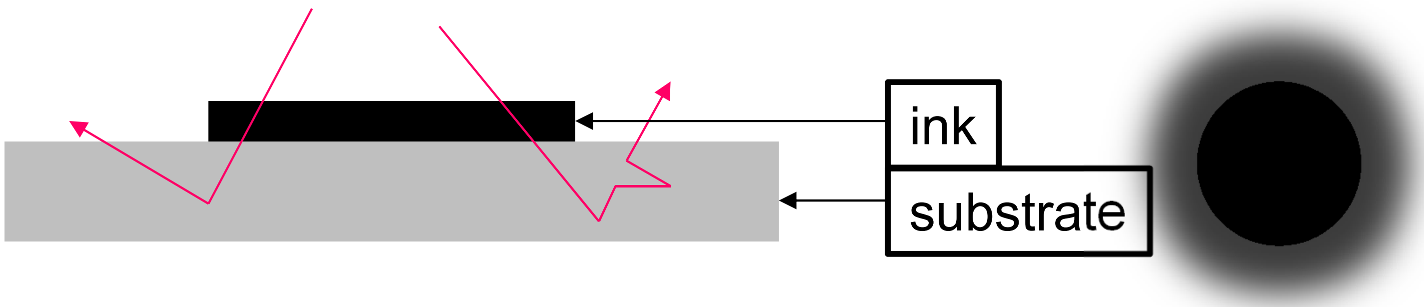
Profile based transforms: Light interactions

- **Effect thickness substrate**
  - Plexiglass
  - Reflectance measurements are not accurate or meaningfull

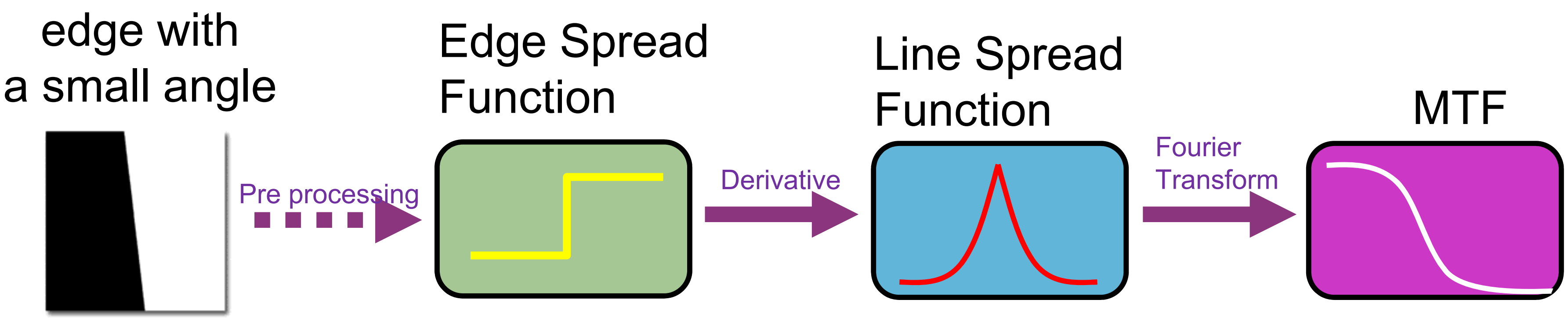


Profile based transforms: Light interactions

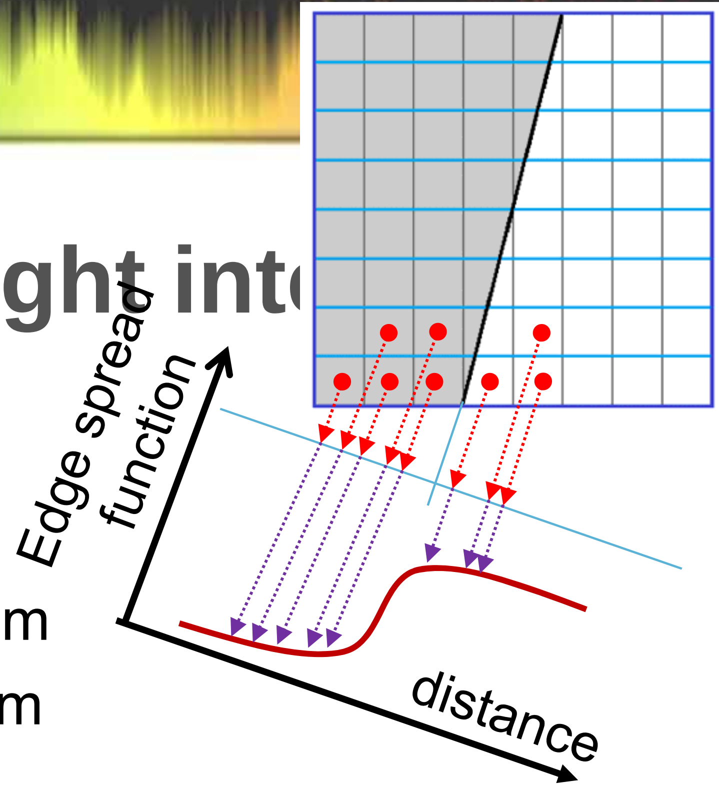
- **Transparent and translucent substrates**
  - Interaction light in substrate



  - Measurement dot gain based on ISO-12233 (Slanted edge method)

