Retargeting Color Content: Color Issues in Tone Mapping

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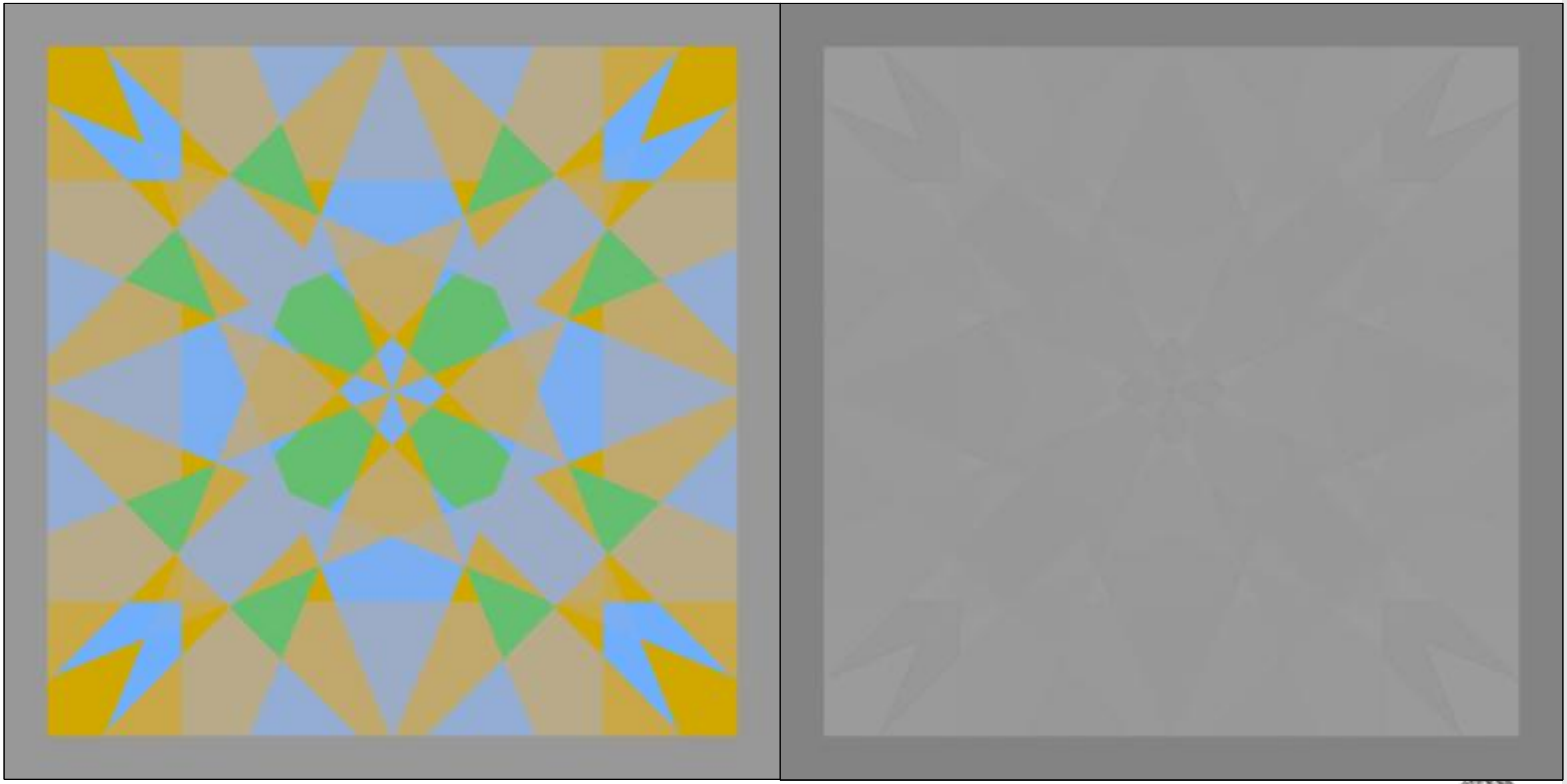
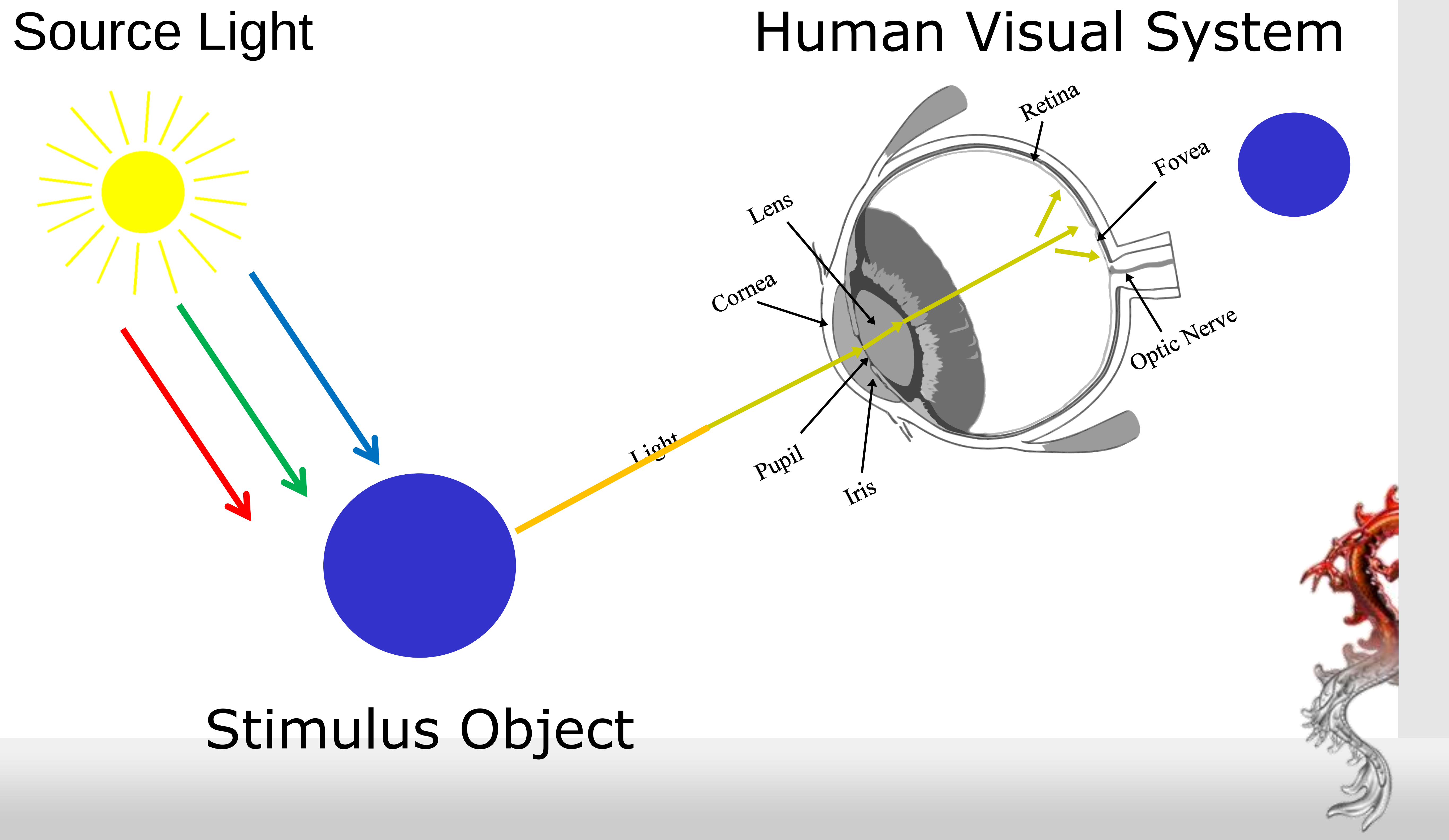
Introduction to Color



What is Color?



Quantifying Color

$I(\lambda)$ SPD of the light

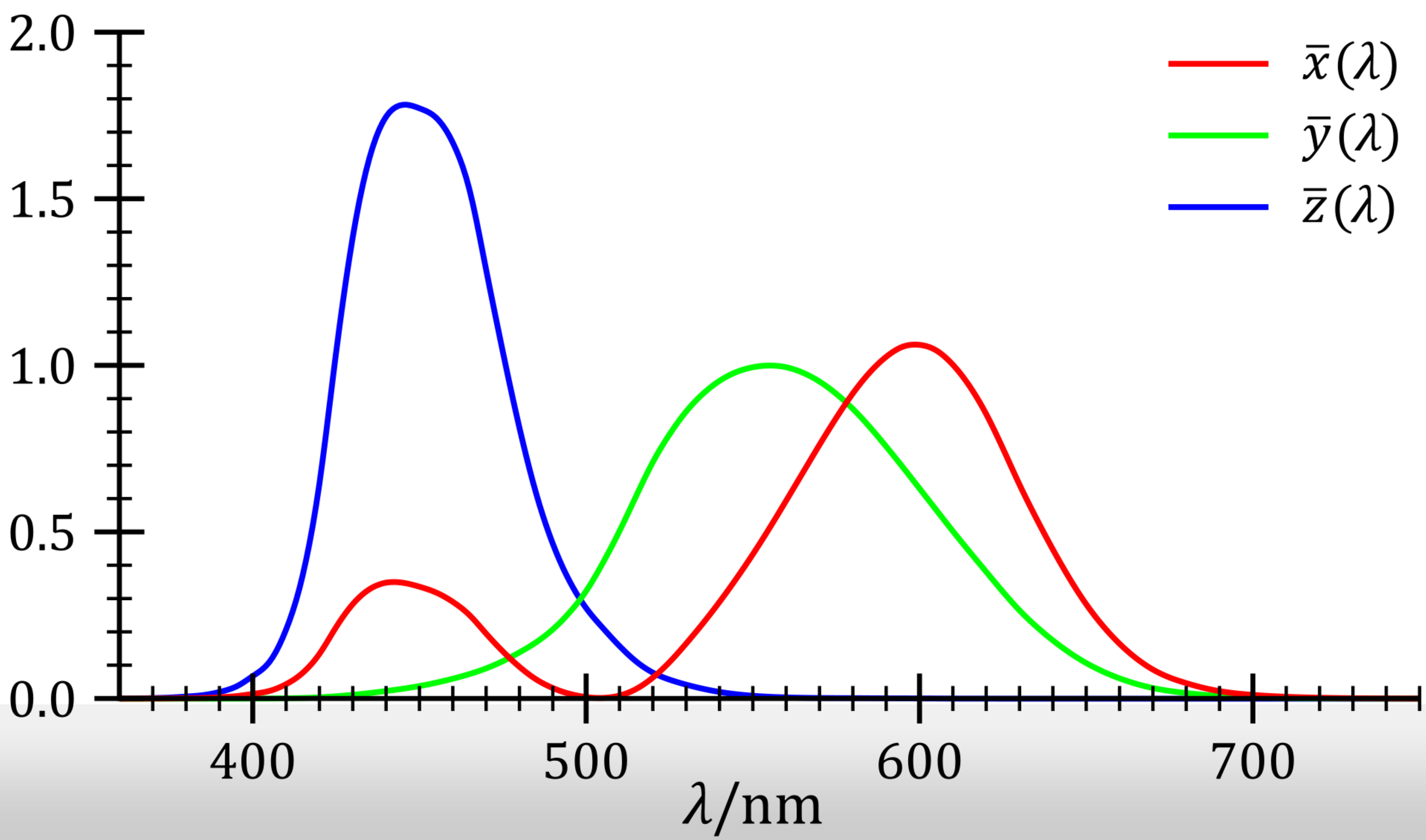
$\rho(\lambda)$ Reflectance of the object

$\bar{x}, \bar{y}, \bar{z}(\lambda)$ CIE color matching functions

$$X = \int_0^\infty I(\lambda)\rho(\lambda)\bar{x}(\lambda)d\lambda$$

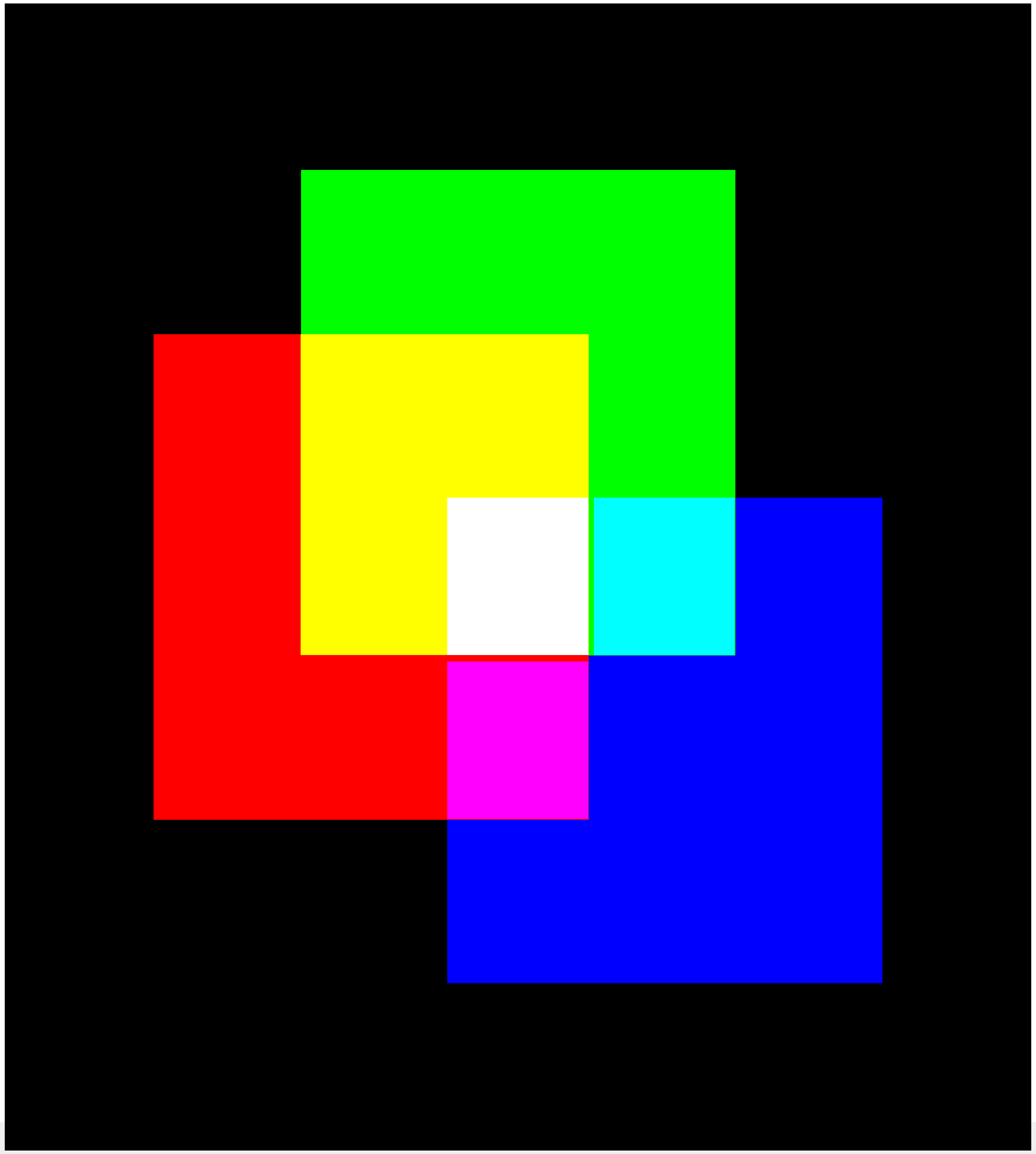
$$Y = \int_0^\infty I(\lambda)\rho(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int_0^\infty I(\lambda)\rho(\lambda)\bar{z}(\lambda)d\lambda$$



