Imaging Processing Pipeline for Color Printers & Printing Systems

Session III

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Outline

- Device Modeling
  - Analytical Modeling
  - Empirical Modeling
  - Model Inversion
- Gamut Mapping

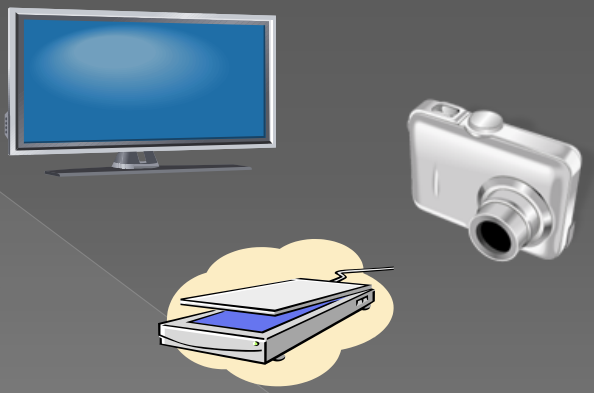
Device Modeling

- How does one build a model of a device?
  - Device Classes
- Typical device modeling falls into two categories
  - Analytic Modeling
  - Empirical Modeling

- Device Classes

Additive Devices

- Displays
- Scanners
- Digital Cameras



Subtractive Devices

- Printers

Common Additive Device Models

- Gain-Offset-Gamma (GOG) Model

$$\{R',G',B'\} = Offset_{\{R,G,B\}} + (\{R,G,B\} * Gain_{\{R,G,B\}})^{\{R,G,B\}\ Gamma}$$

$$[X,Y,Z]^T = M \cdot [R',G',B']^T$$

- Where M is determined by least squares regression

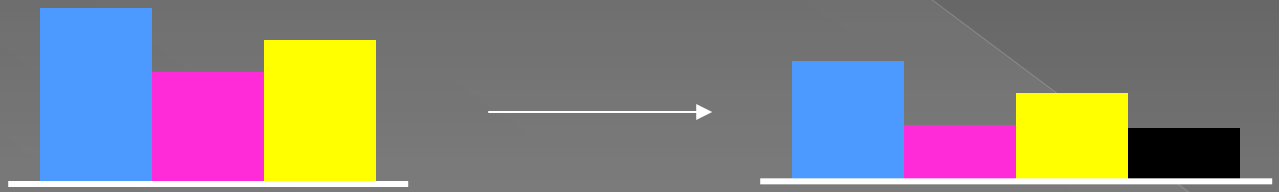
$M = (A^TA)^{-1}A^TB$ Linear Model

$M = (A^TWA)^{-1}A^TWB$ Weighted Linear Model

If higher order coefficients are used (R^2, G^2, B^2, RG, RB, GB, etc.) in A, a higher order polynomial model can be used.

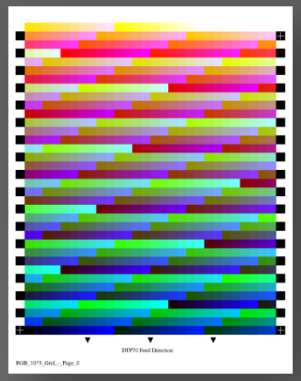
Sharma, Digital Color Imaging Handbook, CRC Press pp. 291-297

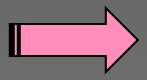
- Modeling Subtractive Devices
  - To address the full range of colors on a CMYK device would need 256^4 combinations, which is not practical
  - Build a CMY to CMYK transform called a color separation

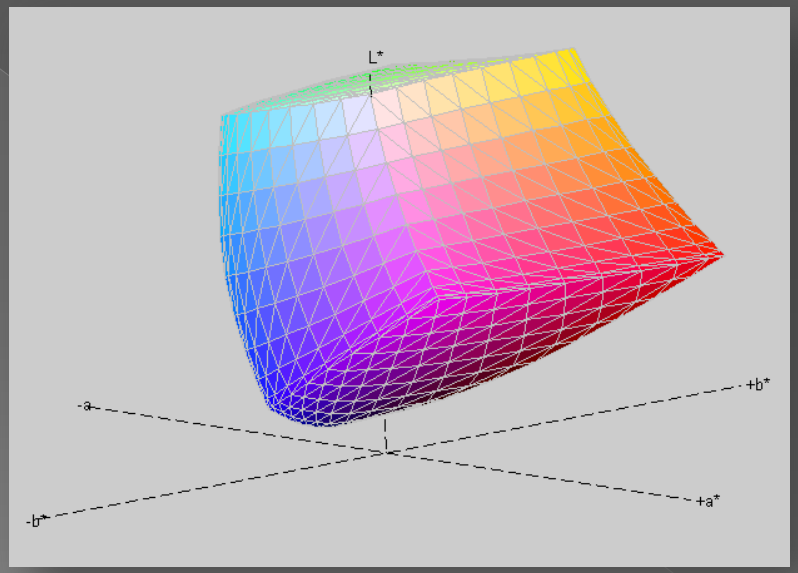


Many color separation schemes exist

Creation → Translation → Rendering → **Color Correction** → Marking Engine







3D Device Model

- Analytic Subtractive models

  Murray-Davies Equation
  Yule-Nielsen Modification
  Kubelka-Munk
  Neugebauer

  Many of these systems perform poorly for complex non-linear models (like printing)

- Murray Davies Equation

$$R(\lambda) = (1-a)R_W(\lambda) + aR_S(\lambda)$$ *where a is fractional area coverage ($0 \leq a \leq 1$)*

$$a = \frac{(R_W - R_N)}{(R_W - R_S)}$$

- Yule Nielsen Modification

$$[R(\lambda)]^{\frac{1}{n}} = (1-a)[R_W(\lambda)]^{\frac{1}{n}} + a[R_S(\lambda)]^{\frac{1}{n}}$$