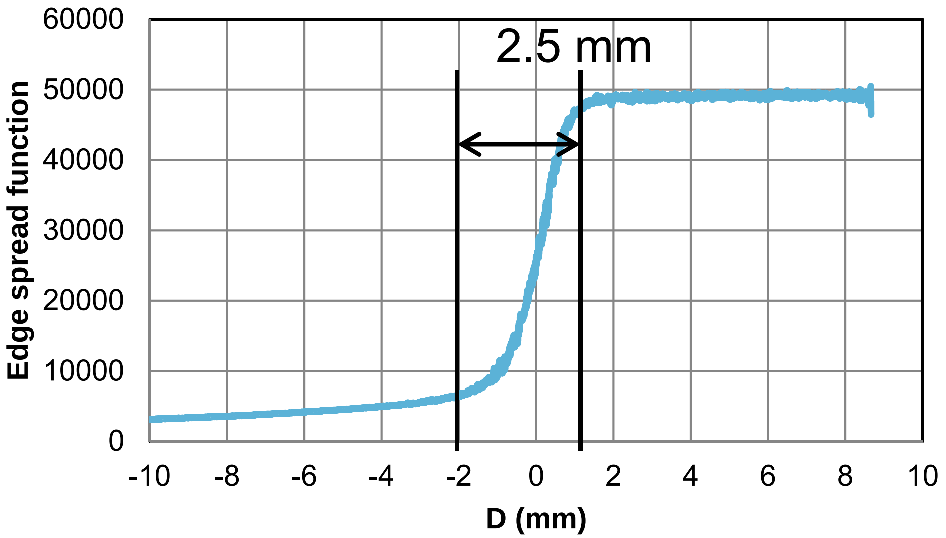


Profile based transforms: Light int

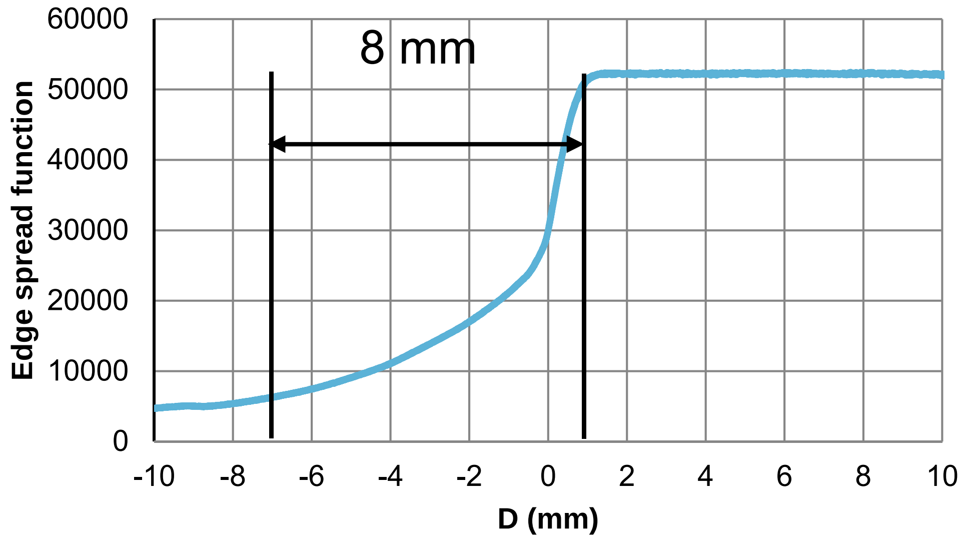


- **Transparent and translucent substrates**
  - Based on edge spread function
    - Patch size on translucent substrates 20 mm
    - Patch size on transparent substrates 5 mm

Transparent substrate

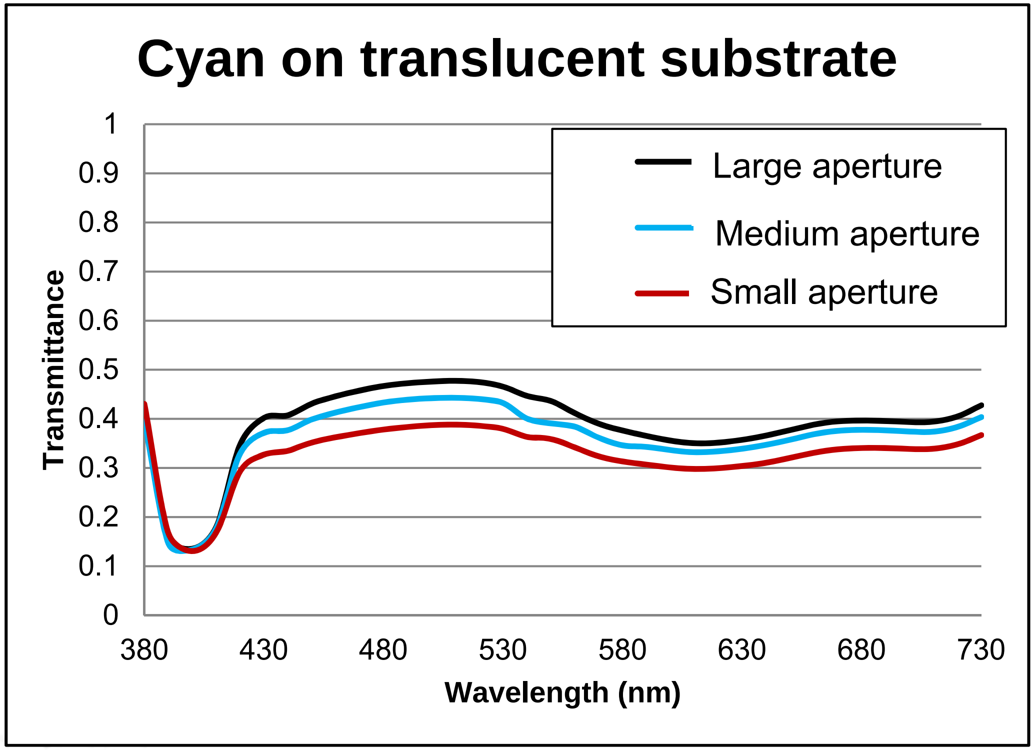


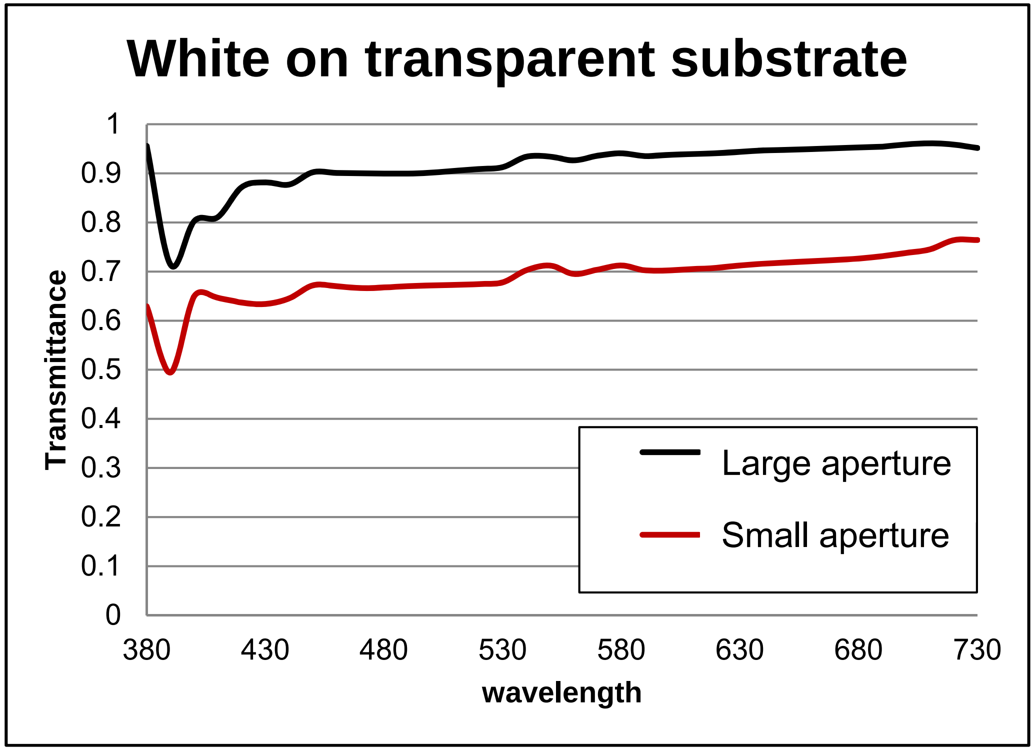
Translucent substrate



Profile based transforms: Light interactions

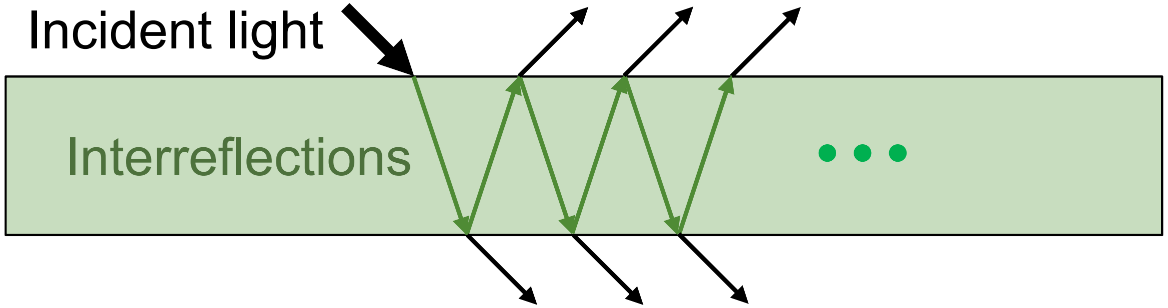
- **Transparent and translucent substrates**
  - Effect illumination size
    - Effect white ink on transparent substrate
    - Effect cyan ink on translucent substrate