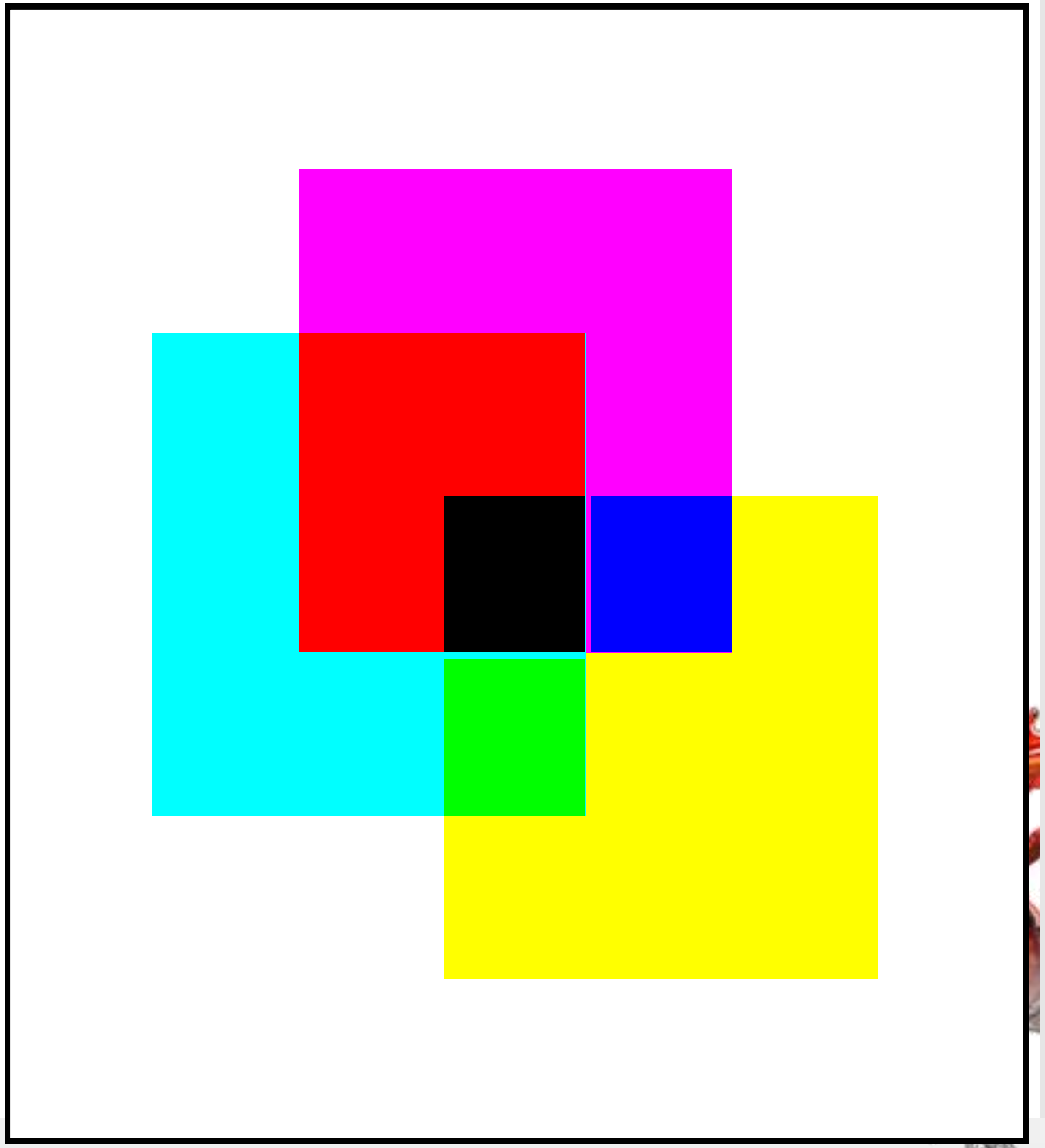
How Color is Produced?

Additive



(a)

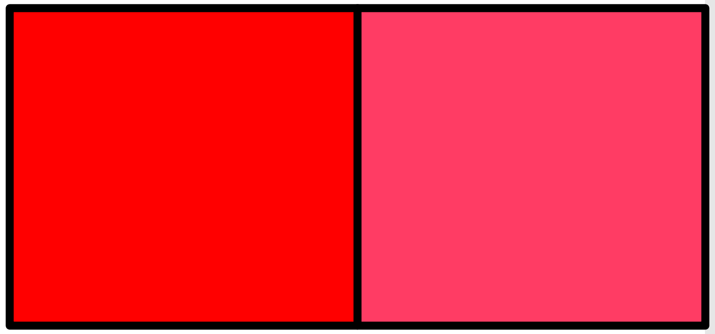
Subtractive



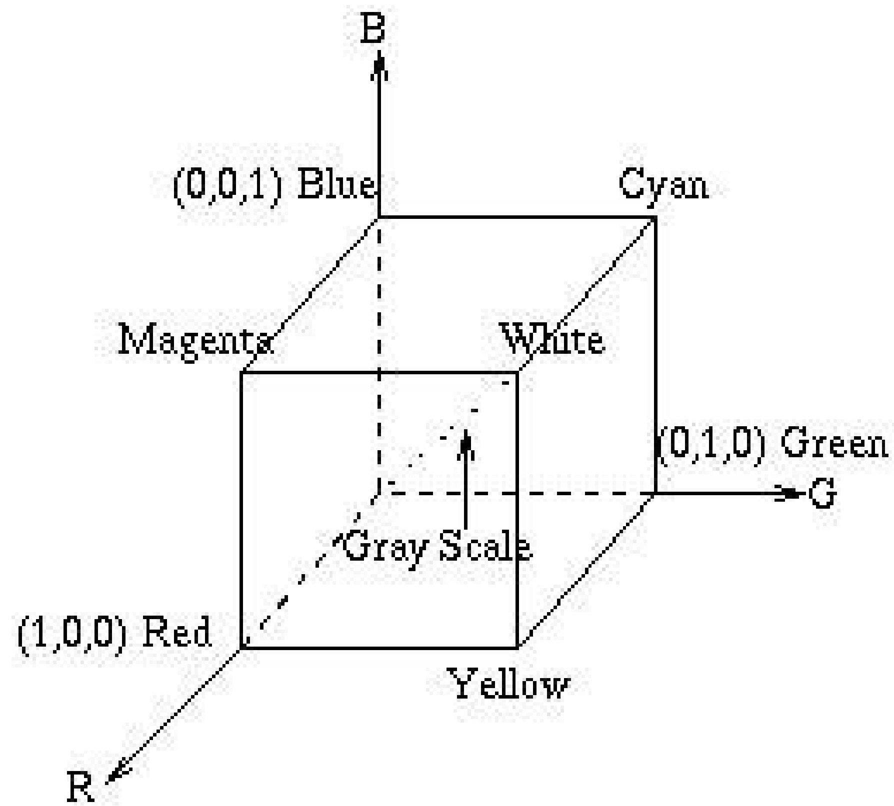
(b)

Color Space

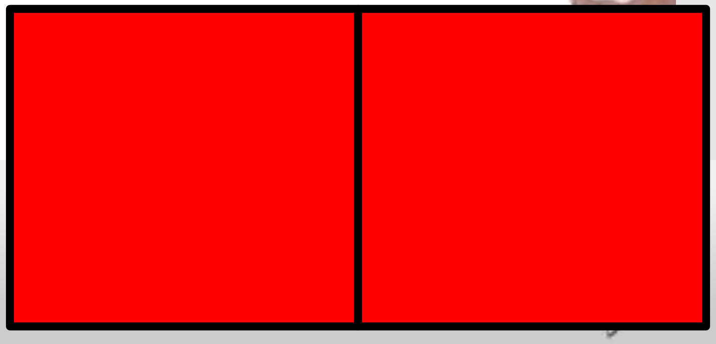
- Device dependent: the description of color information is related to the characteristics of a particular device



  - Set of primaries
  - Technology



- Device independent: the description of color information is not dependent from the characteristics of a particular device
  - CIEXYZ, CIELab, CIELuv etc...

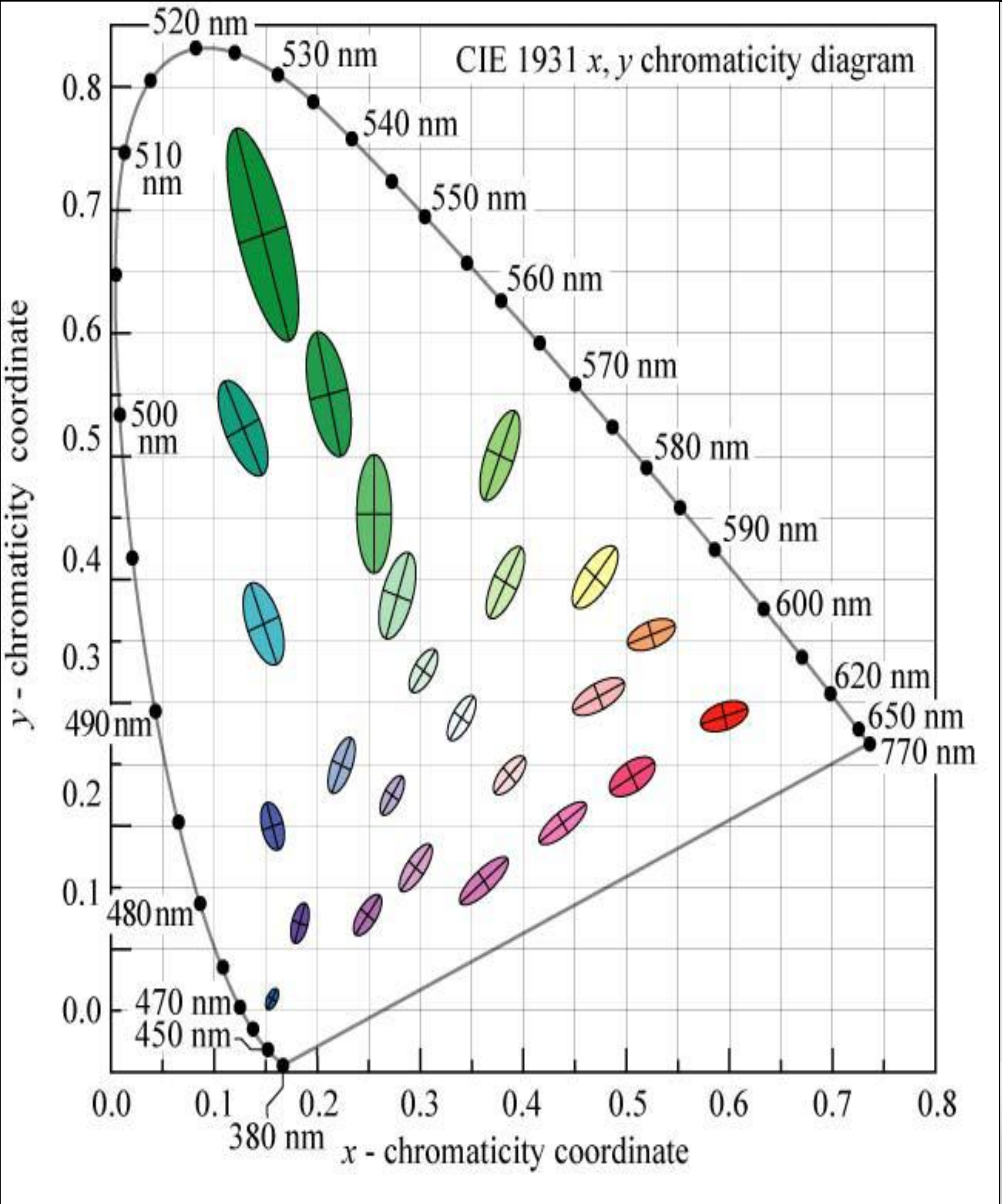


Chromaticity Diagram and MacAdam's Ellipses

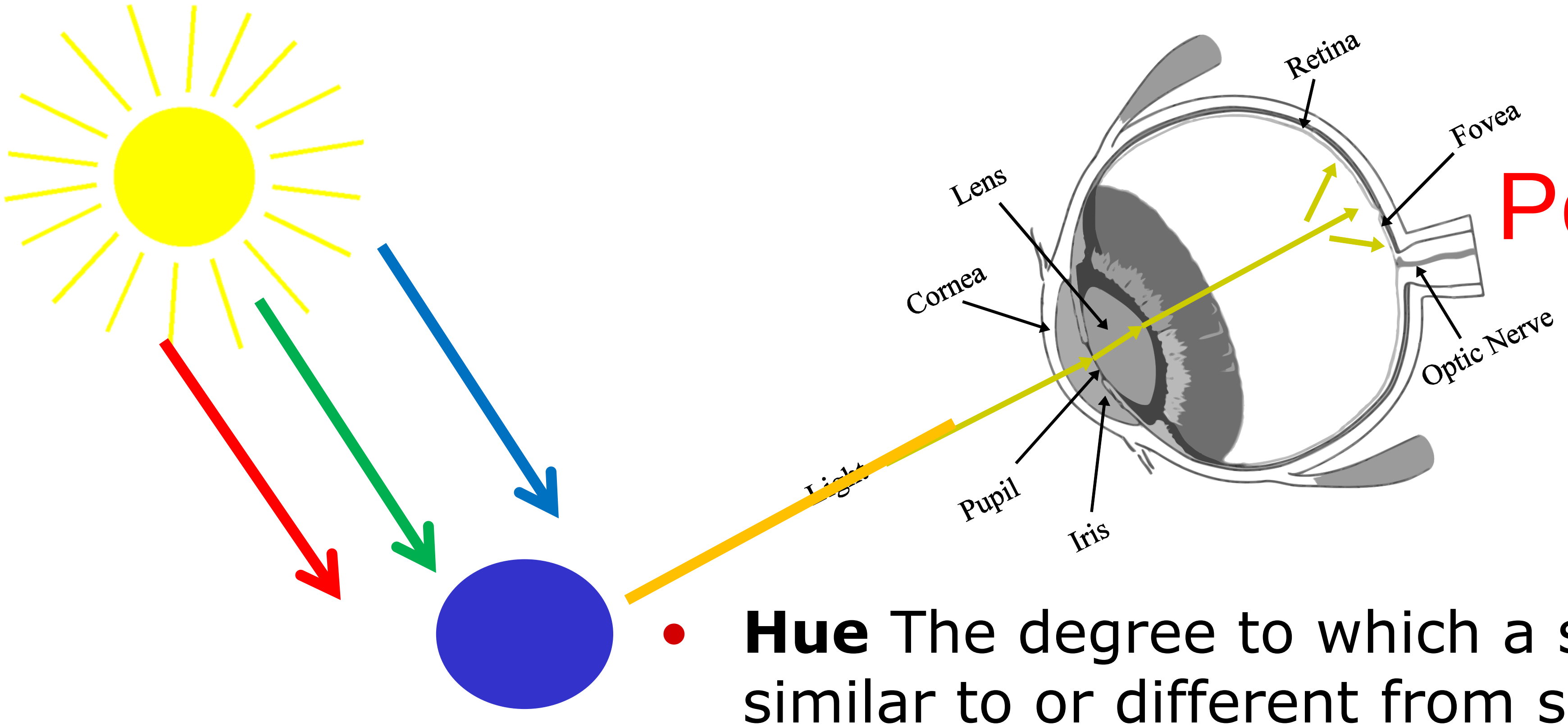
- **MacAdam's Ellipses**
  - contains all colors which are indistinguishable to an human observer from the color at the center of the ellipse
  - the contour of the ellipse represents the just noticeable differences of chromaticity

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$



Color Attributes by the CIE



Perception

- **Hue**
- **Saturation**
- **Lightness**

- **Hue** The degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow.
- **Saturation** is the colorfulness of an area judged in proportion to its brightness.
- **Lightness** Human vision has a nonlinear perceptual response to luminance: The perceptual response to luminance is called lightness.

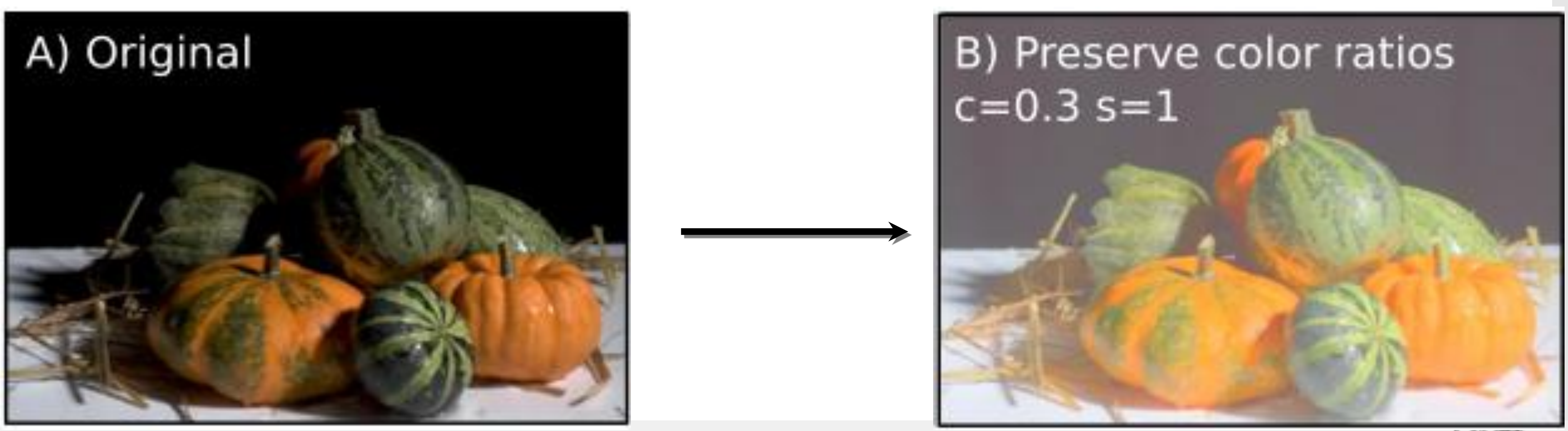
$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 \qquad 0.008856 < \frac{Y}{Y_n}$$

Color in High Dynamic Range

- Color Ratio (Schlick 1994)

$$RGB_{out} = \frac{RGB_{in}}{L_{in}} L_{out}$$

RGB_{in}	Color Input
RGB_{out}	Color Output
L_{in}	Luminance Input
L_{out}	Luminance Output



Mantiuk et al.. “Color Correction for Tone Mapping”, Proceedings Eurographics 2009.