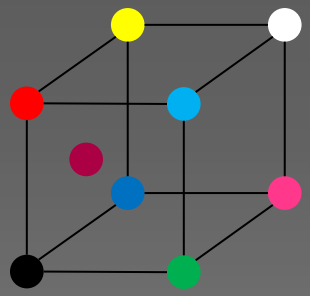
The KM and Y-N equations are very simple, single colorant models that attempt to model halftoned response

Sharma, Digital Color Imaging Handbook, CRC Press pp. 220-228

Neugebauer Equations

- The Spectral Neugebauer model extends to multiple colorants

$$R(\lambda) = \sum_{j=1}^{m} a_j R_j(\lambda)$$



Where m = 2^n colorants

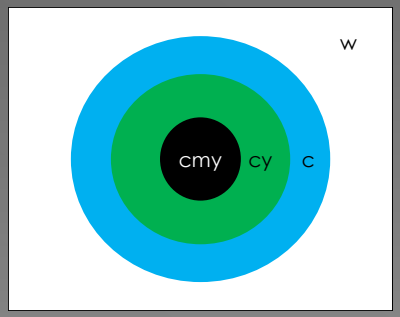
$R_j(\lambda)$ = Spectral reflectance of Neugebauer primary

- The colorant weighting factors (a_j) are computed based on the halftone printing model used

Dot on Dot

Colorants sorted in order of area coverage

White	$a_1 = 1 - c$
1 color	$a_2 = c - y$
2 color	$a_3 = y - m$
3 color	$a_4 = m$



Rotated Screen

Using the Demichel equations, the fractional area coverages are calculated

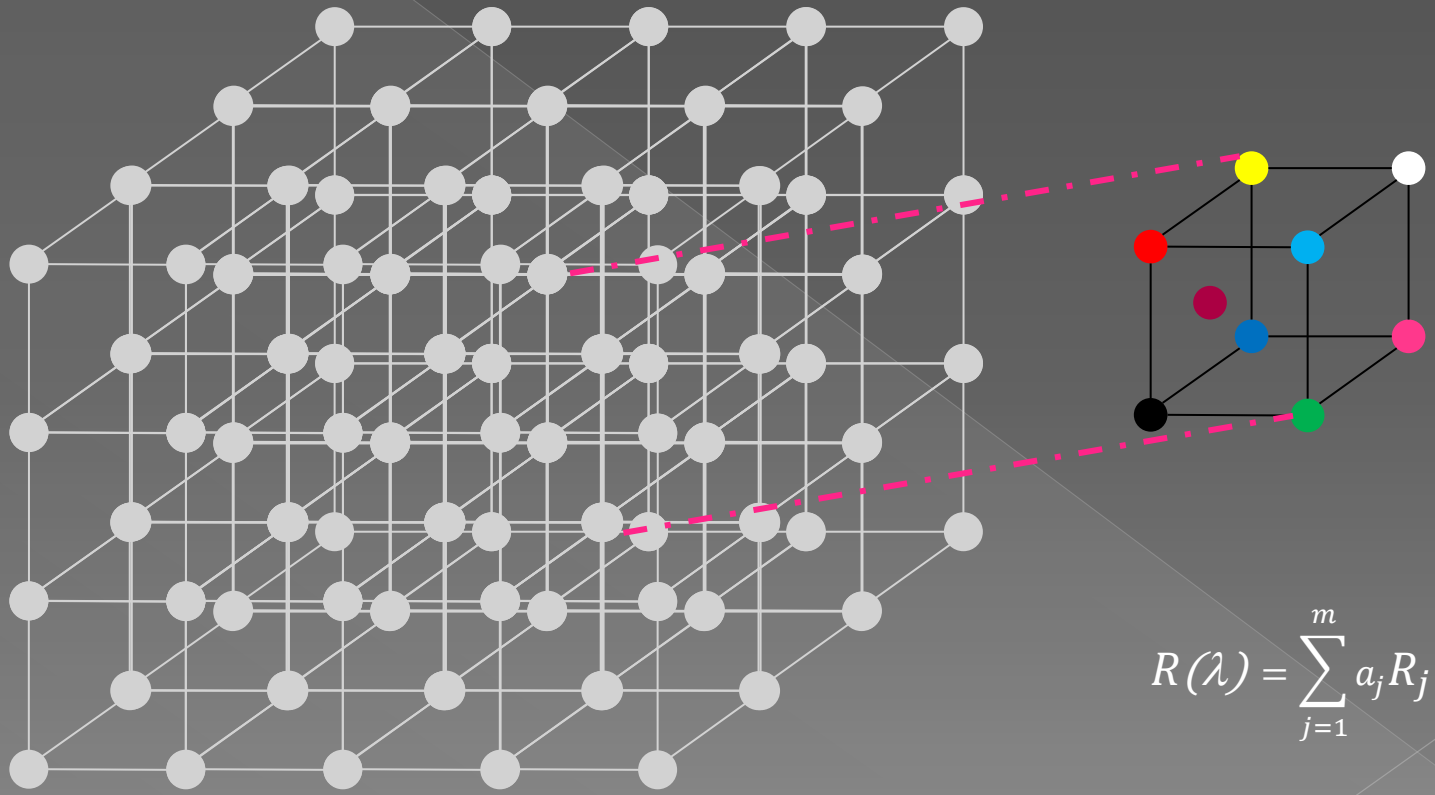
White	$a_1 = (1-c)(1-m)(1-y)$
Cyan	$a_2 = c(1-m)(1-y)$
Magenta	$a_3 = m(1-c)(1-y)$
Yellow	$a_4 = y(1-c)(1-m)$
Red	$a_5 = my(1-c)$
Green	$a_6 = cy(1-m)$
Blue	$a_7 = cm(1-y)$
Black	$a_8 = cmy$