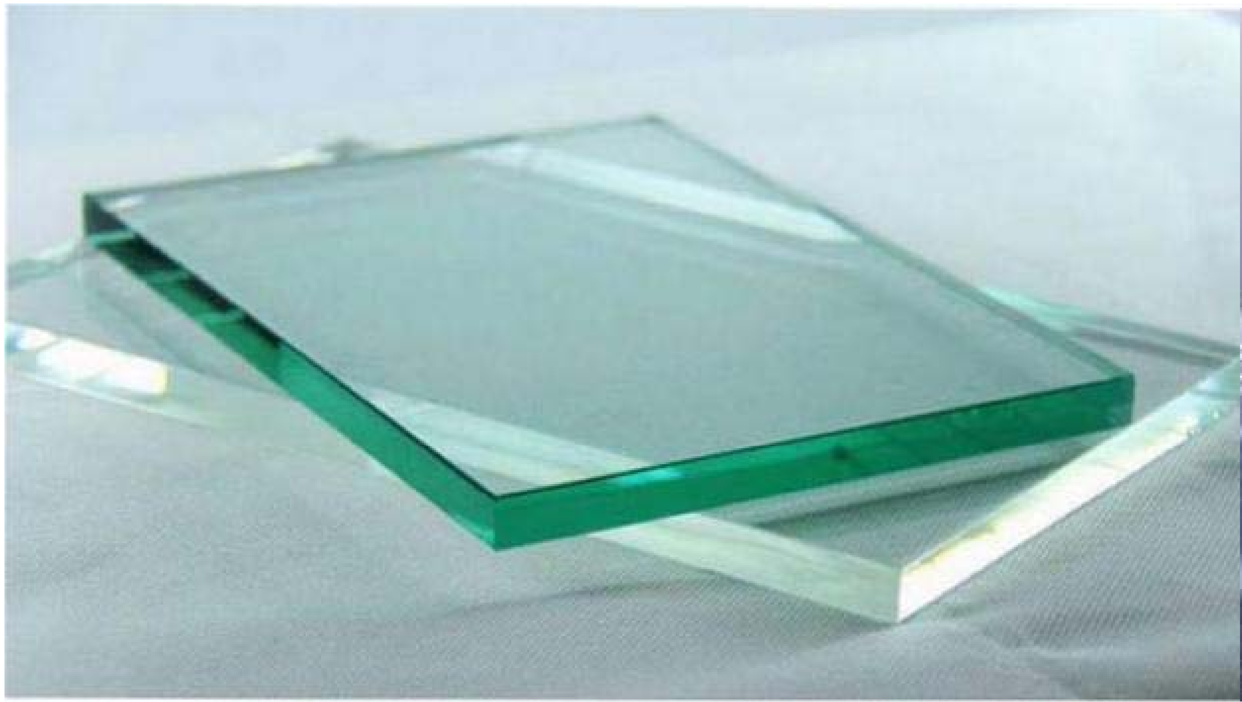


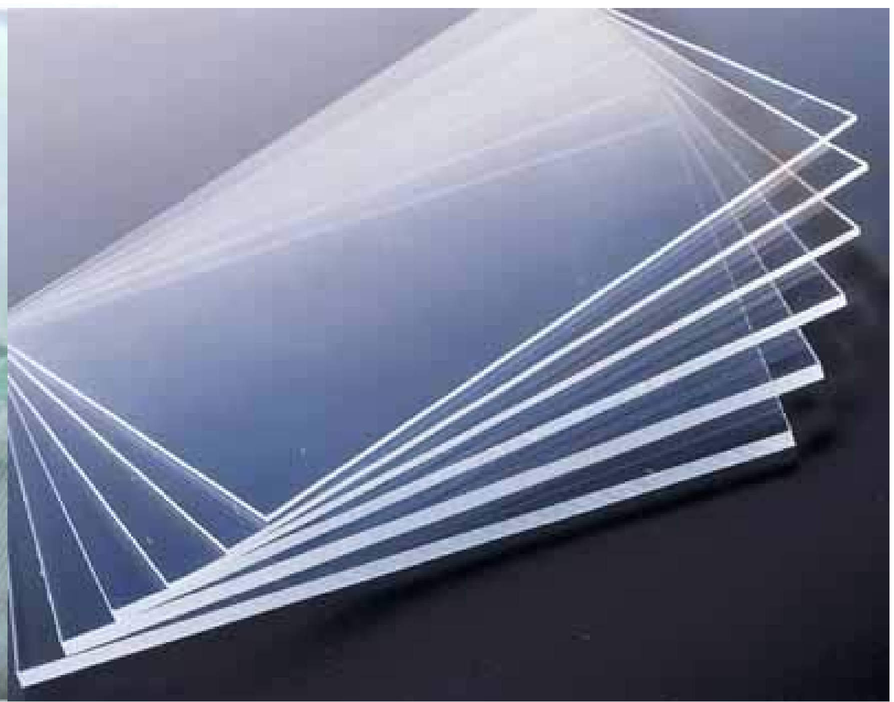


Profile based transforms: Light interactions

- **Transparent substrates**
  - Tunneling effect (inter-reflections in substrate)