Color in High Dynamic Range

- Saturation Control (Thumblin and Turk 1999)

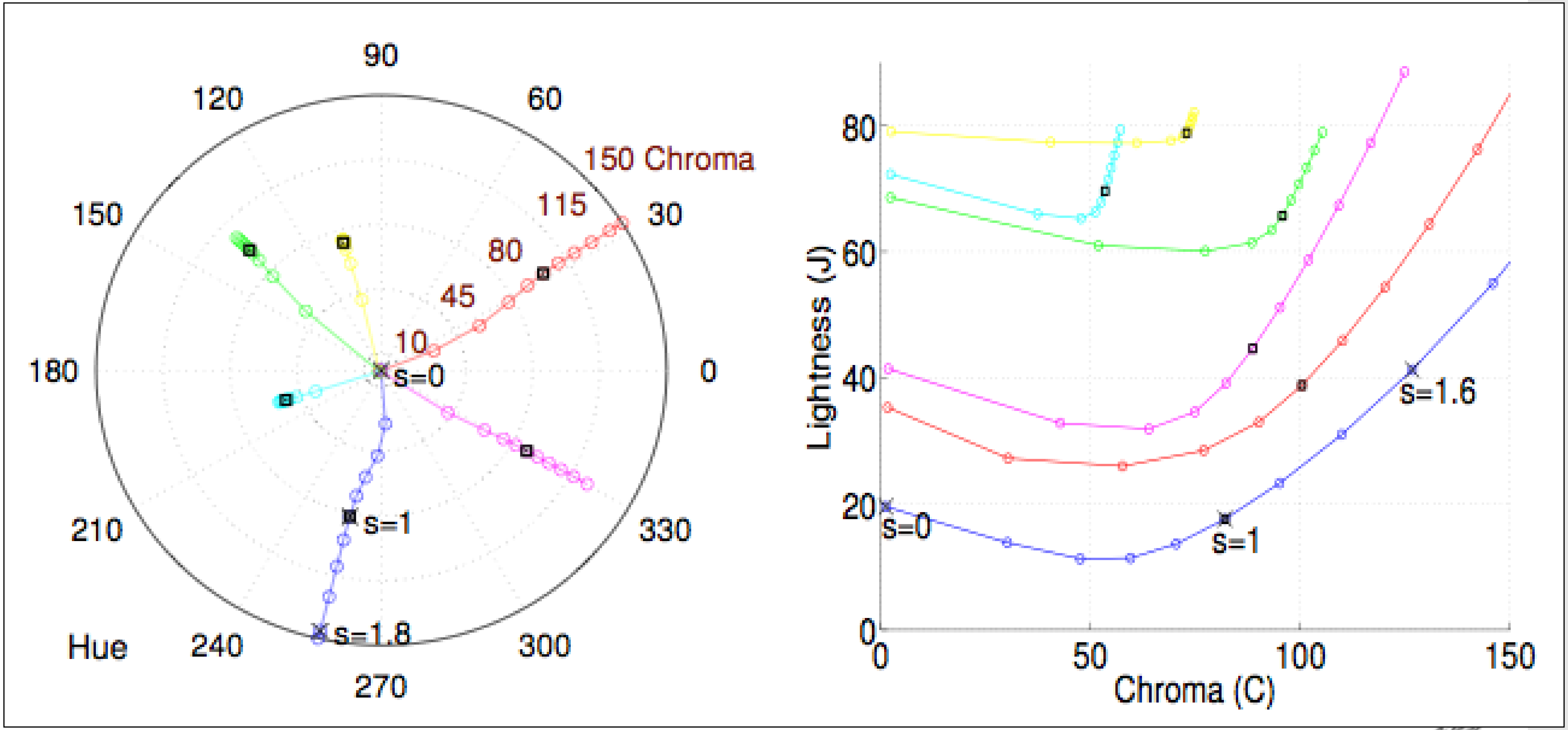
$$RGB_{out} = \left(\frac{RGB_{in}}{L_{in}} \right)^{s} L_{out}$$

s Saturation Parameter
c Contrast Compression

Under-saturated colors for S=C.

Mantiuk et al.. “Color Correction for Tone Mapping”, Proceedings Eurographics 2009.

Color in High Dynamic Range



Mantiuk et al.. “Color Correction for Tone Mapping”, Proceedings Eurographics 2009.

Color Rendering Pipeline (8 Bit)

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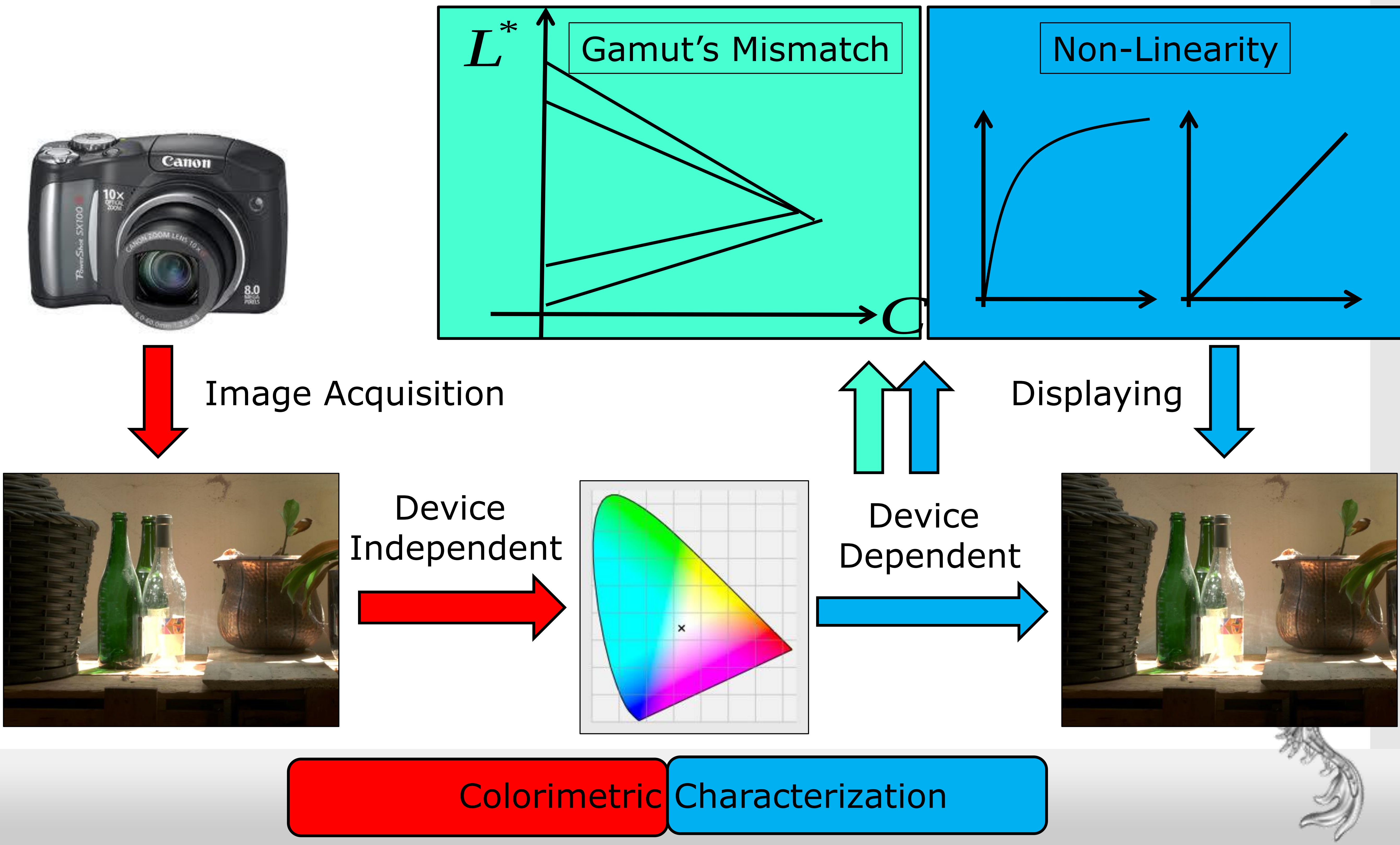


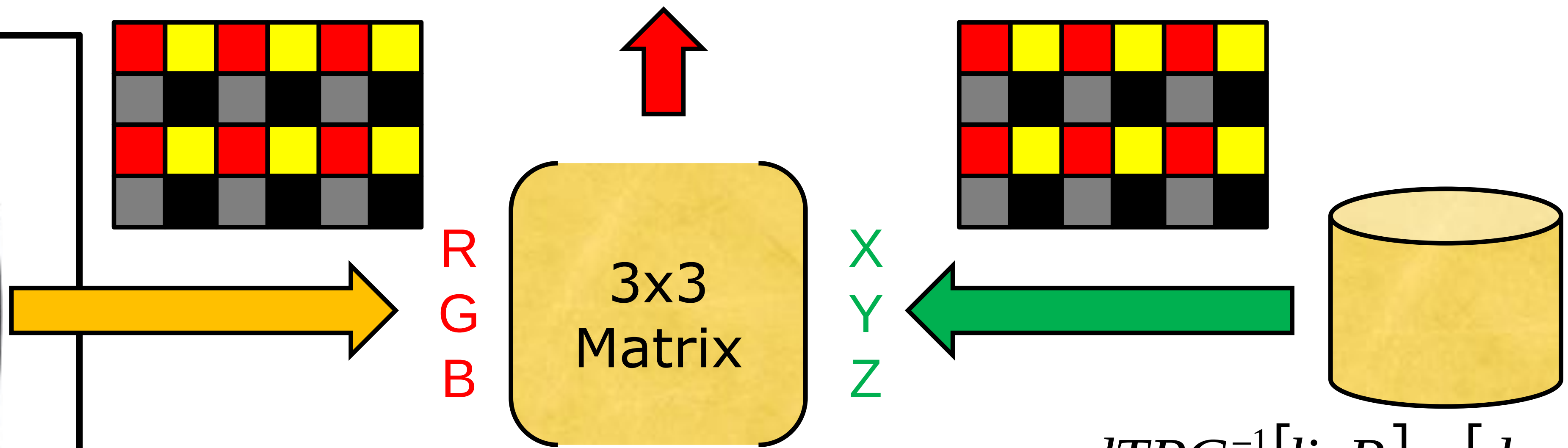
Colorimetric Characterisation of a Device

Device

Minimisation Process

Spectrophotometer

RAW Data are Linear

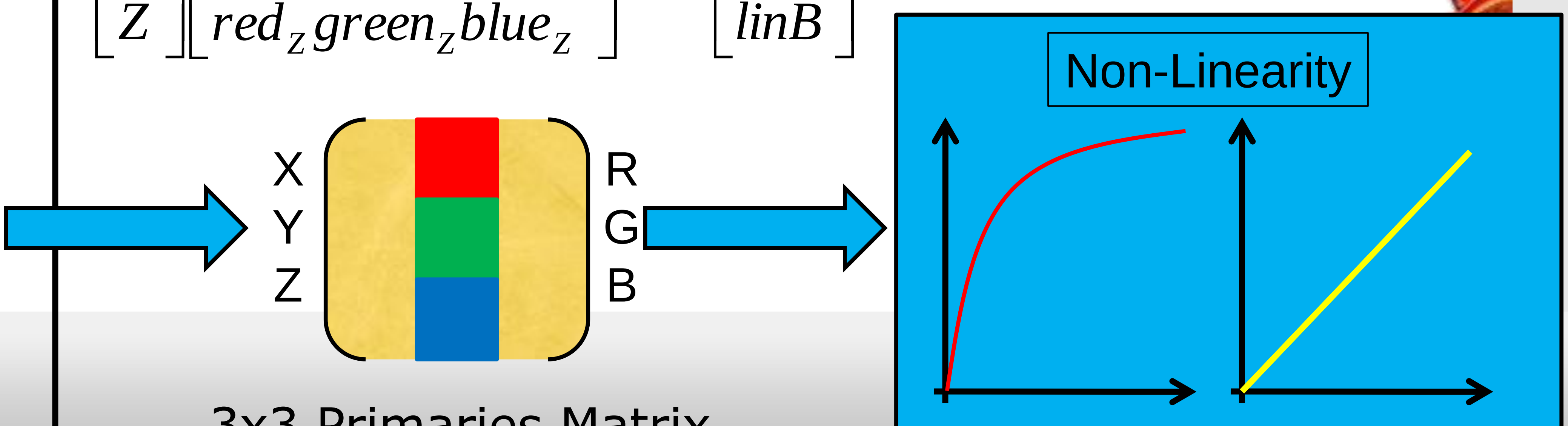


$$redTRC^{-1}[linR] = [deviceR]$$

$$greenTRC^{-1}[linG] = [deviceG]$$

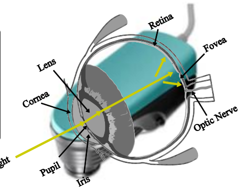
$$blueTRC^{-1}[linB] = [deviceB]$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \begin{bmatrix} red_X\, green_X\, blue_X \\ red_Y\, green_Y\, blue_Y \\ red_Z\, green_Z\, blue_Z \end{bmatrix}^{-1} = \begin{bmatrix} linR \\ linG \\ linB \end{bmatrix}$$