Sharma, Digital Color Imaging Handbook, CRC Press pp. 344-347

- Empirical Device models

  Cellular Neugebauer (Hybrid)
  Tetrahedral
  Tri-Linear
  Prism
  Pyramid

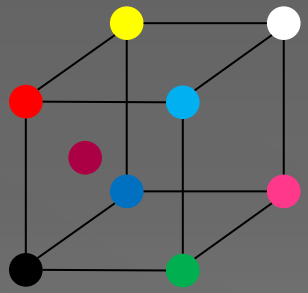
Cellular Neugebauer

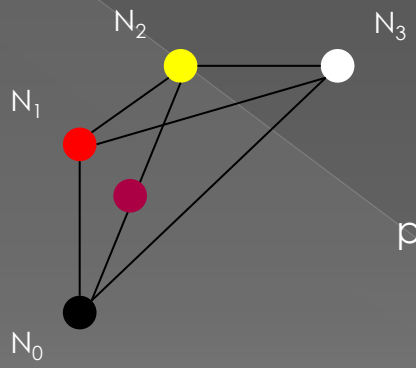


$$R(\lambda) = \sum_{j=1}^{m} a_j R_j(\lambda)$$

Sharma, Digital Color Imaging Handbook, CRC Press pp. 352-354

Tetrahedral Interpolation



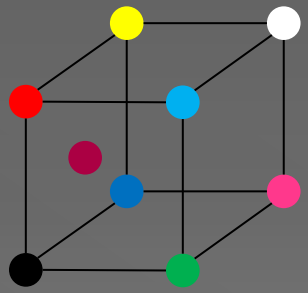


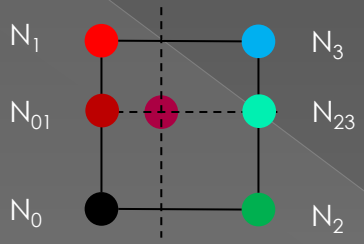
$$p(x,y,z) = N_0 + W_1(N_1-N_0) + W_2(N_2-N_0) + W_3(N_3-N_0)$$

Each interpolation methods has its strengths and weaknesses

Color Technology for Electronic Imaging Devices, Henry R. Kang, SPIE Press, 1997

Tri-linear Interpolation





$$N_{01} = N_0 + W_1(N_1 - N_0)$$
$$N_{23} = N_2 + W_1(N_3 - N_2)$$

$$p(x,y) = N_{01} + W_2(N_{23} - N_{01})$$

In 2 Dimensions (bi-linear)

Weights W_1 and W_2 are the relative distanced between the nodes
Each interpolation methods has its strengths and weaknesses

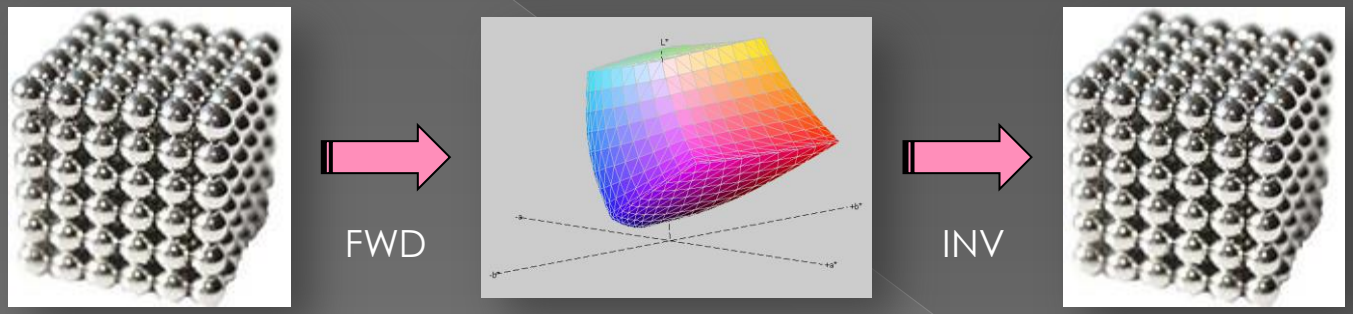
Color Technology for Electronic Imaging Devices, Henry R. Kang, SPIE Press, 1997

- Interpolation Summary

Method	Strengths	Weaknesses
Cellular Neugebauer	Very accurate multi-dimensional model	Complexity grows quickly as # dimensions increases
Tetrahedral	Preserves color balance for neutral axis interpolation	Identifying tetrahedron is computationally expensive
Tri-Linear	Cannot guarantee neutral axis preservation across diagonal	Computationally efficient

Color Table Inversion

- One must be able to "round-trip" with a high degree of accuracy



- The process of building the inverse map is non-trivial, with many-to-one mappings possible