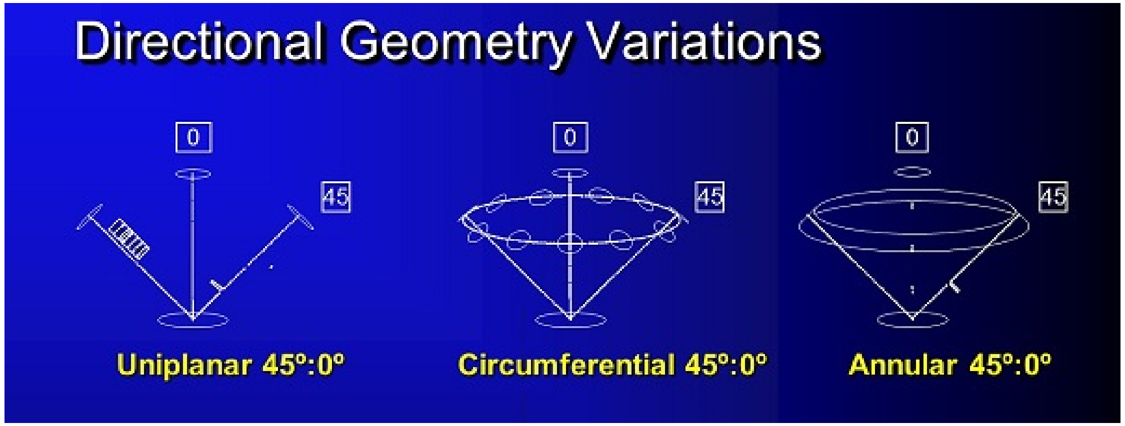




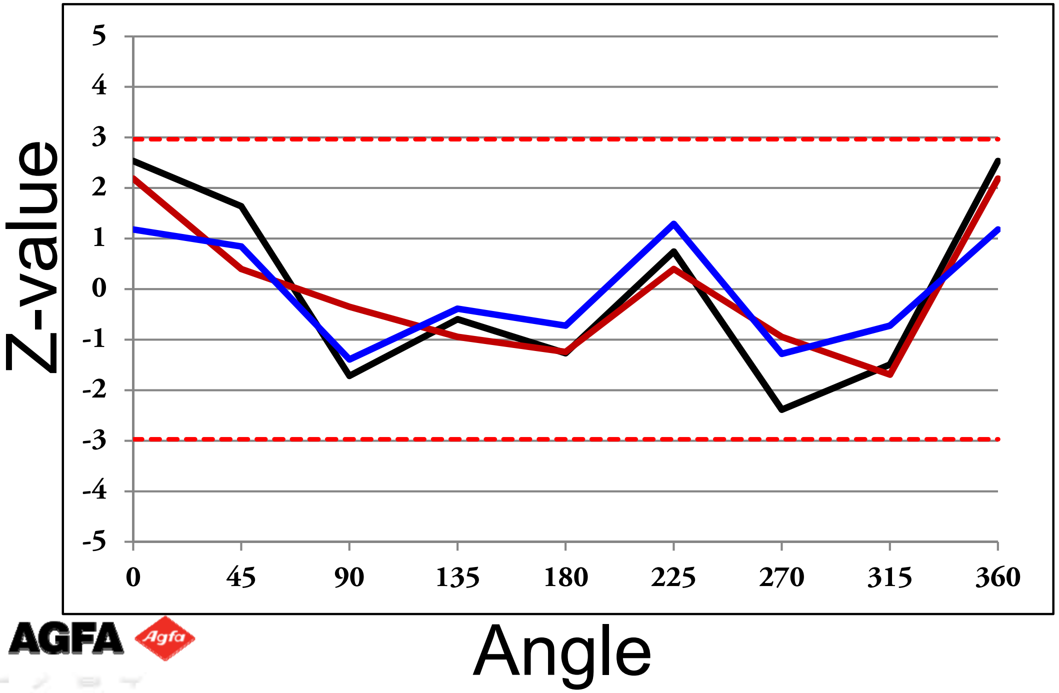


Profile based transforms: Light interactions

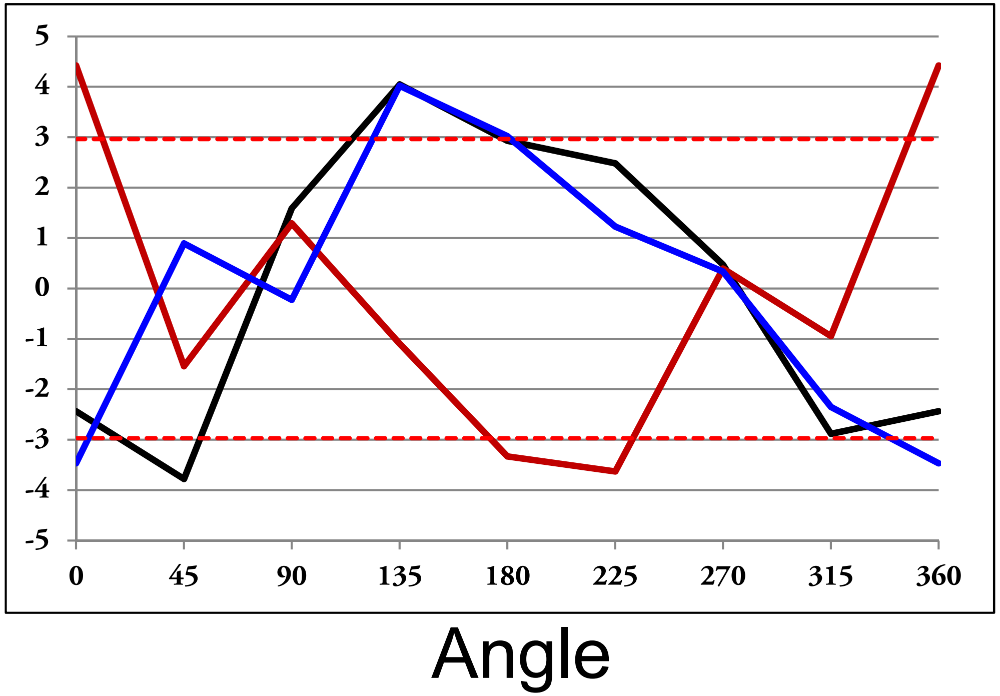
- **Textile**
  - Non-uniform surface
  - Effect directional geometry



Proofing substrate



Textile substrate



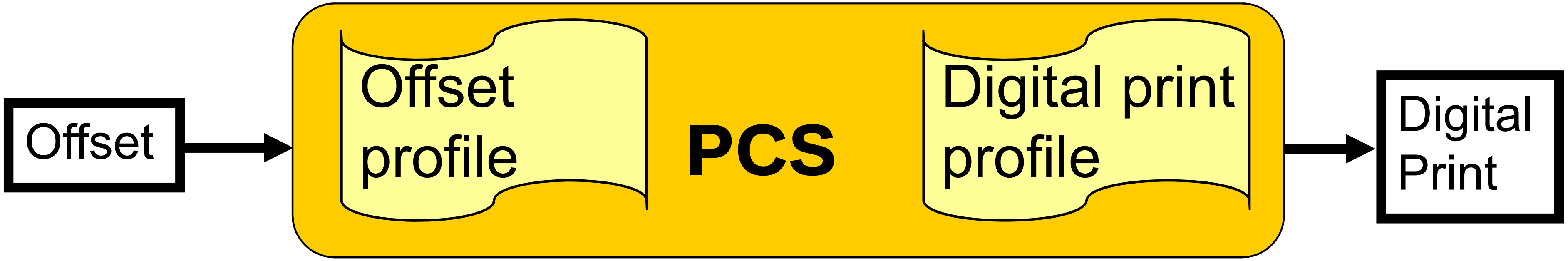
Colorimetric matching

- **Conventional color management**
  - Supported both by ICC.1 and ICC.2 (iccMAX)
- **Use cases**
  - Perceptual match => typically viewing in isolation
  - Proofing => side by side evaluation
- **Object type combinations for ICC.2 (iccMAX)**

Colorimetric match	Opaque	Trans-parent	Trans-lucent	Display	Fluorescent substrate
Opaque					
Transparent					
Translucent					
Display					
Fluorescent substr.					