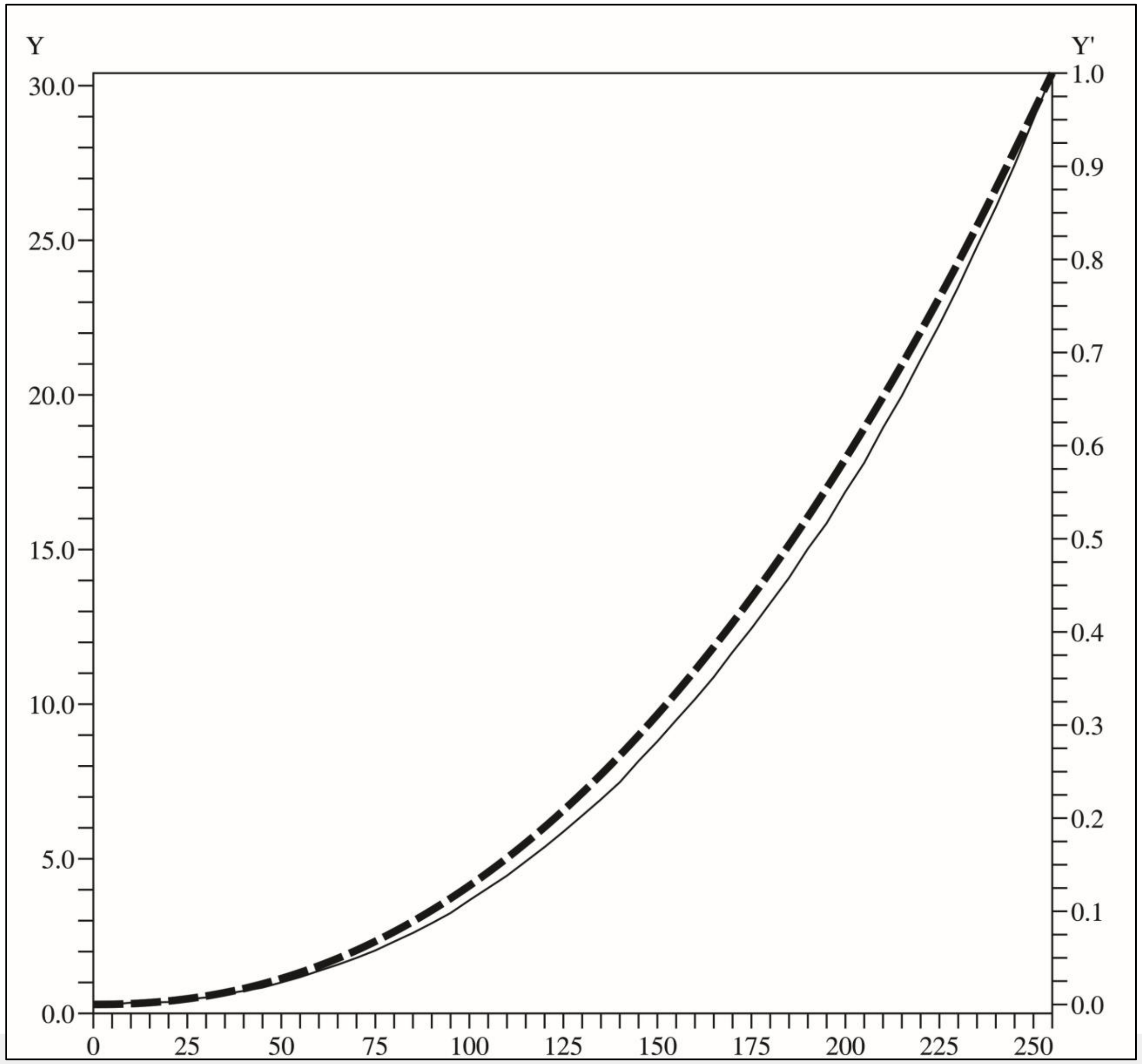
3x3 Primaries Matrix

Gamma – Curve

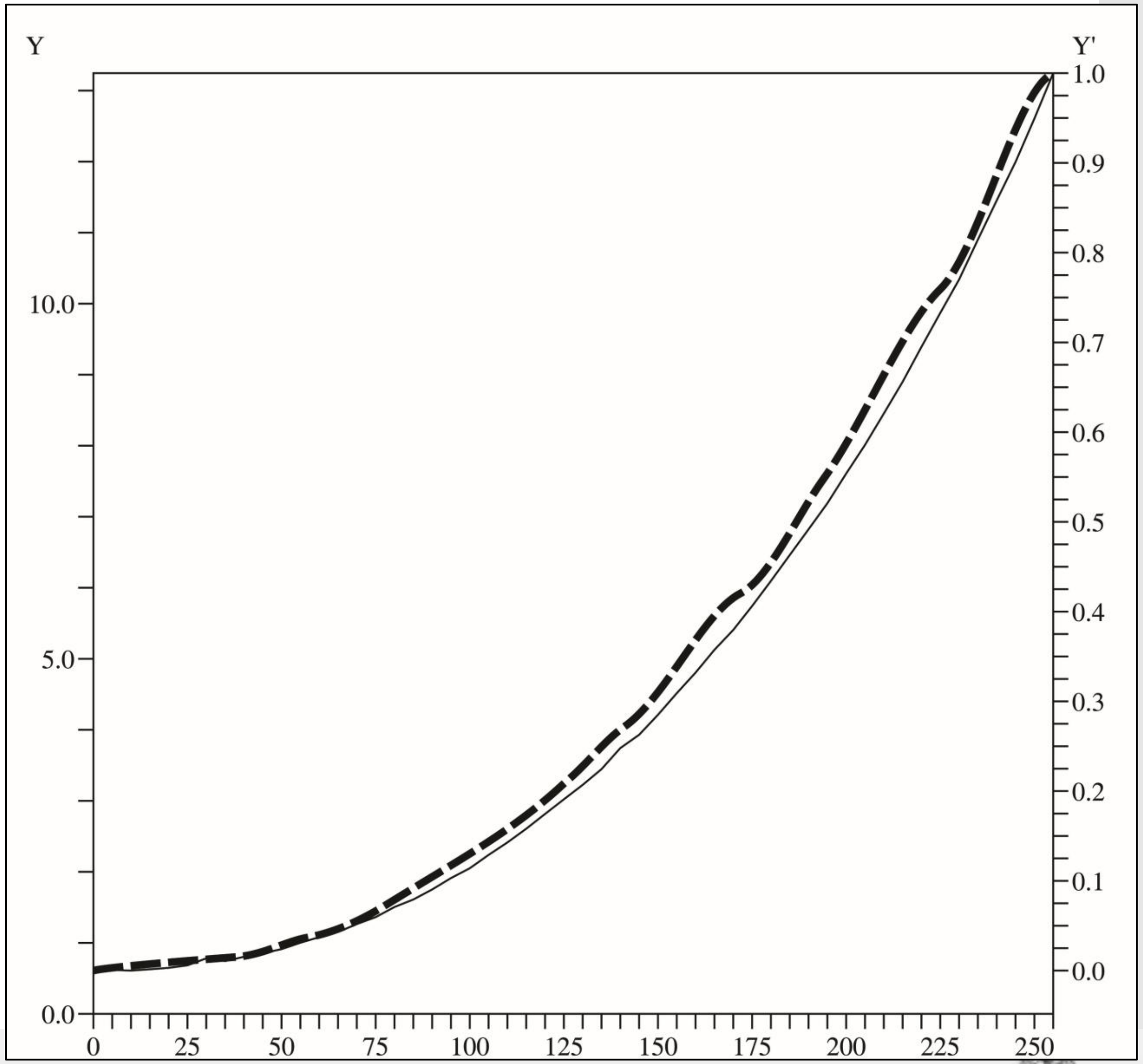


$$R(d_i) = ((1-b)d_i + b)^{\gamma}$$

Gamma Response for RED

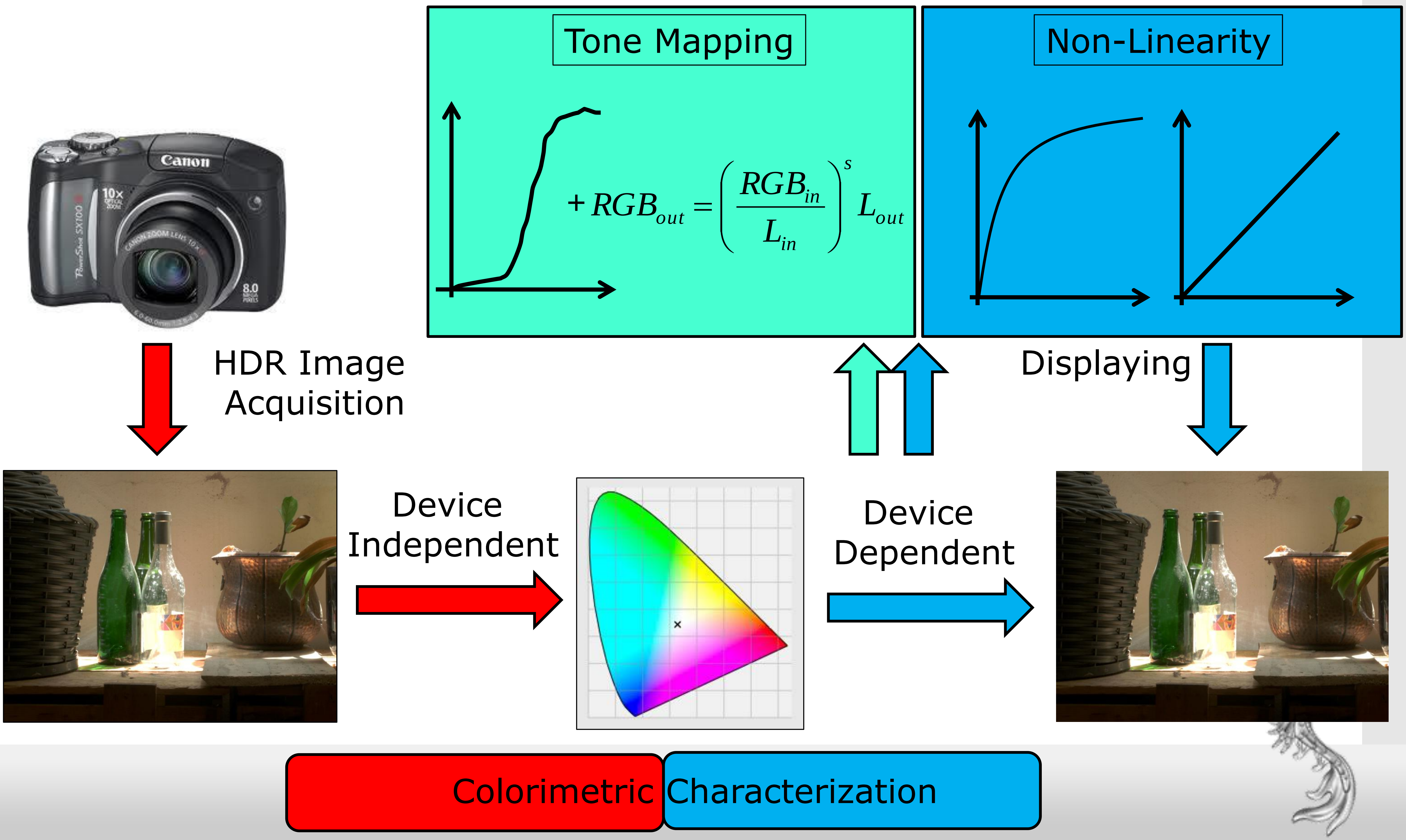


Gamma Response for BLUE



A. Neumann, A. Artusi, L. Neumann, G. Zotti and W. Purgathofer "Accurate Display Gamma Function based on Human Observation".

Color Rendering Pipeline in HDR



HDR ICC Profile

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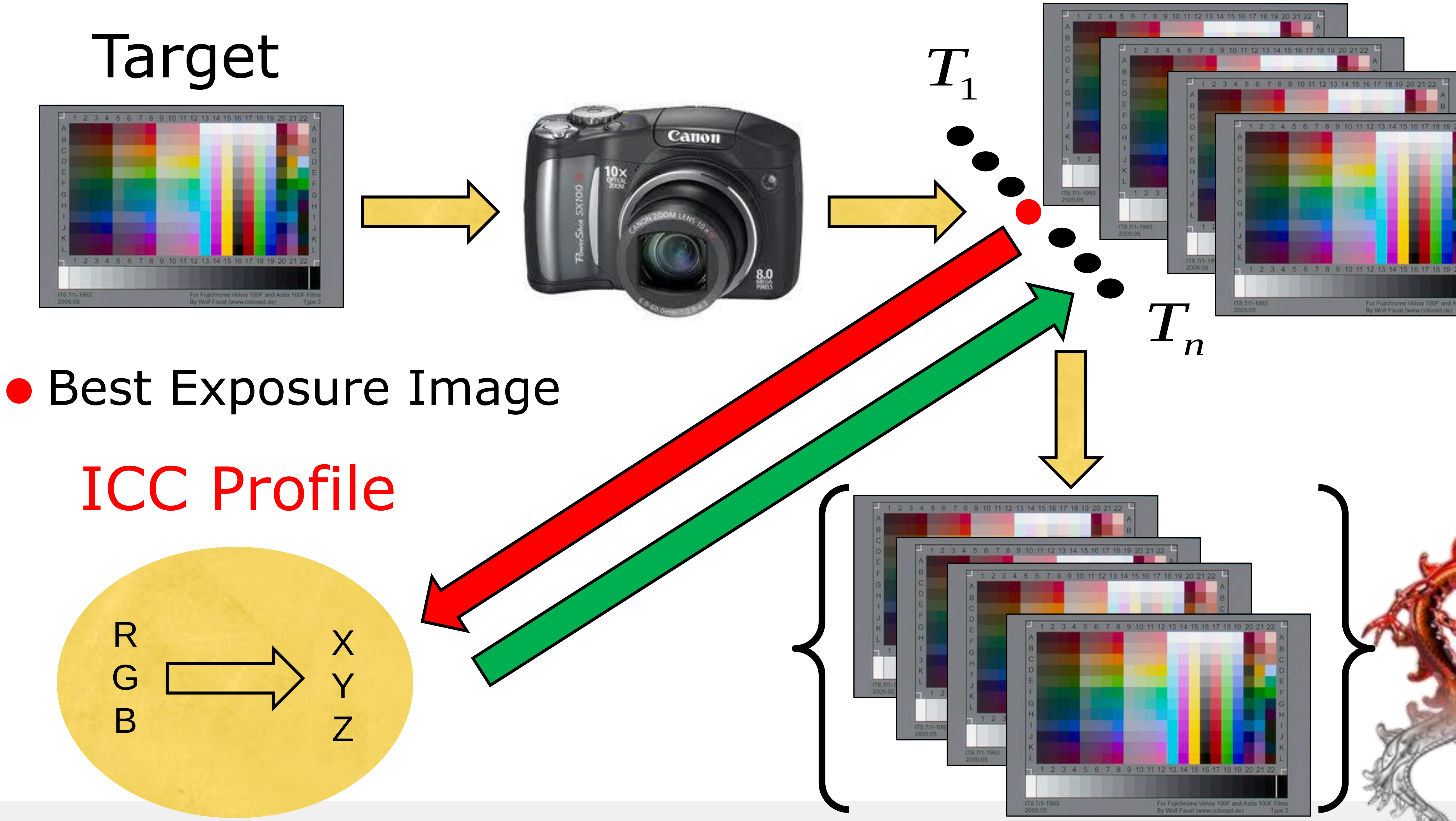

Goesele et al. "Color Calibrated High Dynamic Range Imaging with ICC Profiles."