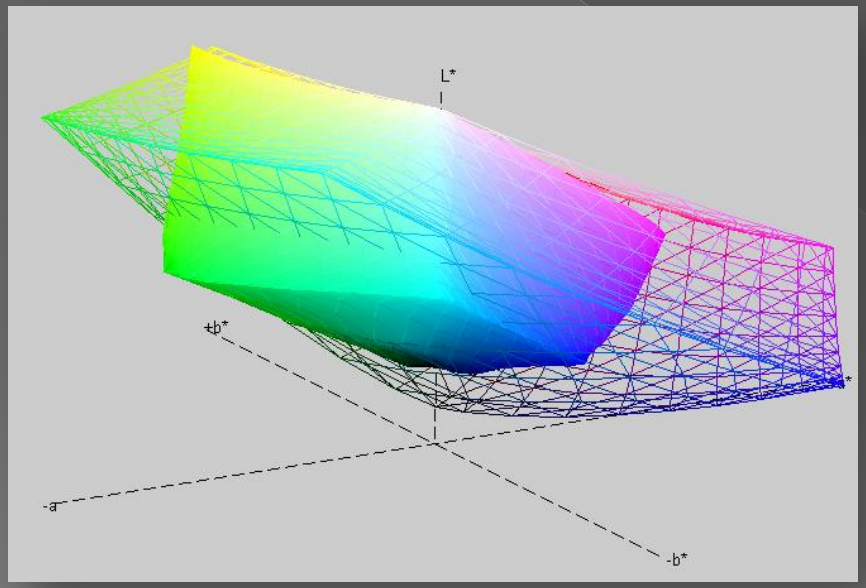
- Common methods : "Brute force" tetrahedral inversion
  Thin-plate splines

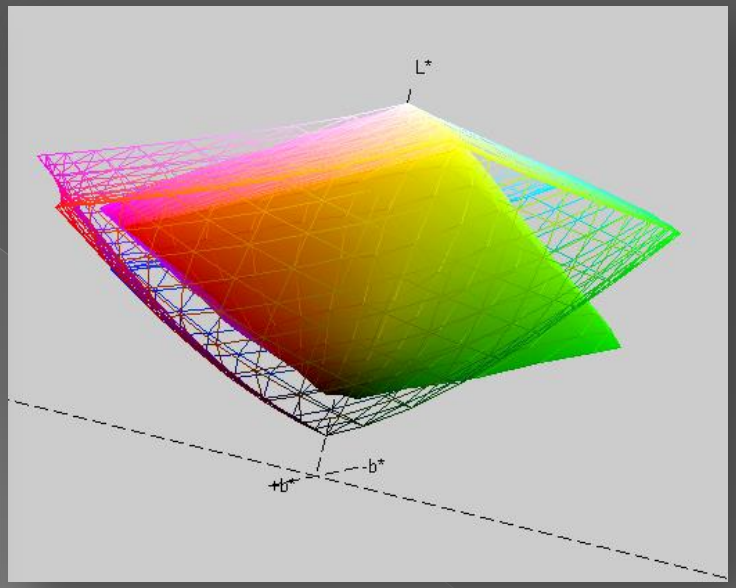
Color Technology for Electronic Imaging Devices, Henry R. Kang, SPIE Press, 1997

Gamut Mapping

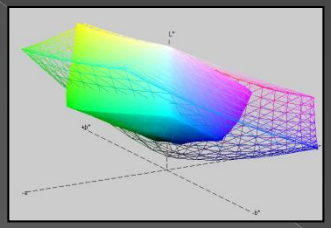
- Attempting to fit the color gamut of one device into another devices gamut
- Color appearance models are used to help preserve appearance attributes
- Different GM algorithms trade the errors in Lightness, Chroma and Hue differently
- Overall objective is to render a pleasant reproduction