Colorimetric matching

- **Handling mismatch in viewing conditions**

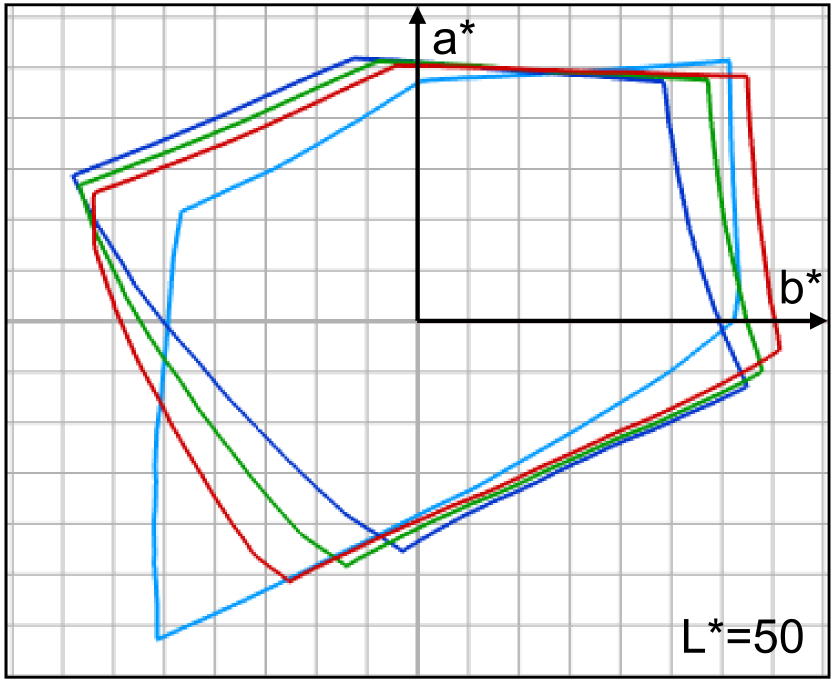


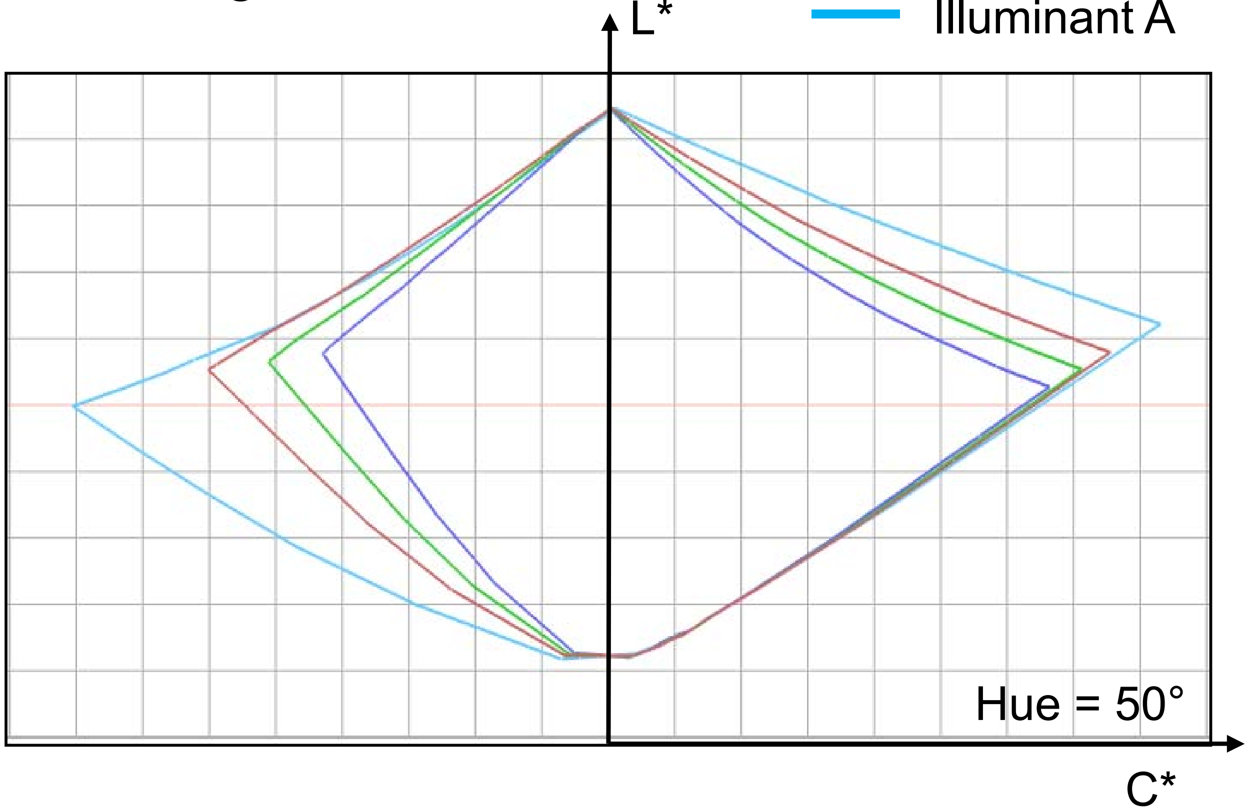
Viewing conditions	**Viewing conditions**
- D_{50} simulator	- D_{65}
- 2° observer	- 2° observer

- ICC.1: CAT's
  - Perceptual: CAT's used
  - Proofing: undo CAT's, recalculation destination profile is needed
- ICC.2: Profile Connection Conditions (PCC's)
  - Perceptual: mechanism in place to handle different PCC's
  - Proofing: inverse table cannot be reused

Colorimetric matching

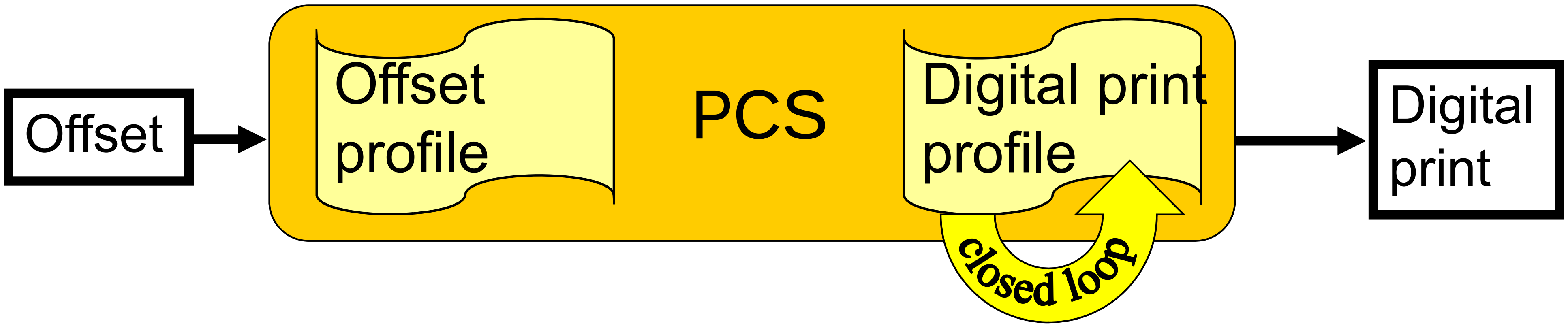
- **Handling mismatch in viewing conditions (con'd)**
  - Effect illuminants on gamut
  - Spectral measurement file for Fogra51





Colorimetric matching

- **Closed loop**



- Iteratively improving device model (forward transform)
- Closed loop approach limited by
  - Accuracy measurements
  - Stability printer
- Results in
  - Increased profile accuracy w.r.t. behavior printer

Colorimetric matching

- **Accurate linking**
  - —Reduction interpolation errors for in-gamut and out-of-gamut colors