HDR Colorimetric Camera Characterization

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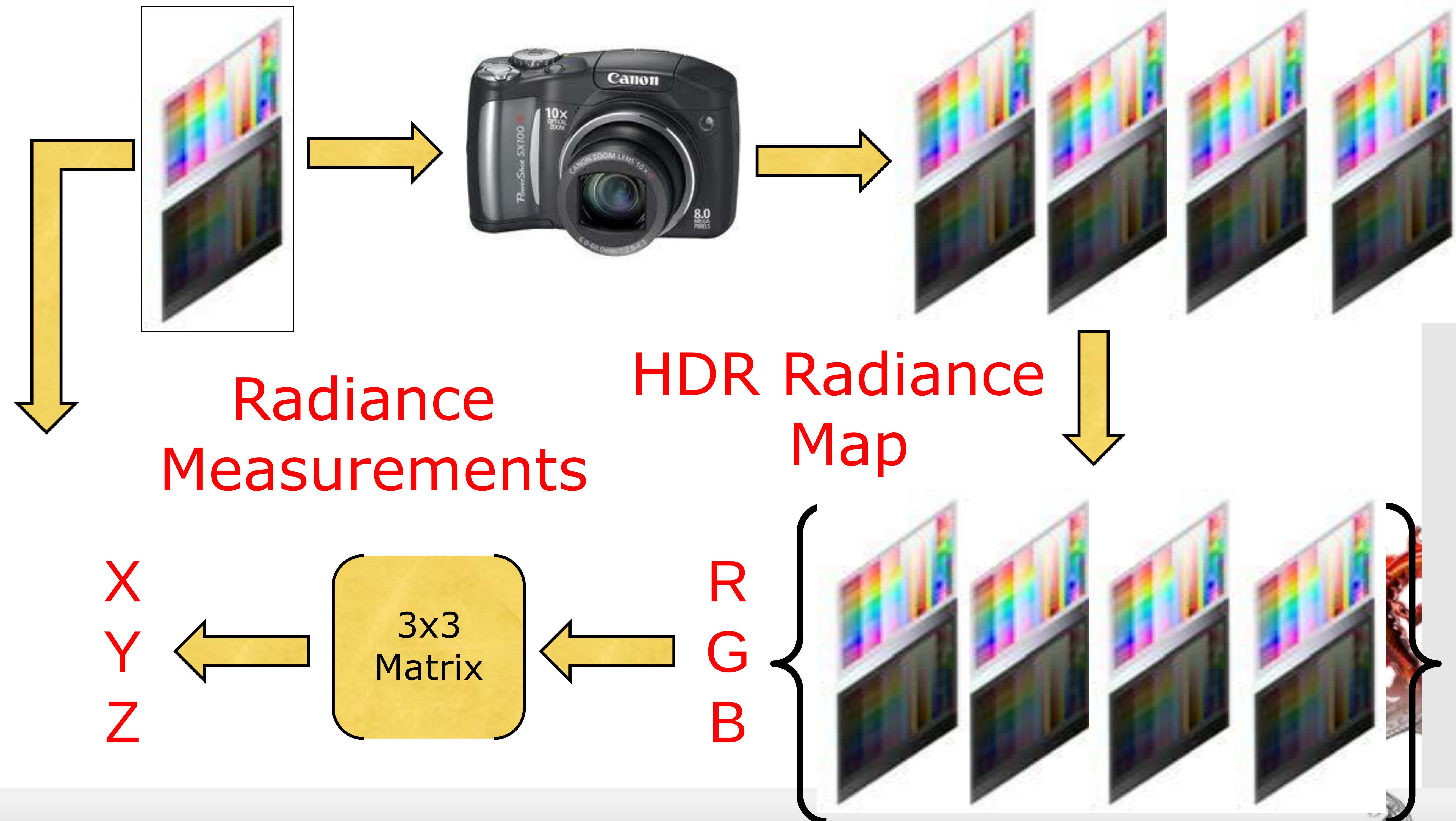
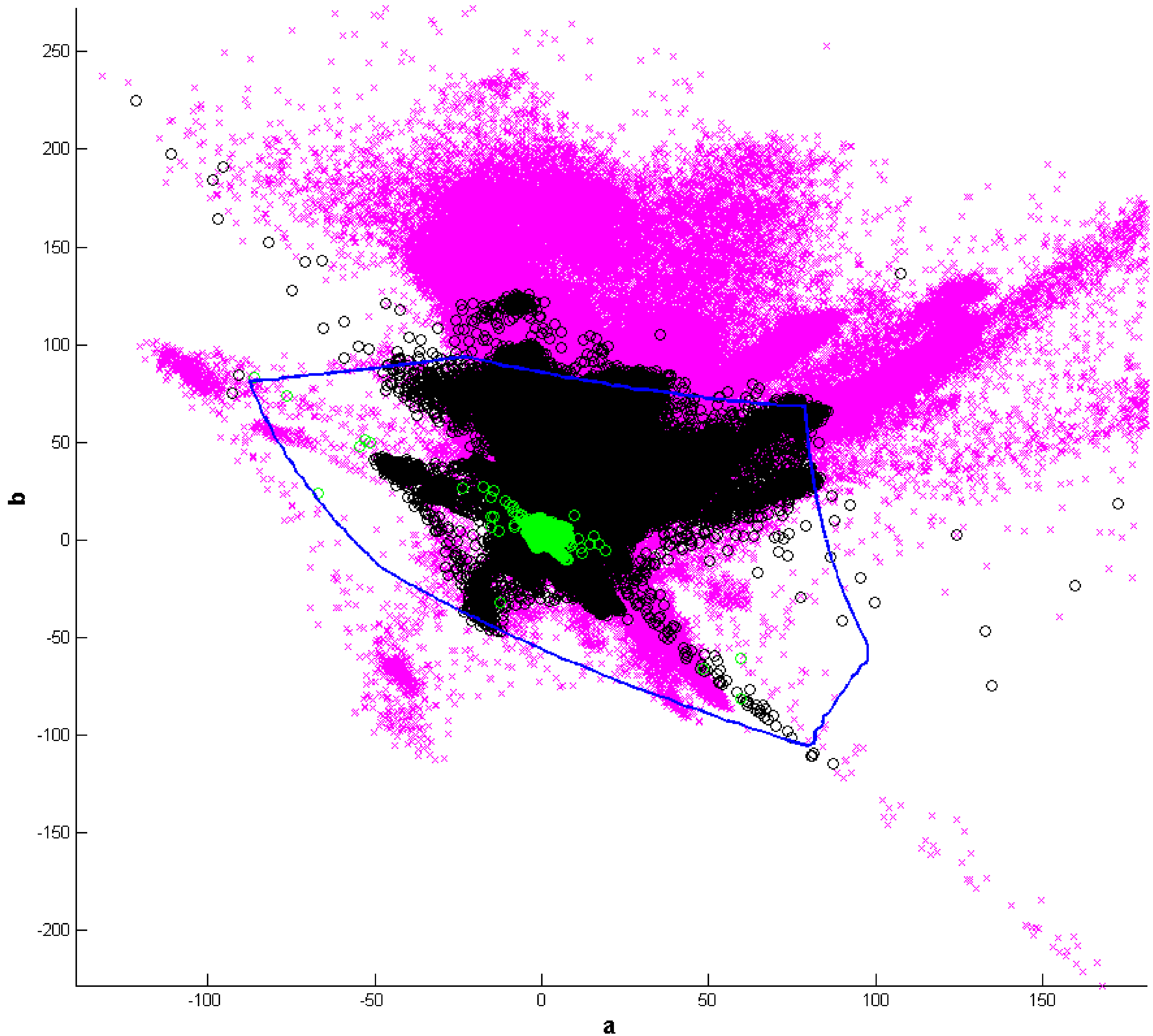
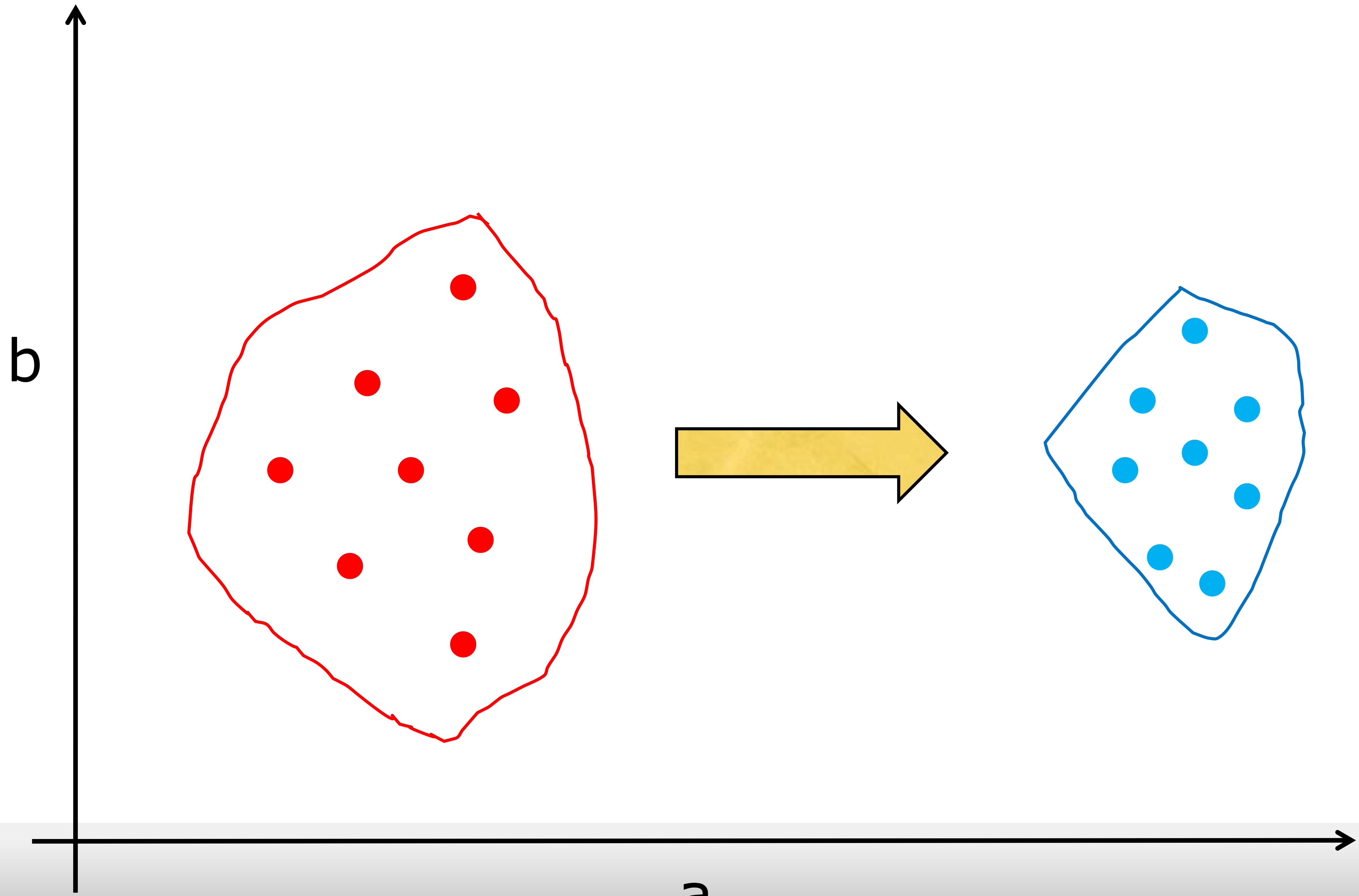


Min H. Kim et al. “Characterization of High Dynamic Range Imaging.”

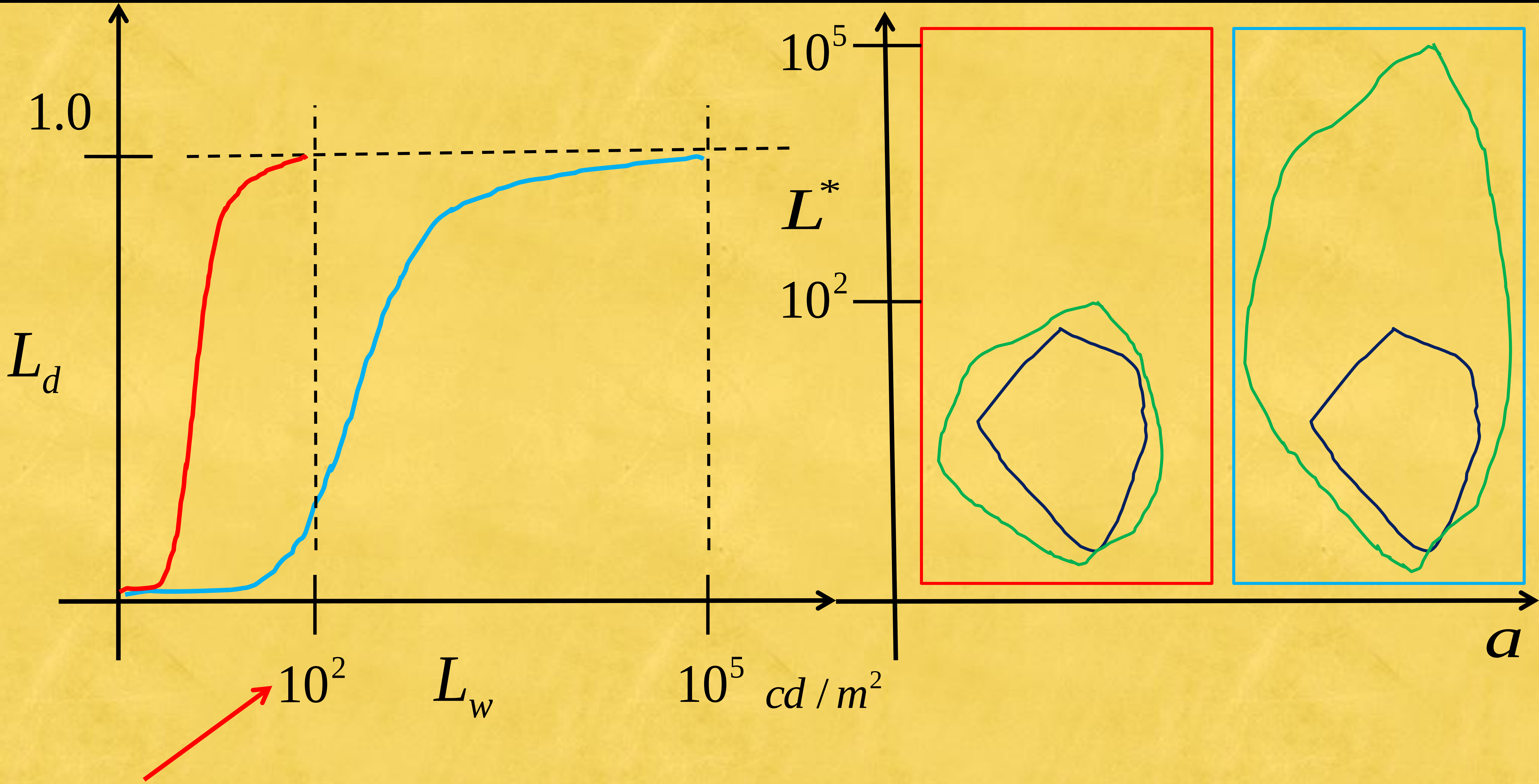


250
200
150
100
50
0
-50
-100
-150
-200
b
-100
-50
0
50
100
150
a

Gamut Mapping



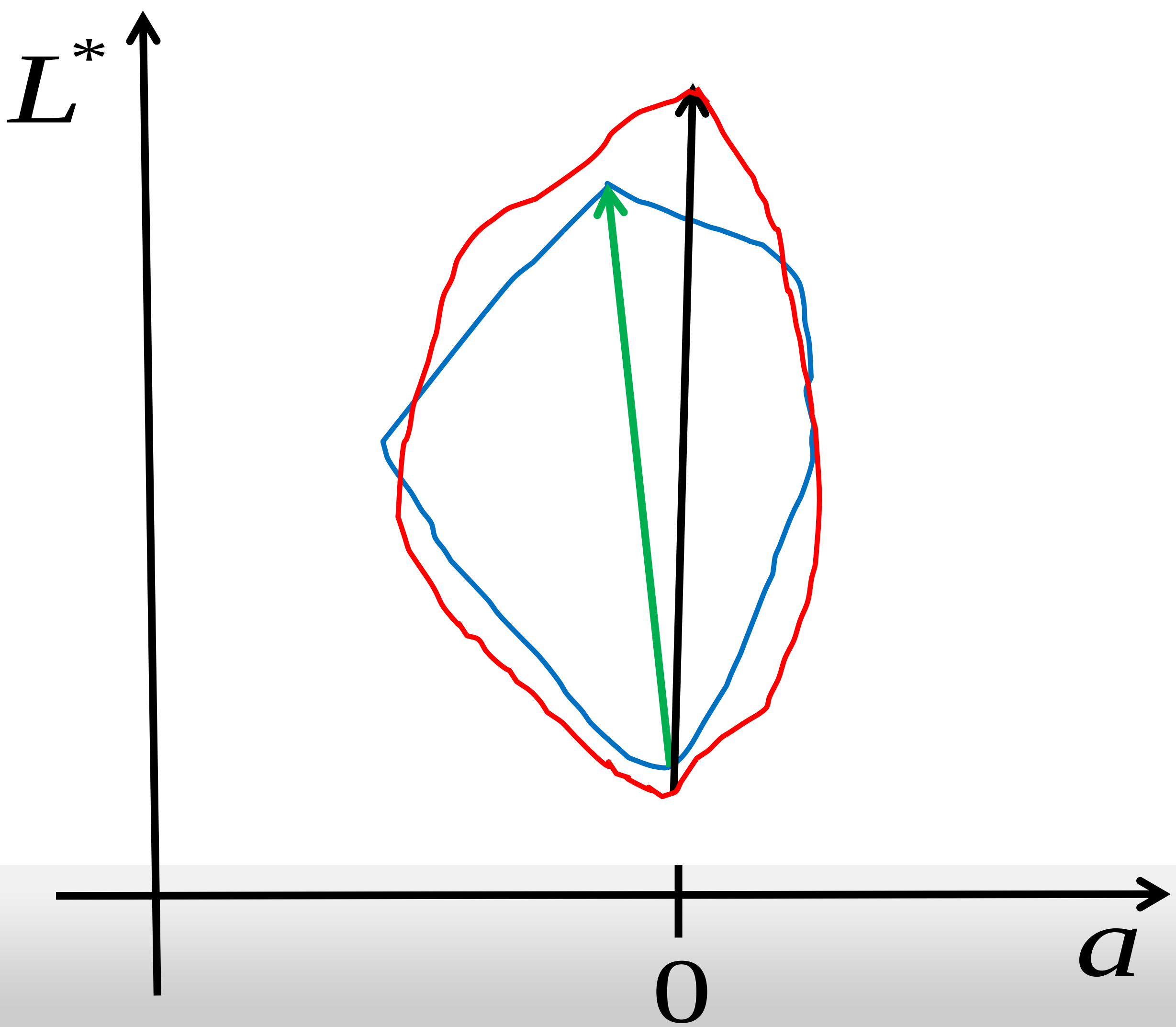
Gamut vs. Tone Mapping

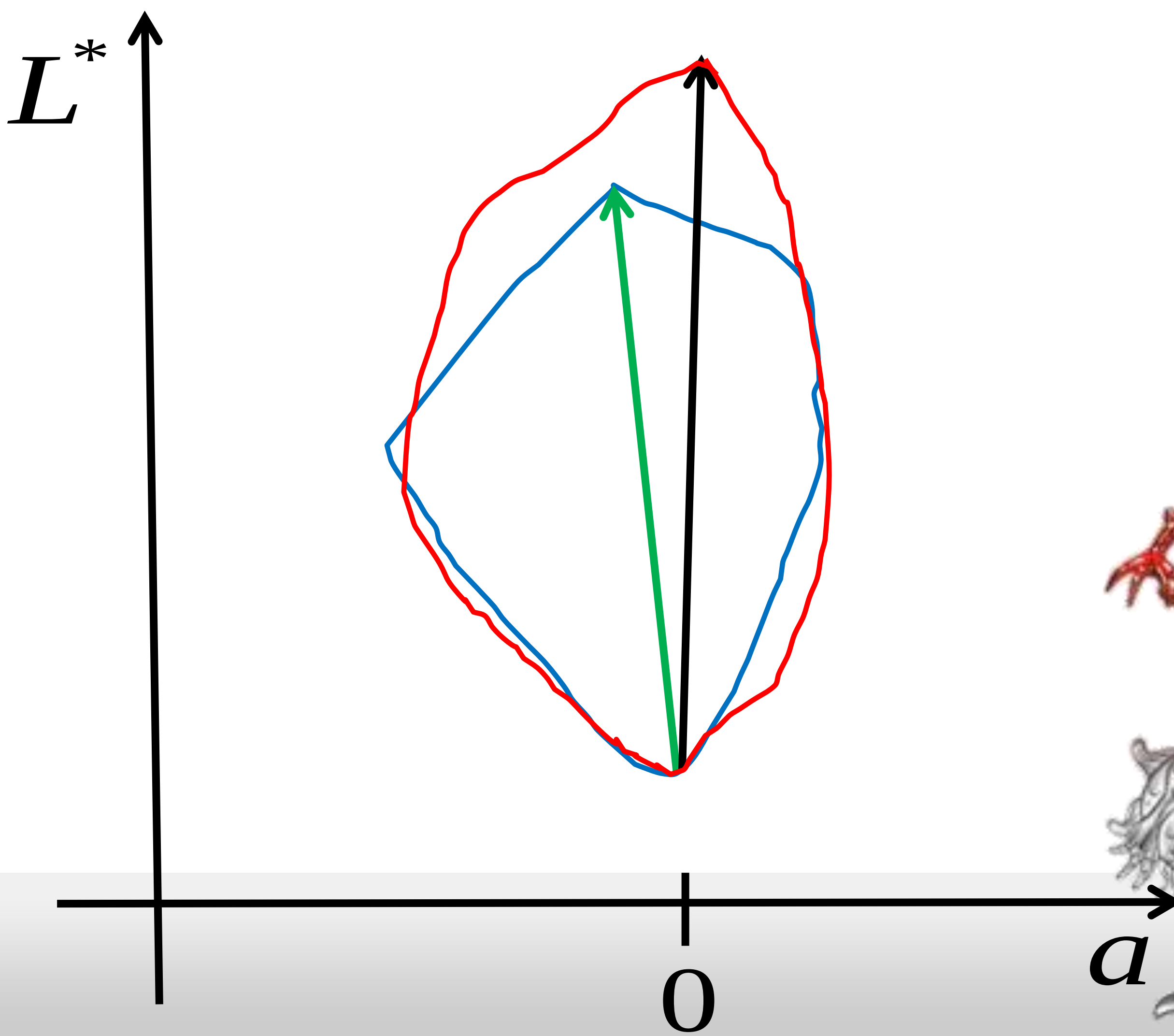


Not HDR Content

Gamut Mapping Aims (CS)