- Comparing Device Gamut's



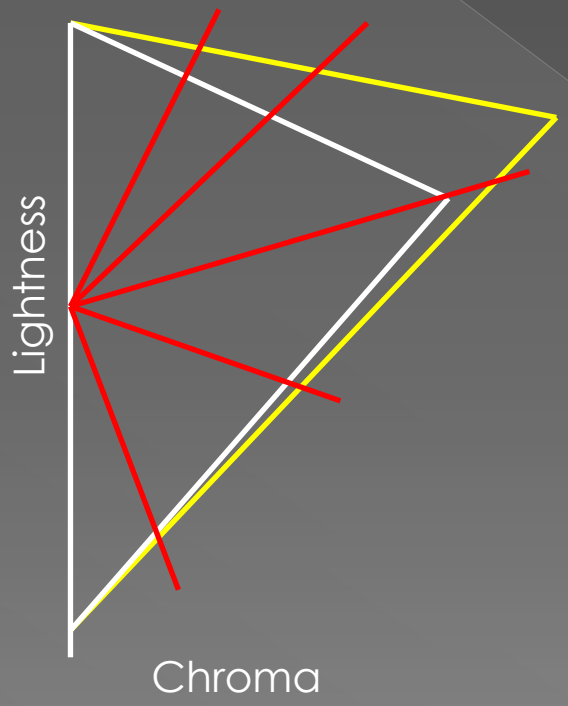


The process of mapping colors from one device to another - ***Gamut Mapping***



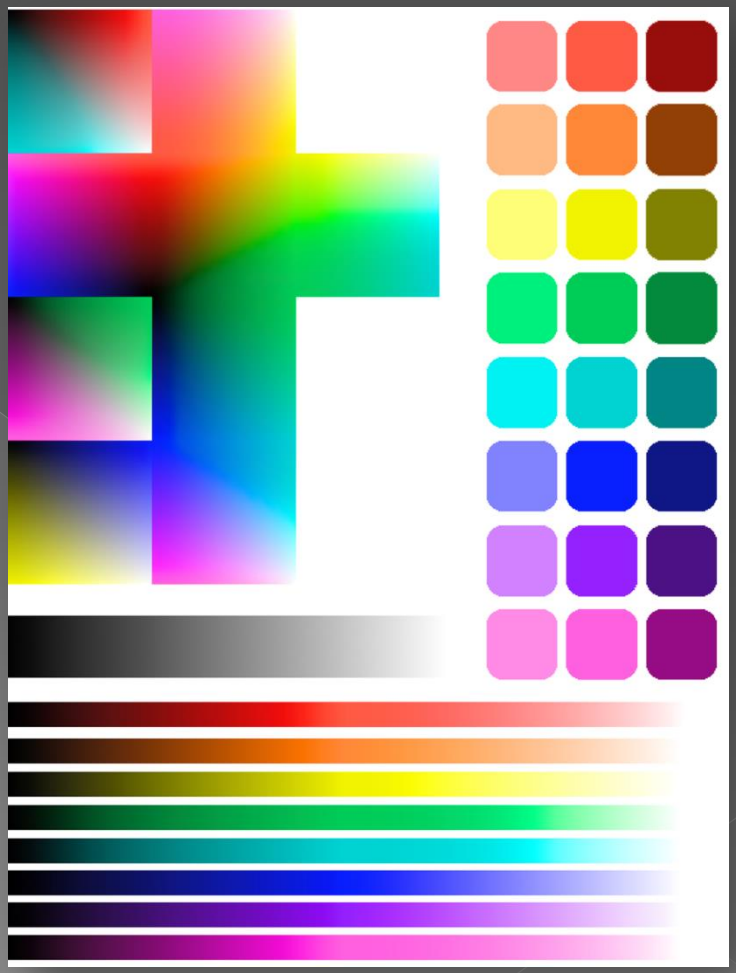
Creation → Translation → Rendering → **Color Correction** → Marking Engine

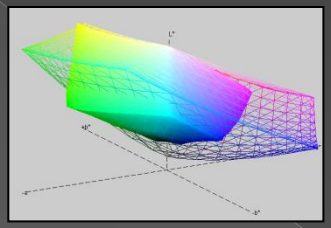
- Centroid



Source Gamut

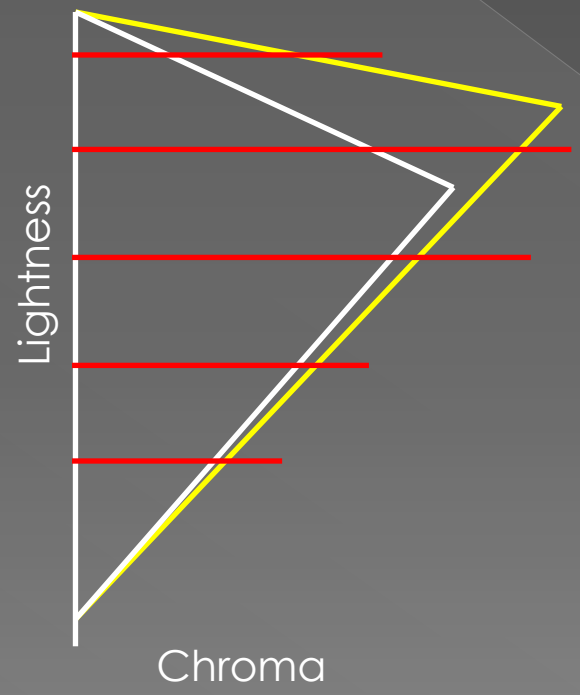
Destination Gamut





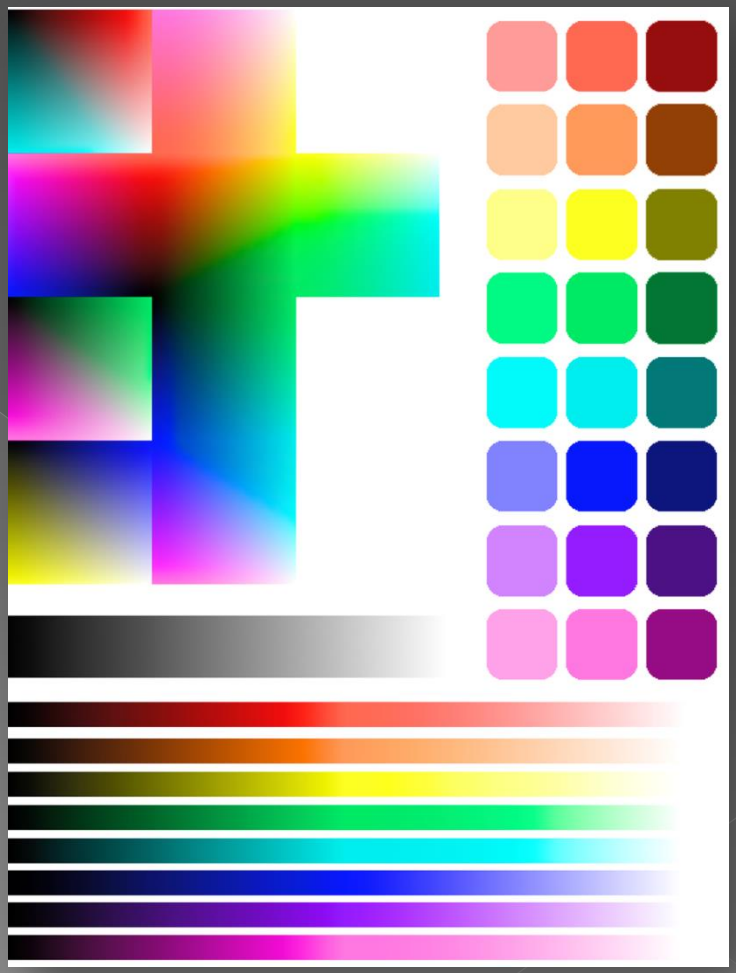
Creation → Translation → Rendering → **Color Correction** → Marking Engine