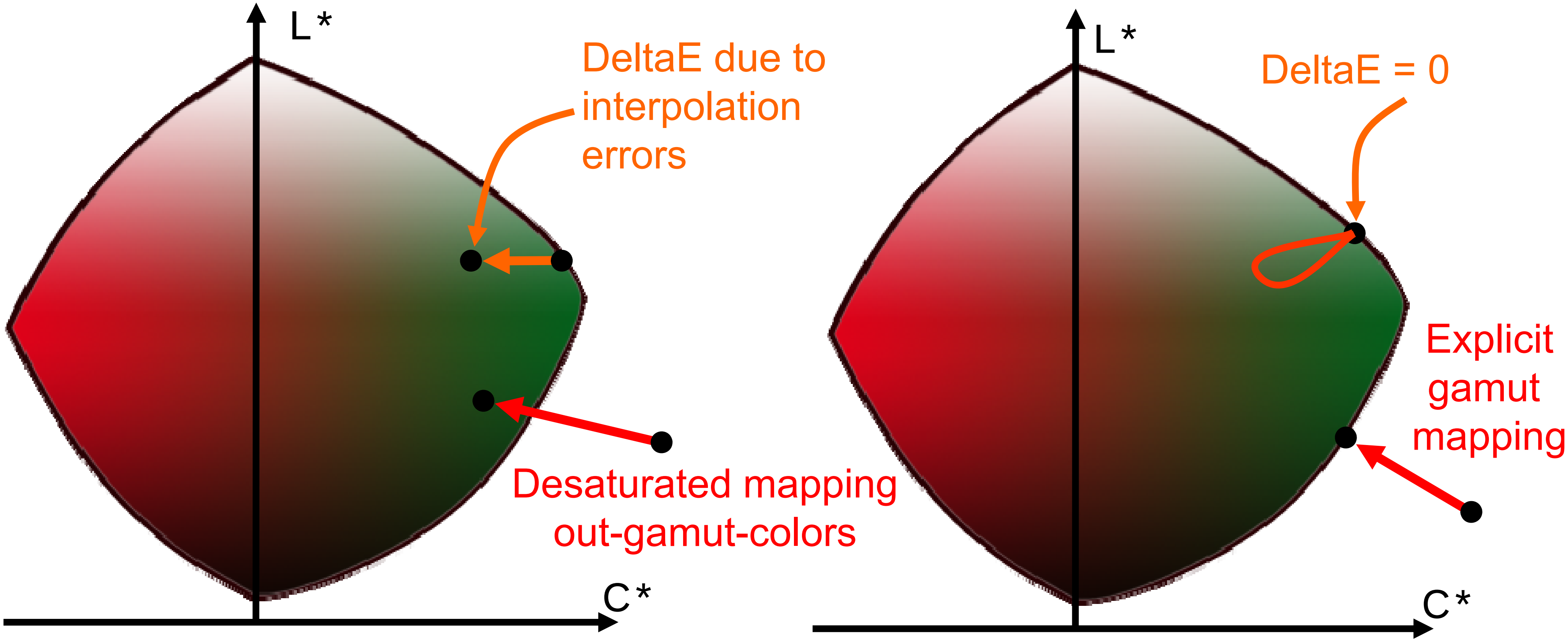
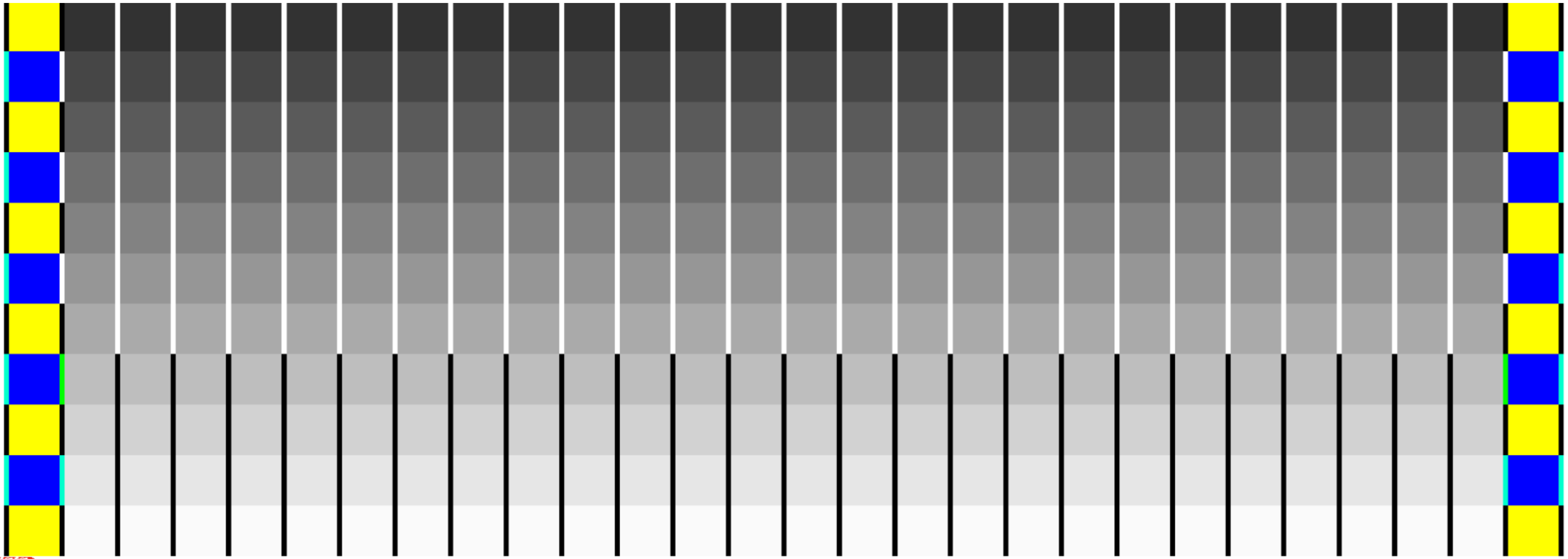