- Gray axes alignment, mapping white to white and black to black





Gamut Mapping Aims (CS)

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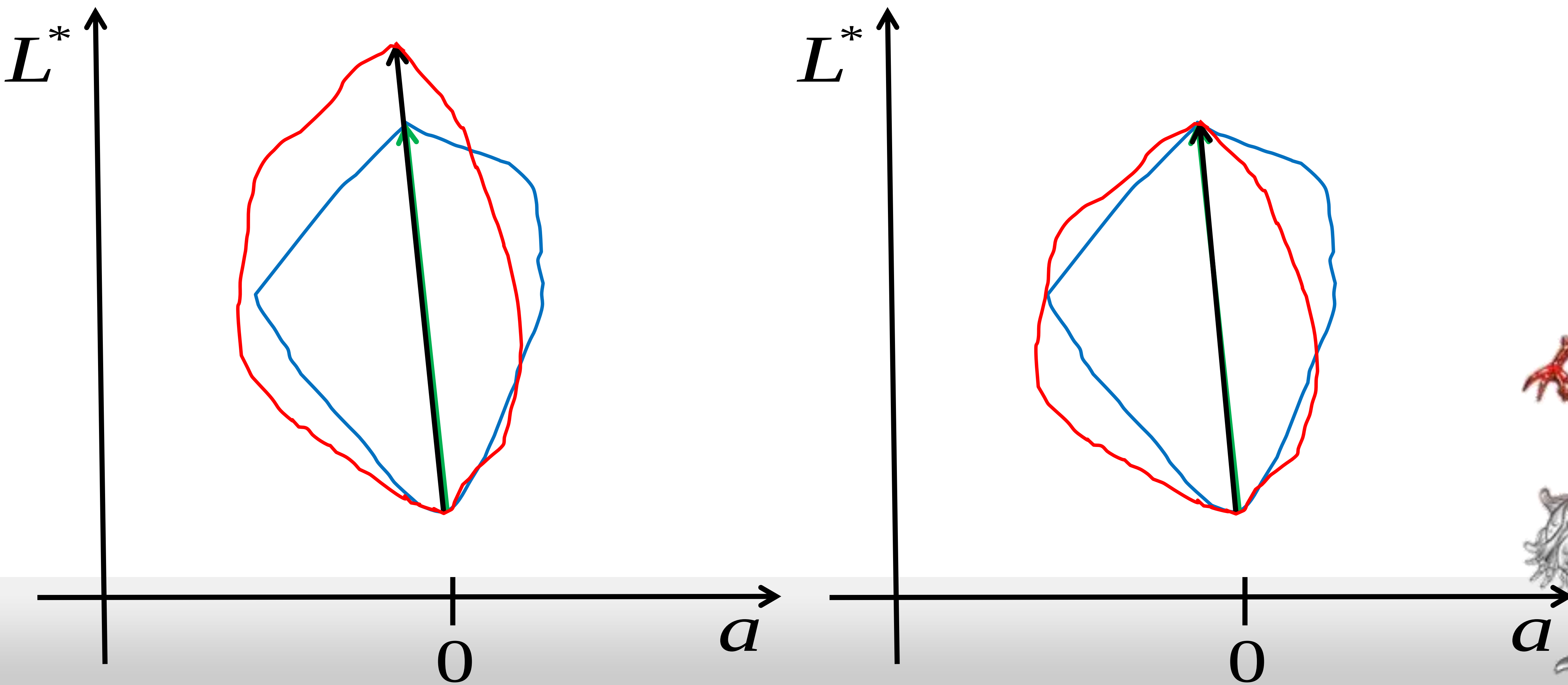
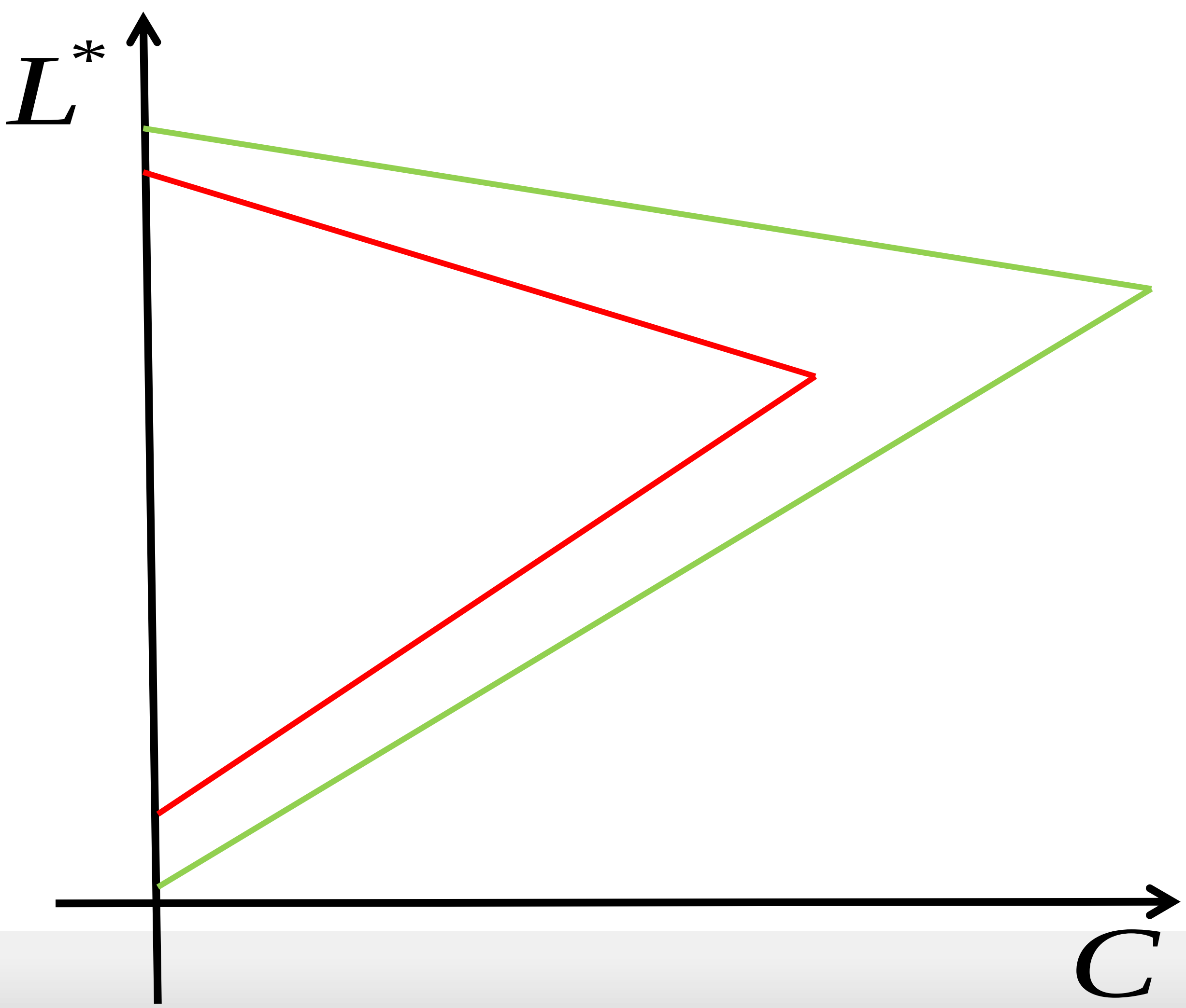
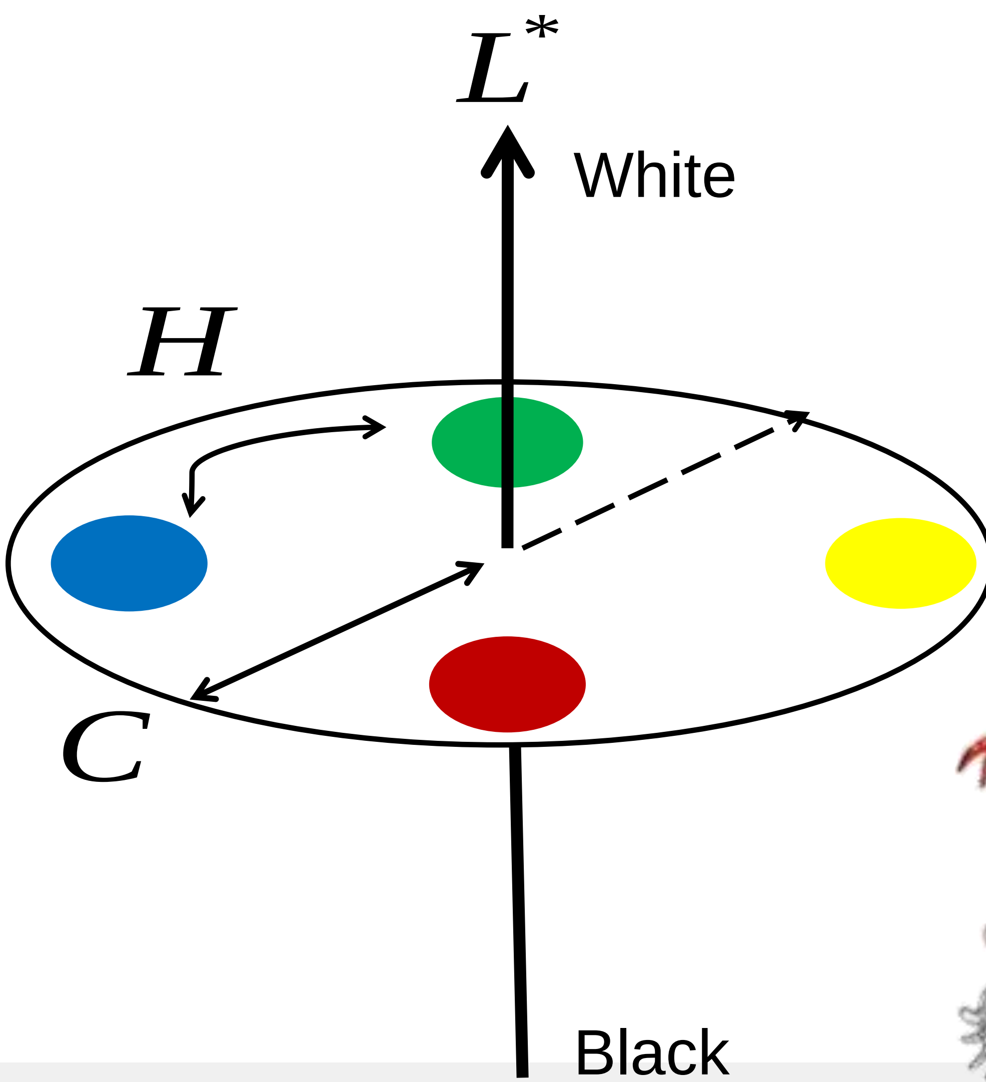


Gamut Mapping Aims (CS)

- Unchanged the Hue shift, will keep the overall image appearance



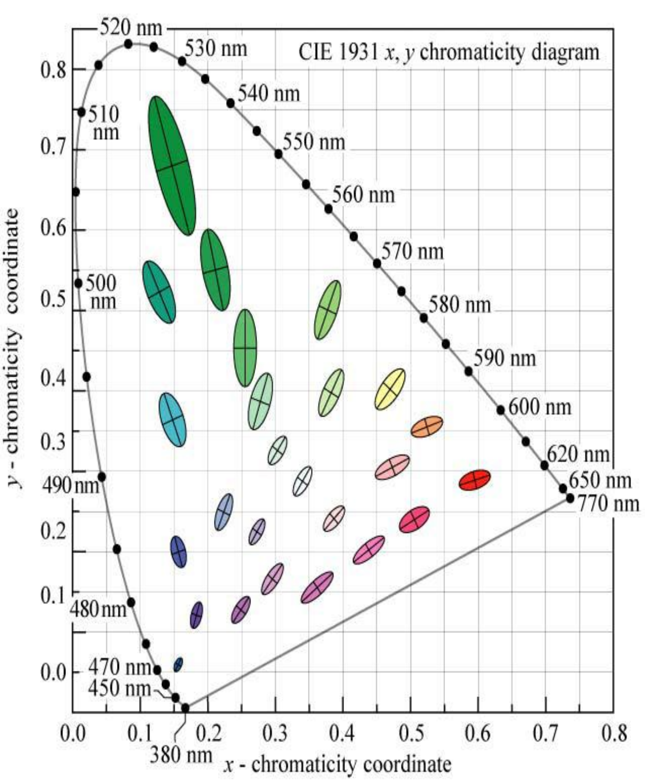


Gamut Mapping Aims (CS)

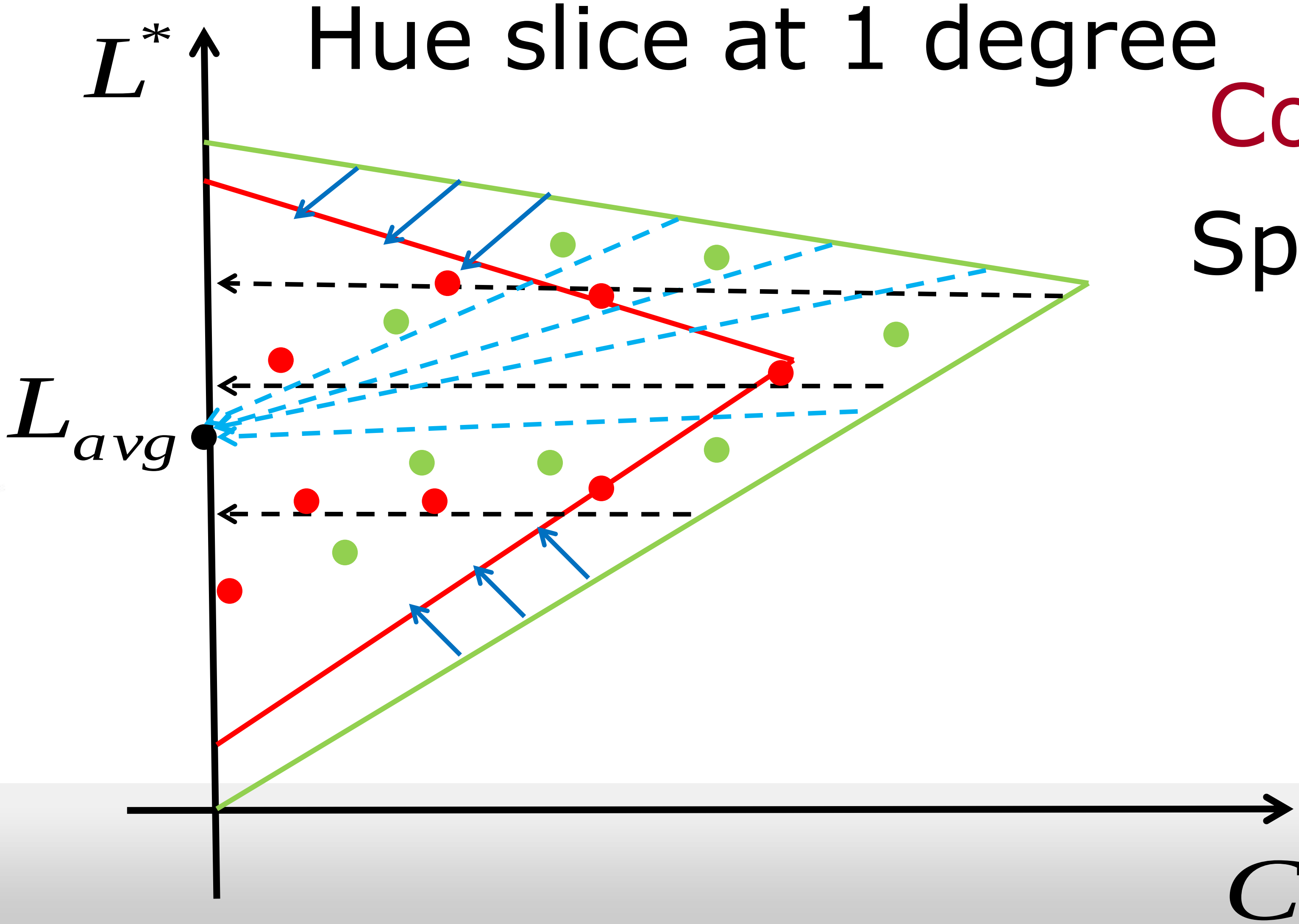
- Limiting out of gamut colours
  - Soft clipping can be afterwards adopted to eliminate these extremes
- Increase Image saturation
  - Destination gamut has reduced saturation
  - Helps maintaining the original chroma differences of the input Image