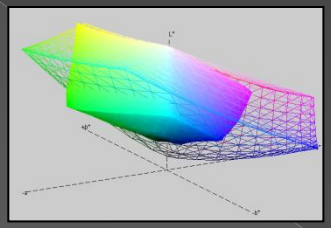
- Constant L*



Source Gamut

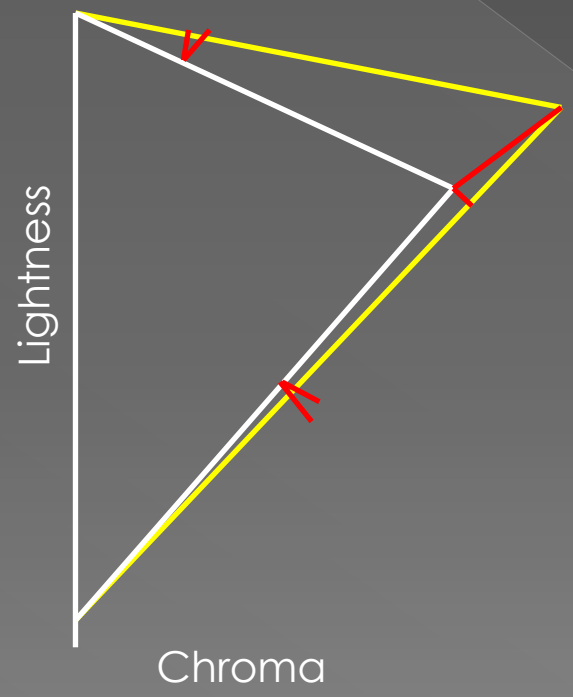
Destination Gamut





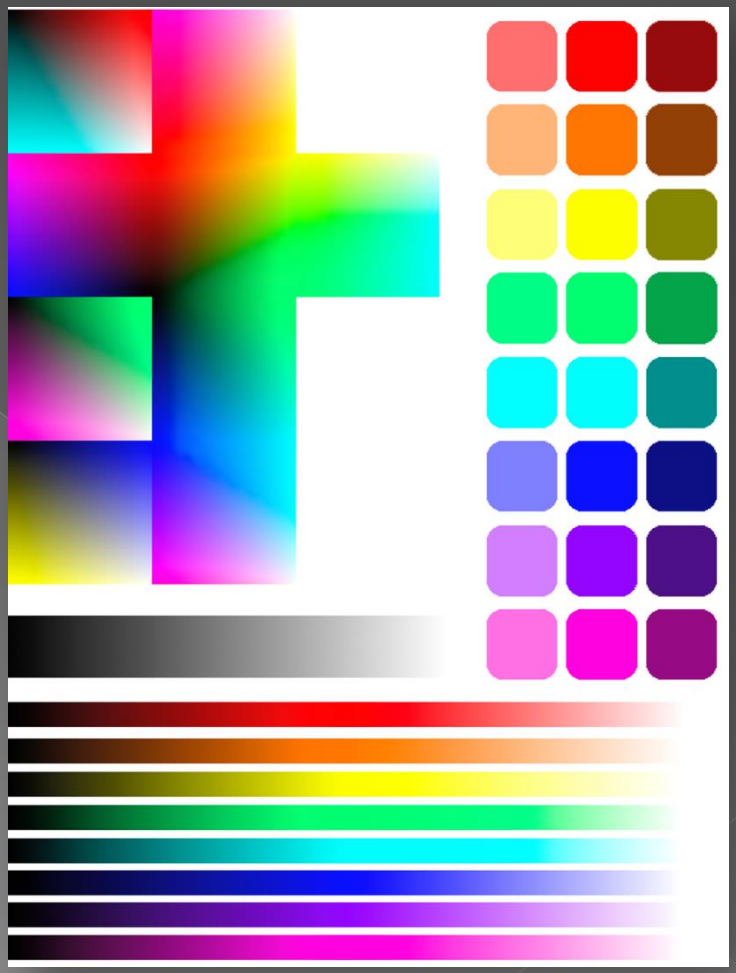
Creation → Translation → Rendering → **Color Correction** → Marking Engine