Table based linking **Accurate linking**

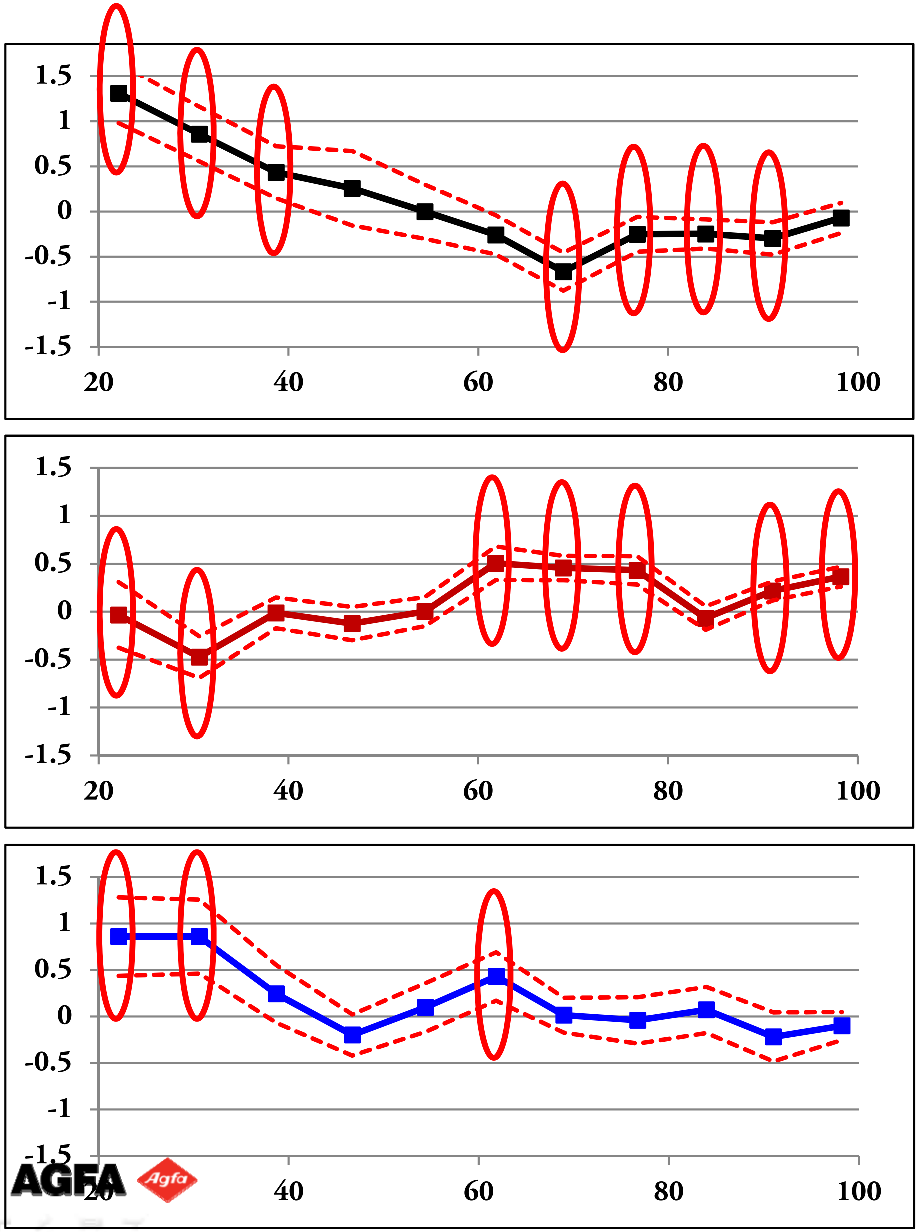
Colorimetric matching

- **Stability neutrals**
  - Proofing: Absolute colorimetric intent
  - Neutral check target
  - RGB target consisting of 11 different neutrals repeated per line (x26)

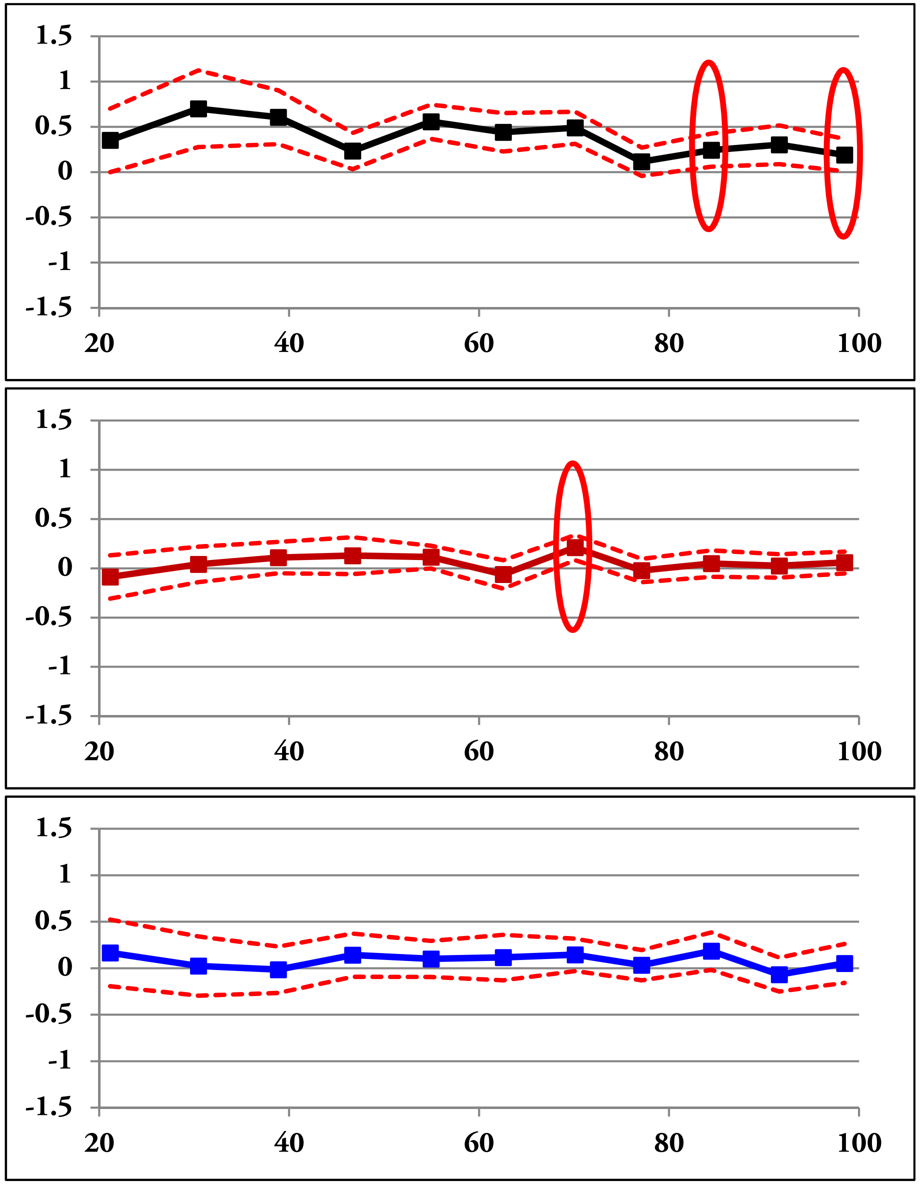


Colorimetric matching: Stability neutrals

Conventional link



Closed loop + Accurate linking



Spectral matching

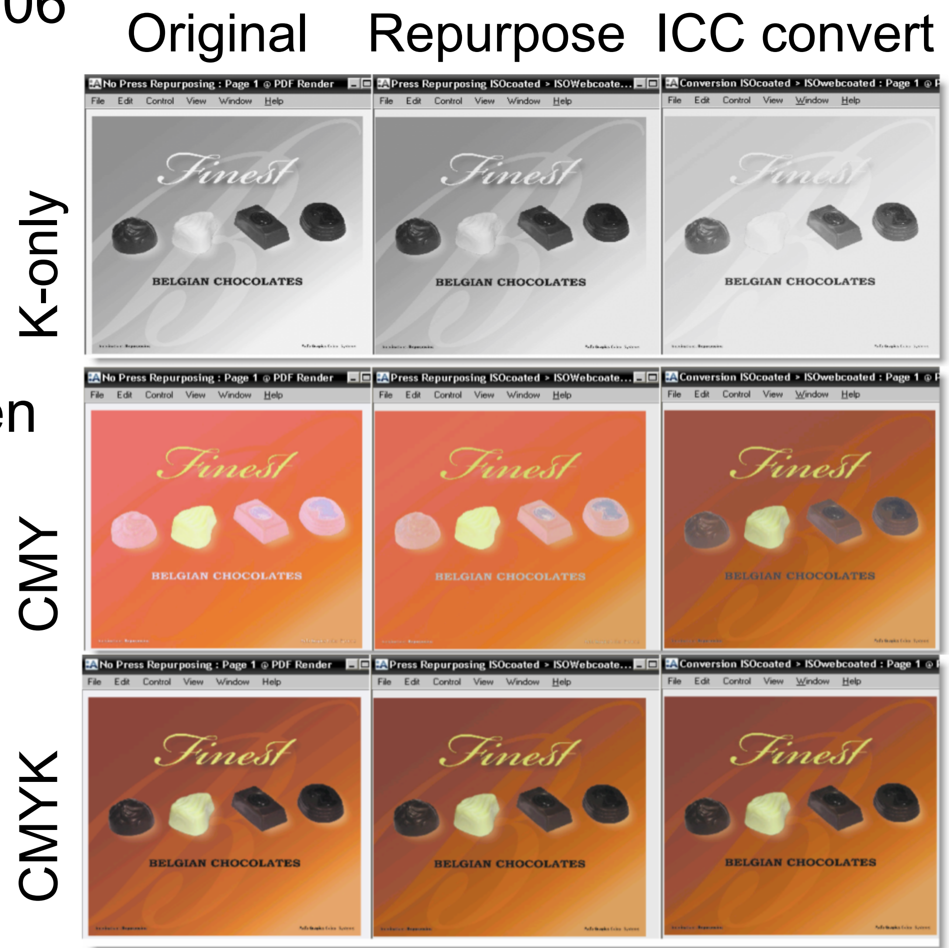
- **Not explicitly supported by conventional color management**
  - Dedicated support provided by ICC.2 (iccMAX) only
- **Use cases**
  - Similar appearance prints from different CMYK presses
  - Packaging: spot color processing
- **Object type combinations for ICC.2 (iccMAX)**