Gamut Mapping Pipeline

Color Space → Gamut Boundary Descriptor → Line Gamut Boundary → Mapping



Hue slice at 1 degree

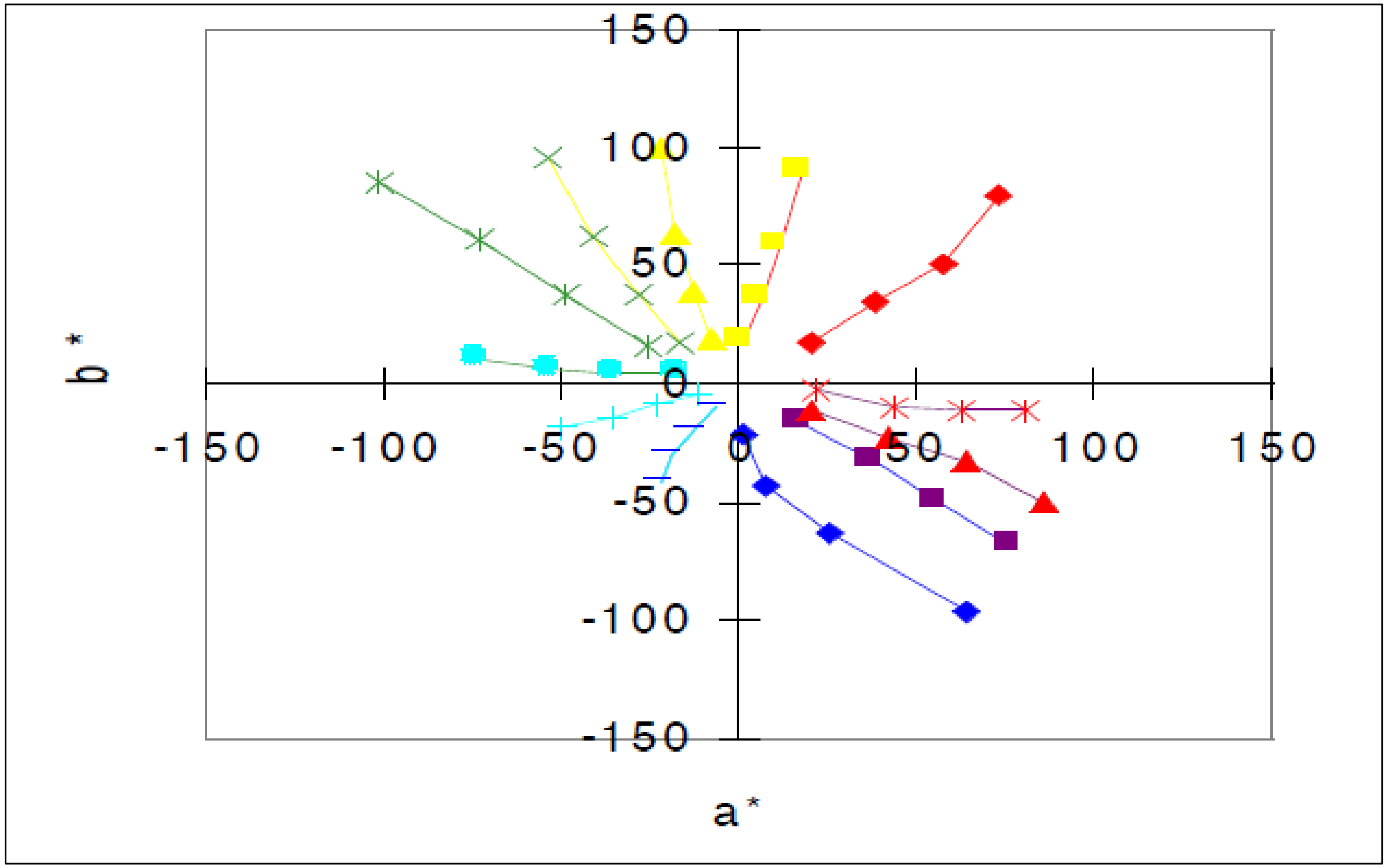


Clipping

Compression

Spatial GMAs

Color Space Issue



- Gamut Mapping that preserves metric hue angle
  - No Hue shift after compression or clipping
- CIELab is suffering of non linearity in blue regions, but also in red regions

Braun and Fairchild. “Color Gamut Mapping in Hue-Linearized CIELab Color Space”

Point-wise Gamut Mapping Techniques

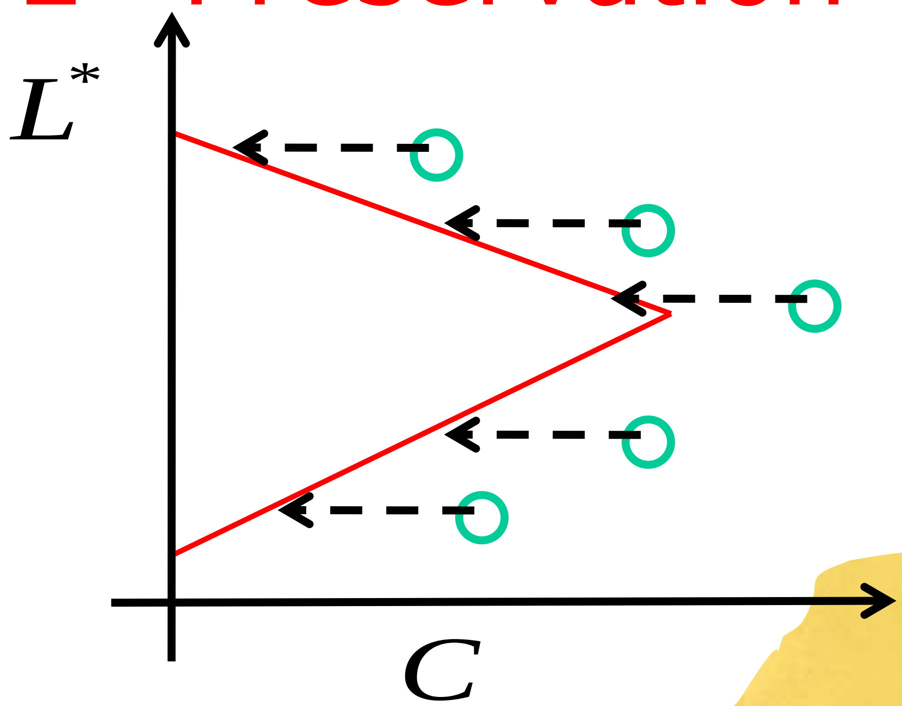
- **Clipping**

It changes colours which are outside of the destination gamut, mapping them on the boundaries of the destination gamut

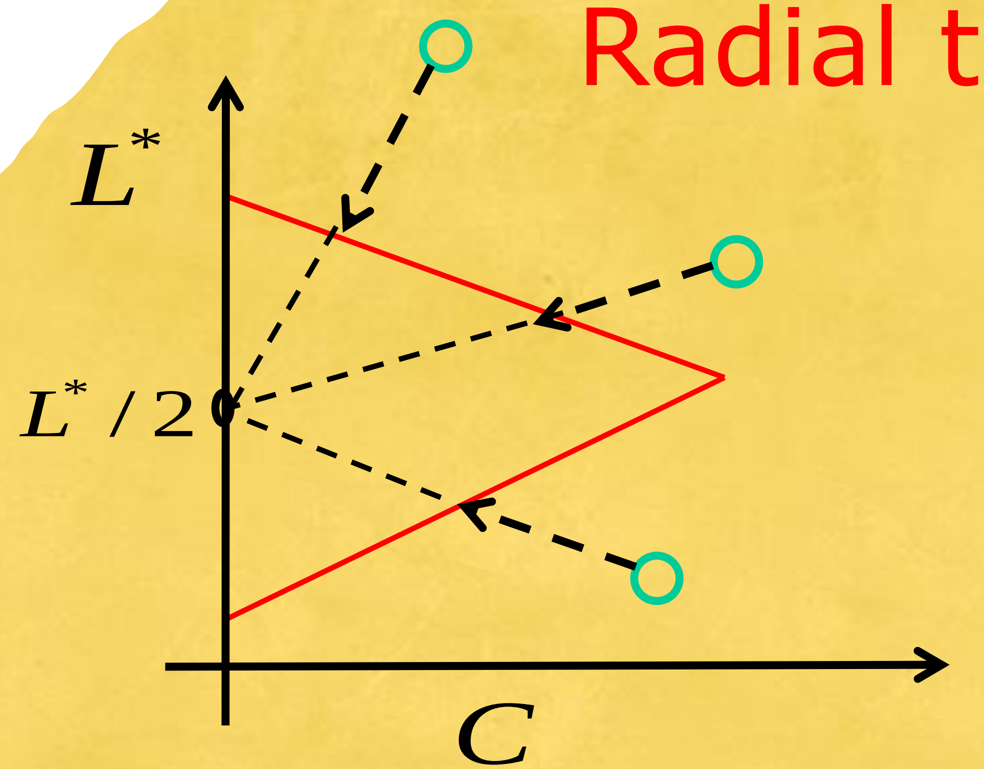
- **Horizontal** (lines of constant lightness)
- **Radial to a centre of Gravity**
  - Centre of lightness axis (Constant)
  - Lightness corresponding to the Chroma Cusp (variable)
- **Distance in CIELab**
  - To the colour boundary of the destination gamut that has the smallest distance (**HPMin**ΔE **Clipping**)

Clipping

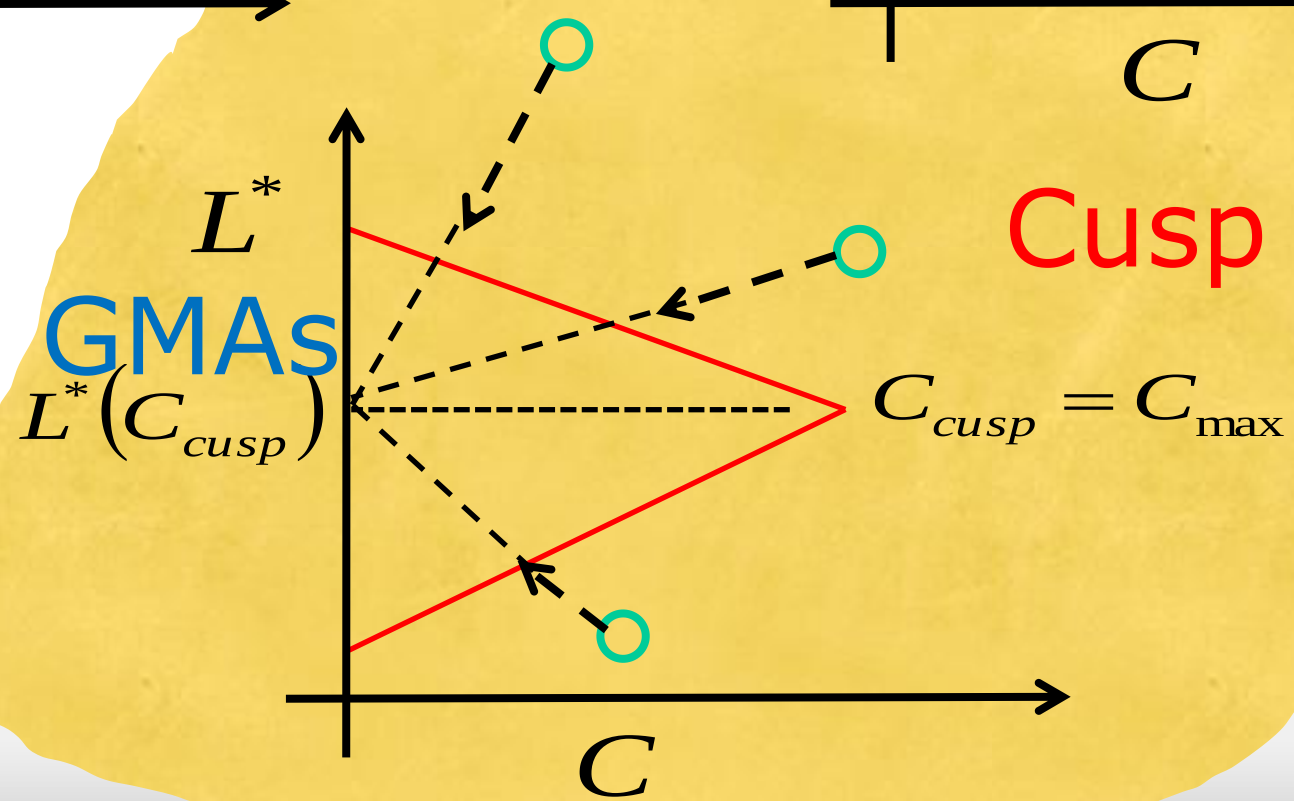
L* Preservation



Radial to L*/2



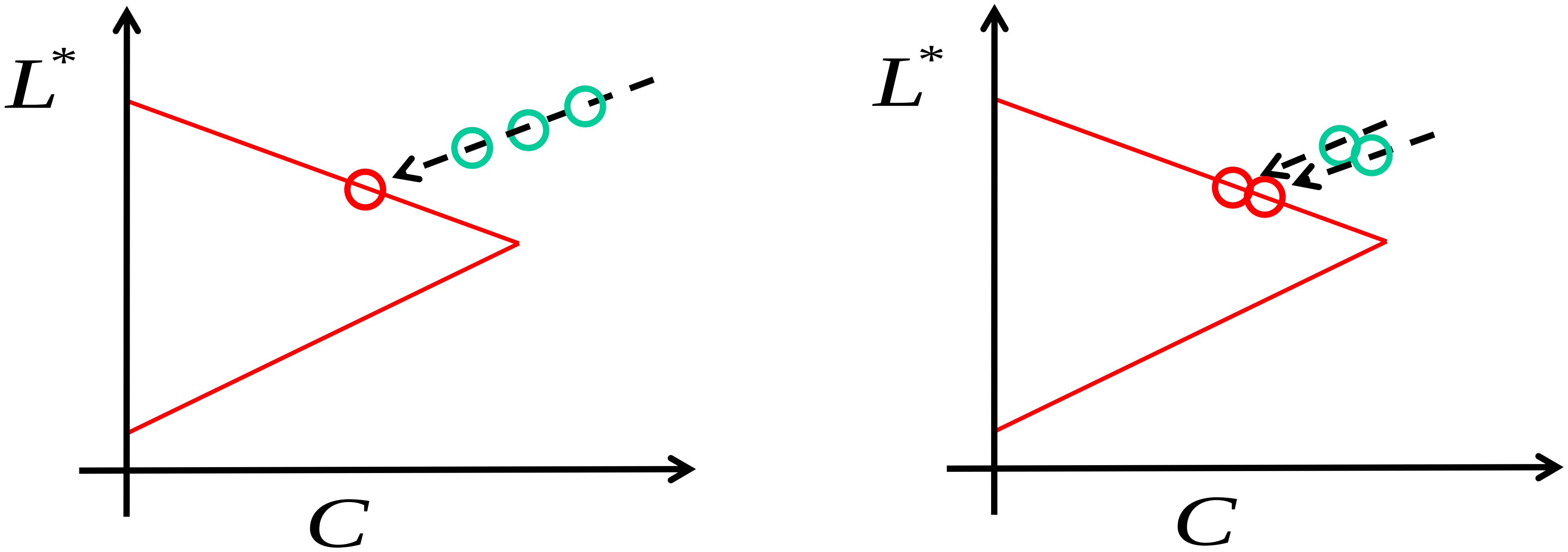
Cusp Radial



Simultaneous GMAs

Clipping – Major Drawbacks

Erase Local Image variation (Details)