- Min DE



Source Gamut

Destination Gamut



Centroid

Constant L*

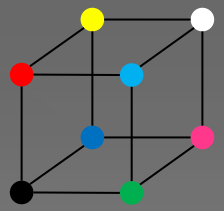
Min DE

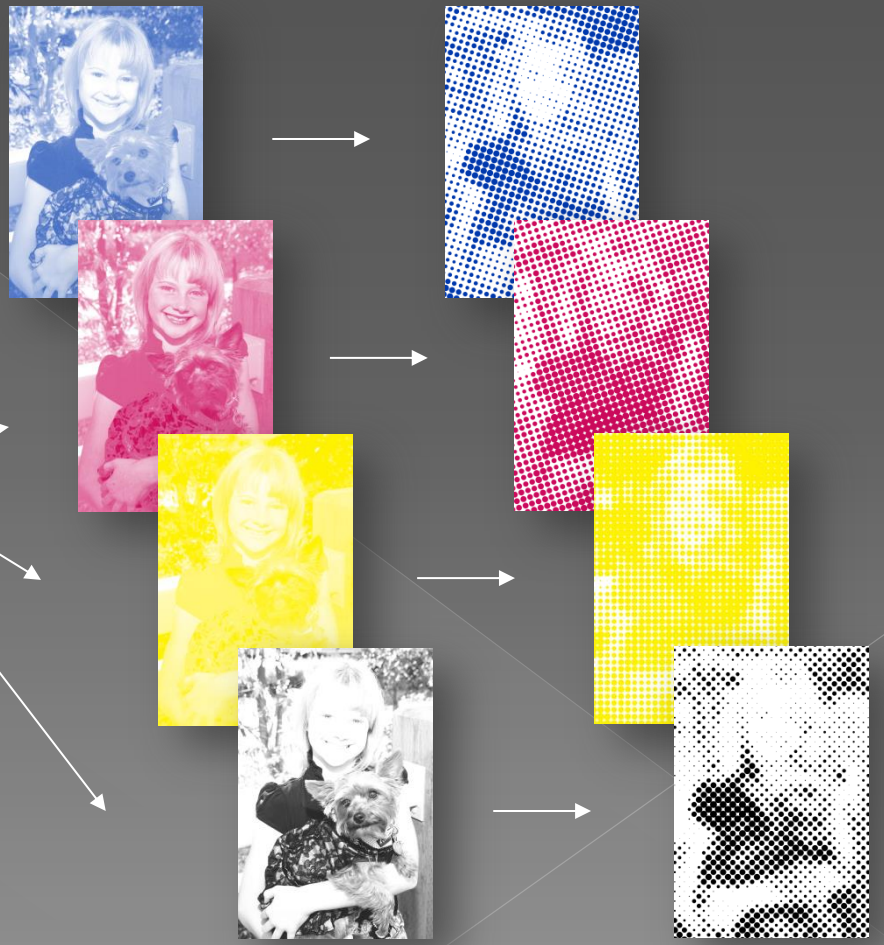
Color Separation

Halftoning and edge control

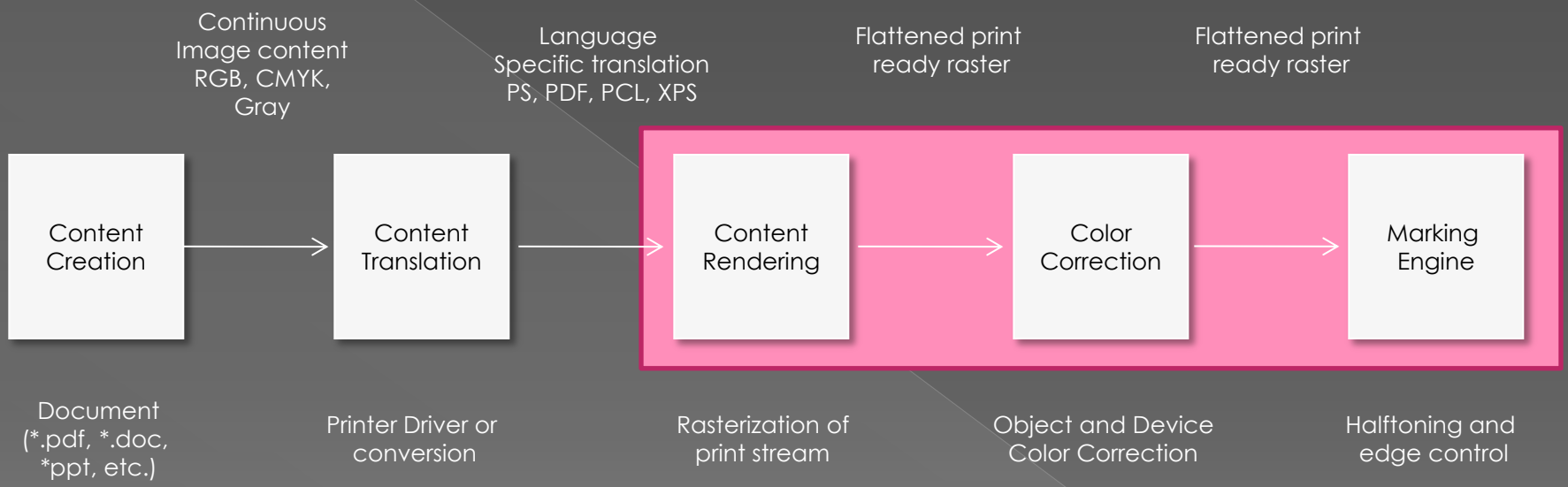
Rendering

Color Management





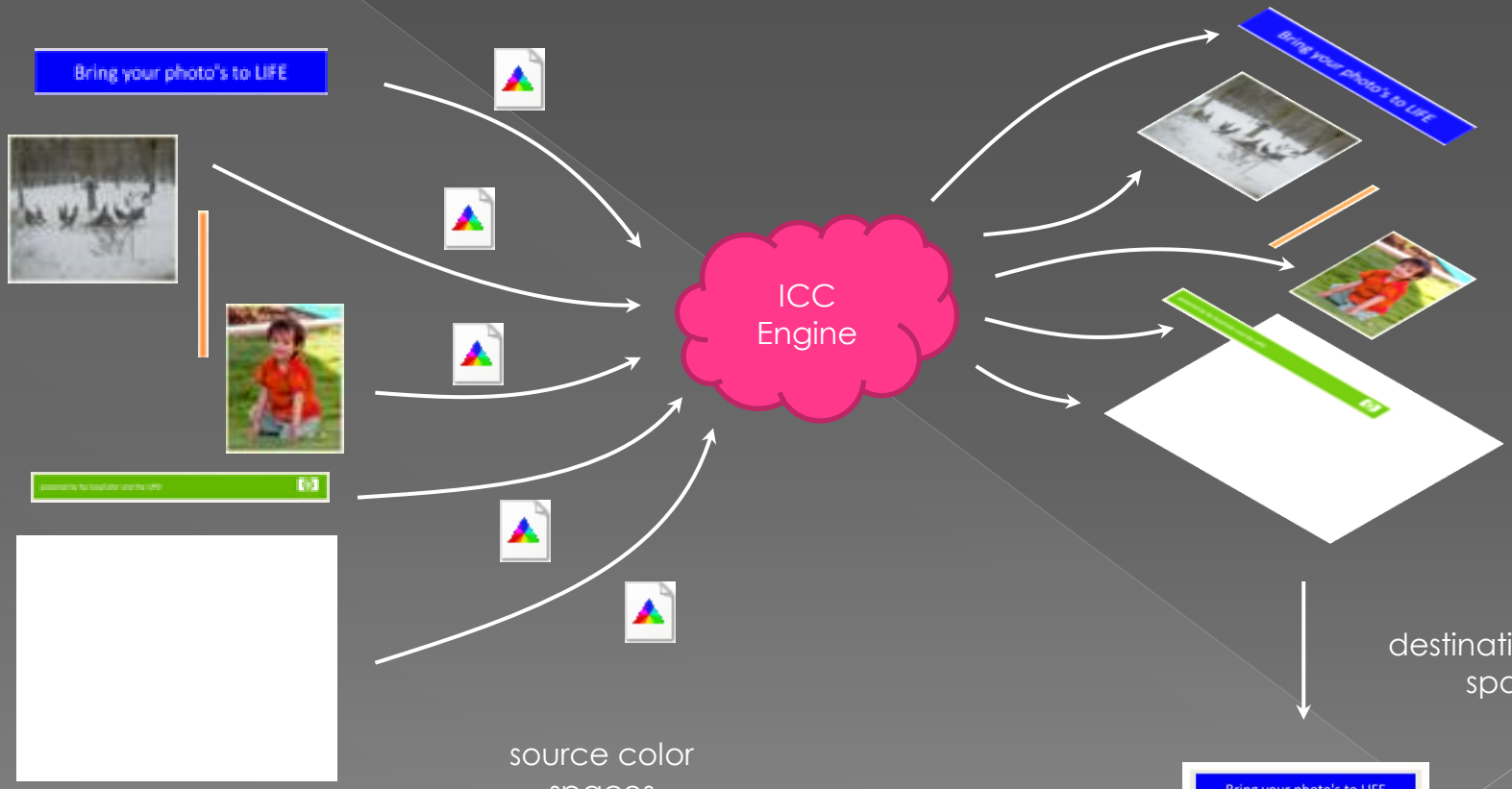
Embedded Systems



Summary

- End-to-end document imaging workflow
- Content Creation
- Document Translation
- Rendering Stream
- Color Management
- Device Modeling
- Gamut Mapping

Creation → Translation → Rendering → Color Correction → Marking Engine