Spectral match	Opaque	Trans-parent	Trans-lucent	Display	Fluorescent substrate
Opaque					
Transparent					
Translucent					
Display				Identical	
Fluorescent substr.					Identical

- Focus on matching between opaque objects, CMYK printed output

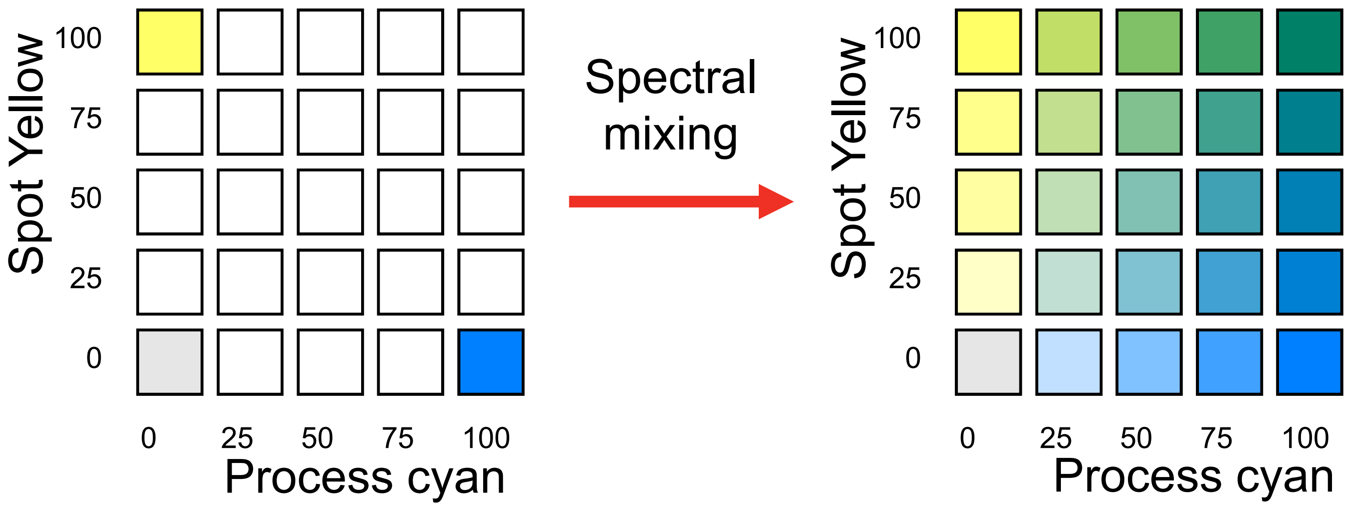
Spectral matching

- **Spectral match preserving transformations**
  - Repurposing transformation
    - From Fogra51 to CGATS TR 006
    - Preserves GCR from source
    - ⇒ Acceptable spectral match
  - Identity transform
    - Repurposing transform between identical profiles
    - ⇒ Preserves spectral match



Spectral matching

- **Spot color mixing**
  - Dynamic rendering of spot colors
    - Spectra step wedge on white and black background (CxF/X-4)
    - Output profile defines substrate and viewing conditions
  - Rendering characteristics
    - Realistic rendering of ink combinations based on spectral mixing
    - Continuity between different subsets of ink values
  - Spectra substrate and process inks: **spectral reflectance estimation**



Spectral matching

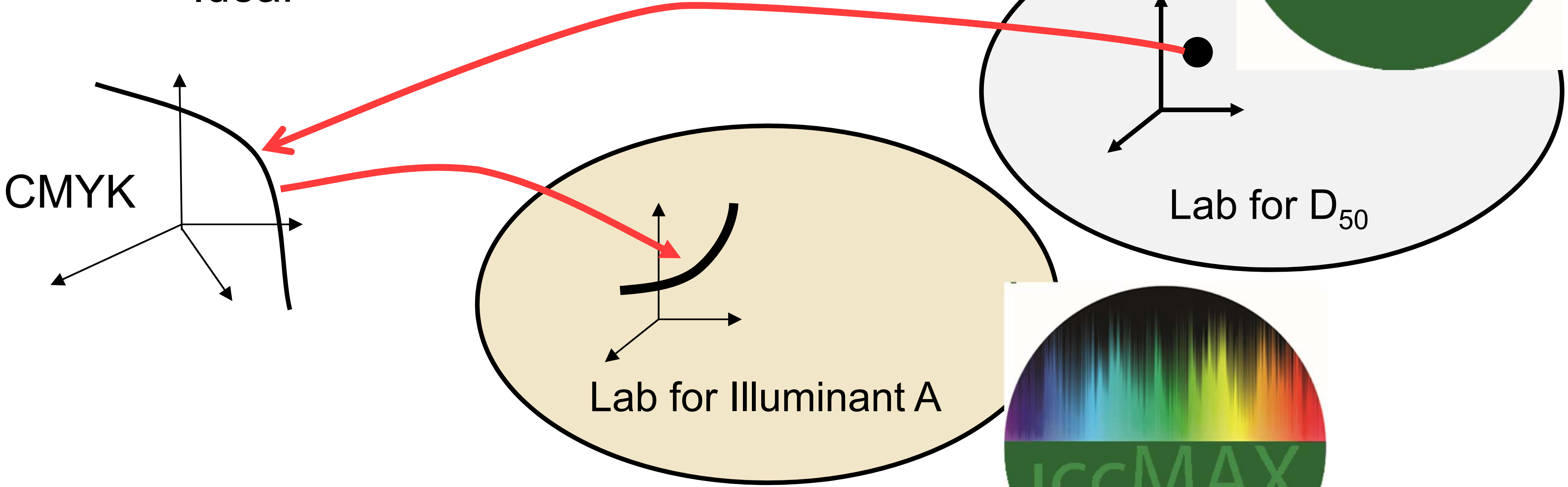
- **Spot color mixing (cont'd)**
  - Spectral reflectance estimation
    - Given discrete version of the tristimulus values XYZ

$$X = k\sum_{i=1}^{N} R_i I_i X_i \qquad Y = k\sum_{i=1}^{N} R_i I_i Y_i \qquad Z = k\sum_{i=1}^{N} R_i I_i Z_i$$

      - with R_i reflectance spectrum object
        I_i spectral power distribution illuminant
        $X_i Y_i Z_i$ color matching functions
        N dimension spectral space
    - Invert tristimulus values XYZ and solve for R_i with constraints
      - » Reflectance: $0 \leq R_i \leq 1 \quad i : 1 \rightarrow N$
      - » Smoothness criteria
      - » Typical aim curves

Color matching: Metameric colors

- **Illuminant discriminating metameric colors**
  - Idea:



  - Calculation illuminant discrimination met r:
    - Look for a set of CMYK values that
      - are the same for a first illuminant
      - have a maximum ΔE^*_{ab} for a second illuminant

Thank you for your attention ● Any questions?