Preserve Saturation



Point-wise Gamut Mapping Techniques

- **Compression**

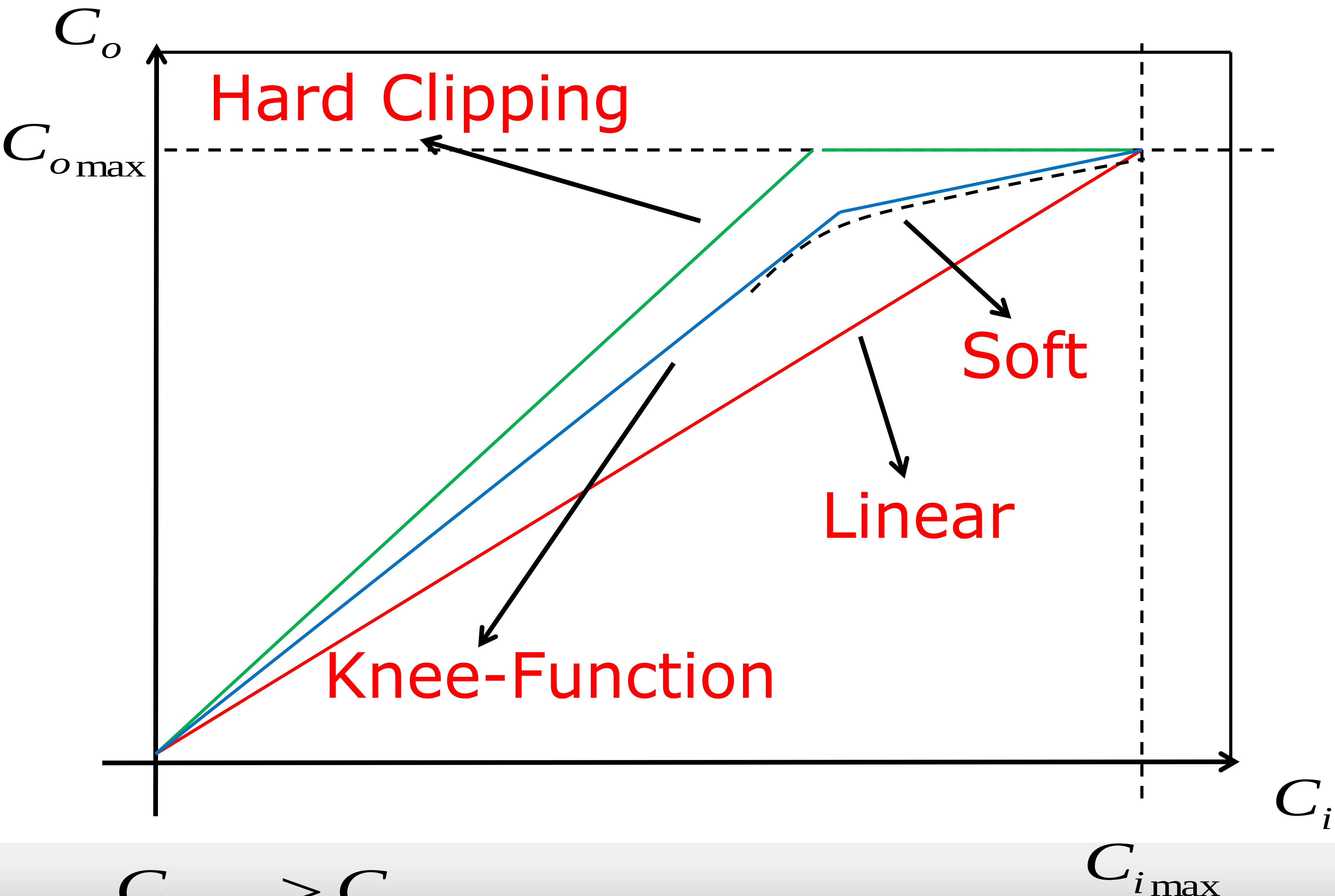
It makes changes to all the colors of the source gamut to be accommodated into the destination gamut .

  - **Linear**
  - **Sigmoid**
  - **Knee-function**

- **Parametric**

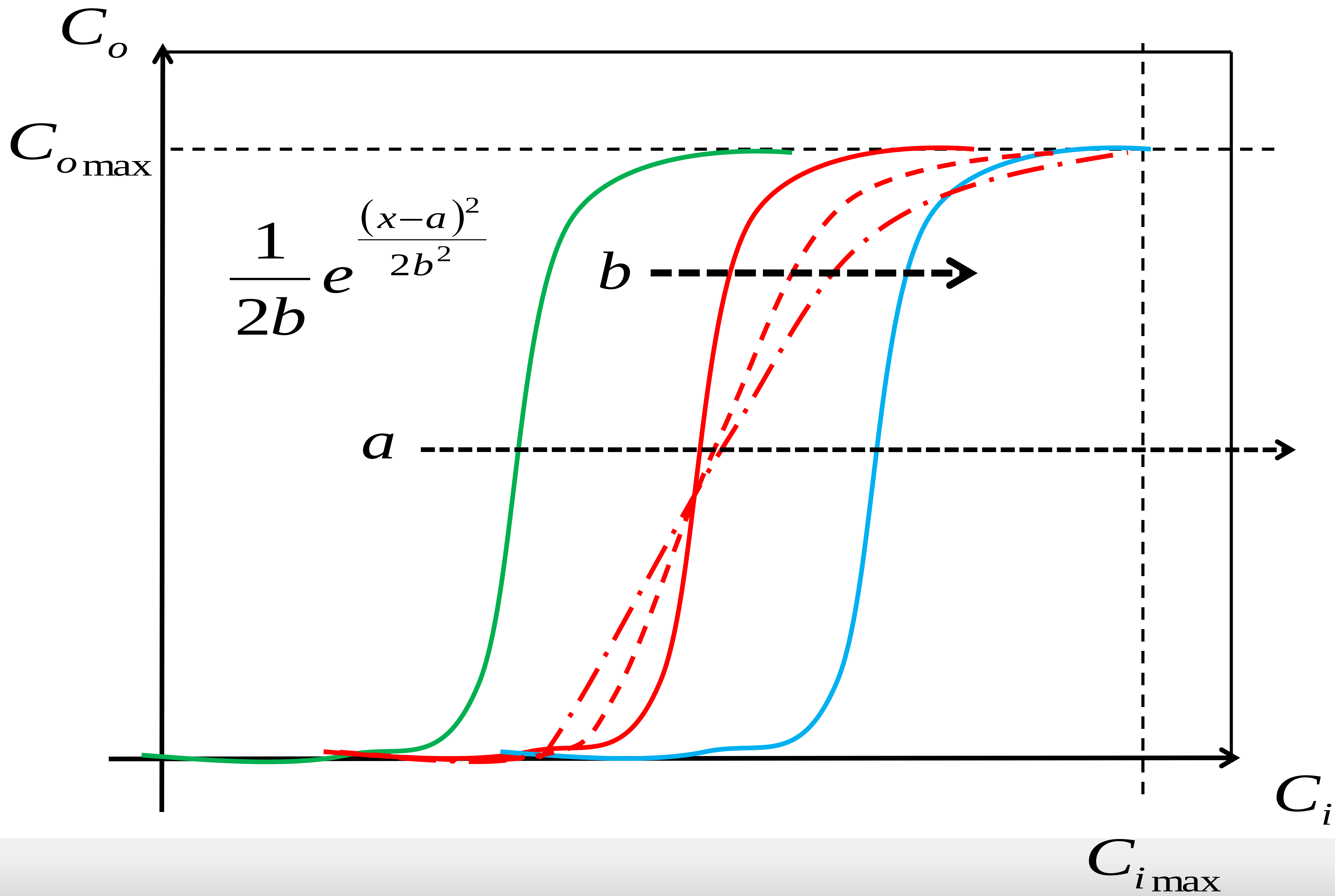
The behaviour change based on the shapes of the two gamut’s (source and destination) at the hue angle, or it depends from user parameters. (Clipping and Compression)

Compression



$$C_{i\max} > C_{o\max}$$

Compression



Parametric

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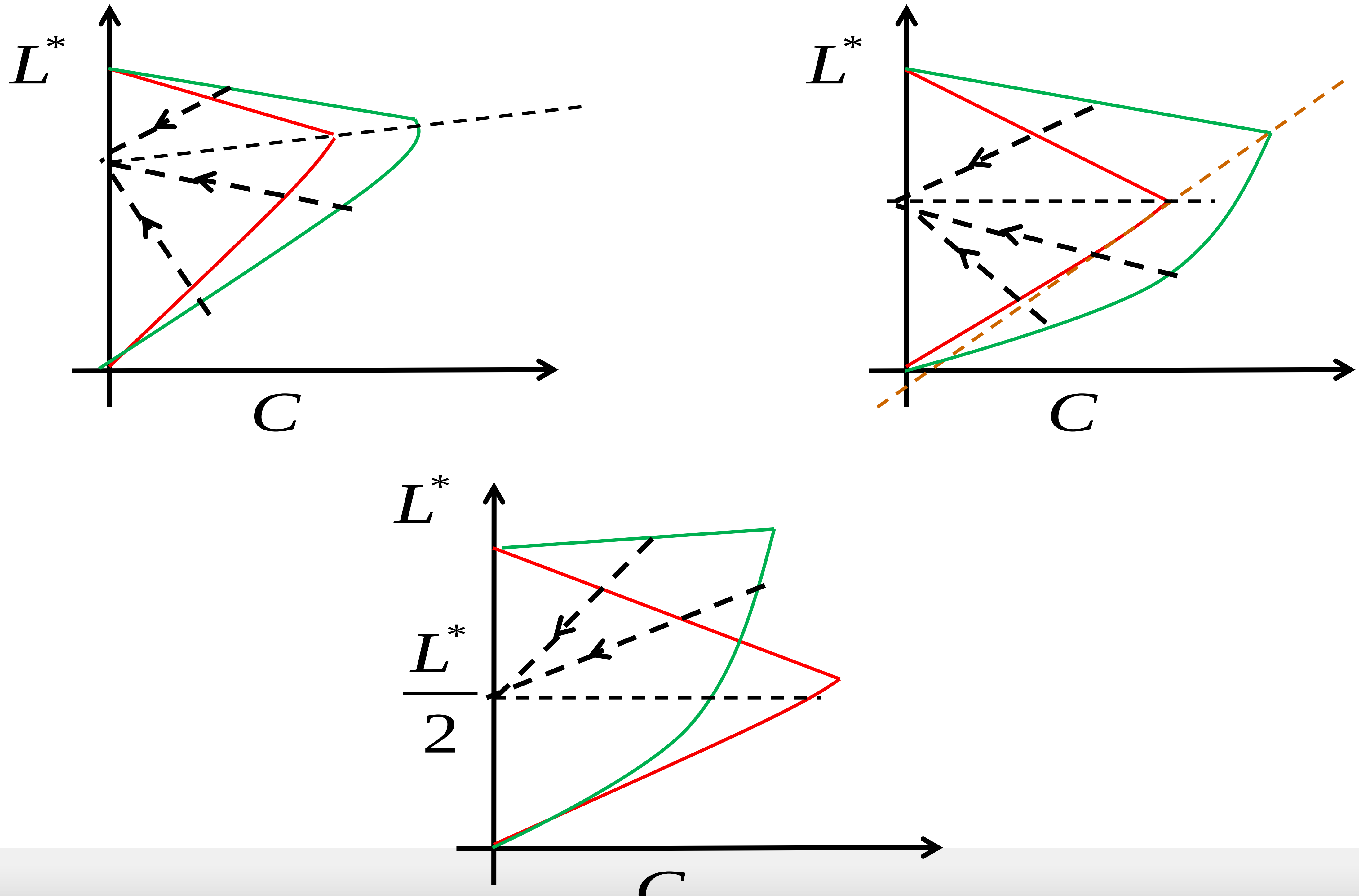


Preservation of Spatial Details

- **Optimization**

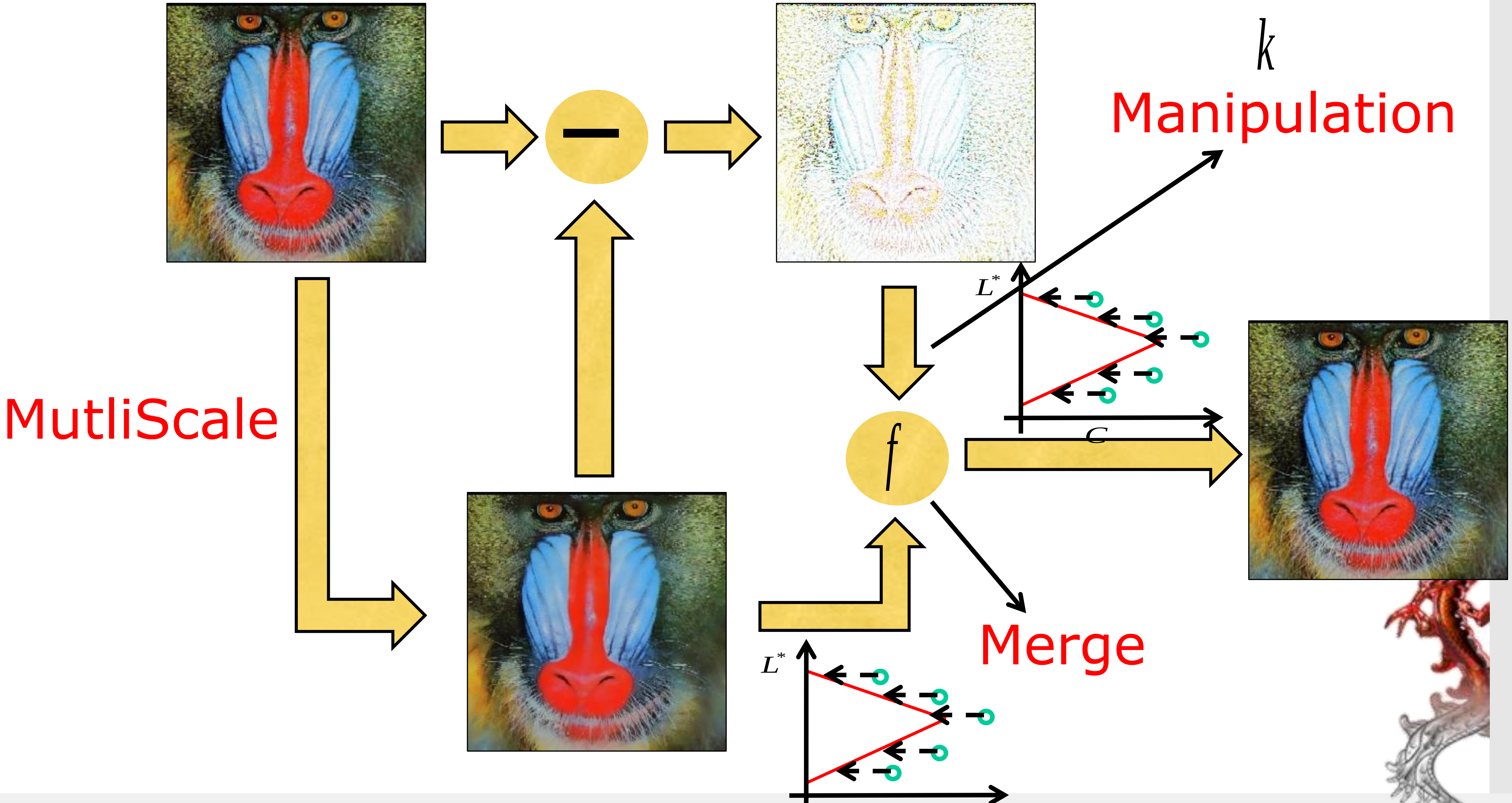
Making use of Human Visual System Models minimize the perceived differences between the input and output image.

- **Multiscale**

Re-inserts high-frequency information content in the gamut mapped image (clipped).

  - Clipping – loss of details
  - General framework has been proposed that includes the different cases

Preservation of Spatial Details



Bonnier et al. “Spatial and Color Adaptive Gamut Mapping: A Mathematical Framework and Two New Algorithms.”

Mantiuk et al. "Color Correction for Tone Mapping"

Automatic estimation of desaturation (s) factor in function of contrast compression (c) (<u>non-linear color correction</u>).

$$C_{out} = \left(\frac{C_{in}}{L_{in}}\right)^{s} L_{out}$$

$$s(c) = \frac{(1+k_1)\,c^{k_2}}{1+k_1\,c^{k_2}}$$

k1=2.3892, k2=0.8552

s = f(c) determined based on results of perceptual experiment

Mantiuk et al. “Color Correction for Tone Mapping”

luminance(C_{in}) = luminance(C_{out})

$$C_{out} = \left(\left(\frac{C_{in}}{L_{in}} - 1 \right) s + 1 \right) L_{out}$$

k1=2.3892, k2=0.8552

$$s(c) = \frac{(1 + k_1)\, c^{k_2}}{1 + k_1\, c^{k_2}}$$

Unchanged luminance value after color correction
(luminance preserving solution)

Conclusions

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- Works on high dynamic range imaging have mostly operated on luminance (lightness) information
  - some works start to appear proposing solution for color saturation, acquisition of colorimetric correct high dynamic range color values, and color appereance
- In Color Science a lot of works have been presented in the context of colorimetric characterisation, color appearance and gamut mapping on low dynamic range [0, 100]
  - Some of these works have been extended or re-used for high dynamic range applications
  - Tone mapping can bee seen as an extension or a particular case of gamut mapping (if we consider only the luminance information)
  - Many gamut mapping works started to analyse the details preservation on color information

Low Dynamic Range [0,100]

Acknowledgments

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- Image IM2-Color (slide 2) Courtesy of Laszlo Neumann
- Material from the paper “Color Correction for Tone Mapping” Courtesy of Rafal Mantiuk
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- Images (slides 18, 30 and 41) Courtesy of Ela Sikudova
- HDR Image s(skide 18) Martin Cadik