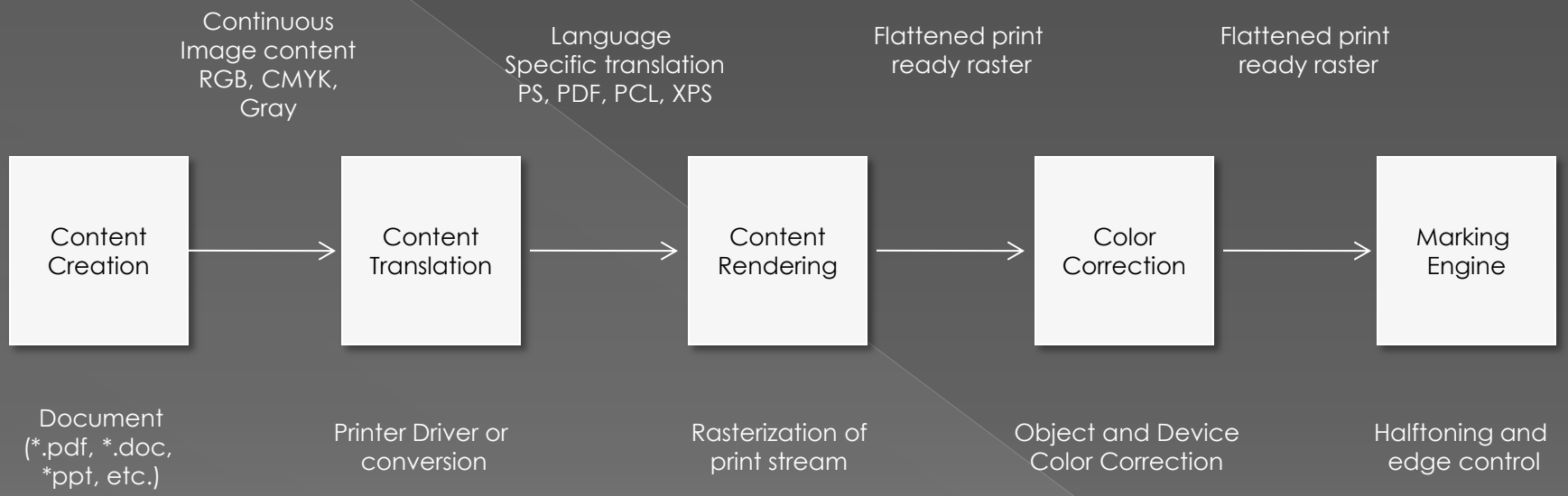


source color spaces

sRGB, Adobe RGB, etc

destination color space

Summary


Continuous Image content RGB, CMYK, Gray
Language Specific translation PS, PDF, PCL, XPS
Flattened print ready raster
Flattened print ready raster
Content Creation
Content Translation
Content Rendering
Color Correction
Marking Engine
Document (*.pdf, *.doc, *ppt, etc.)
Printer Driver or conversion
Rasterization of print stream
Object and Device Color Correction
Halftoning and edge control

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