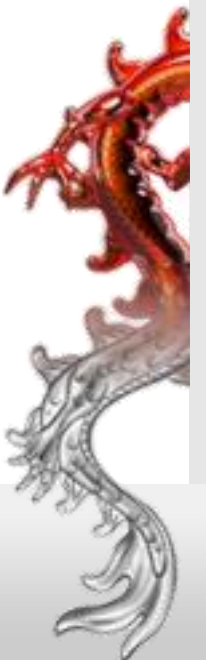


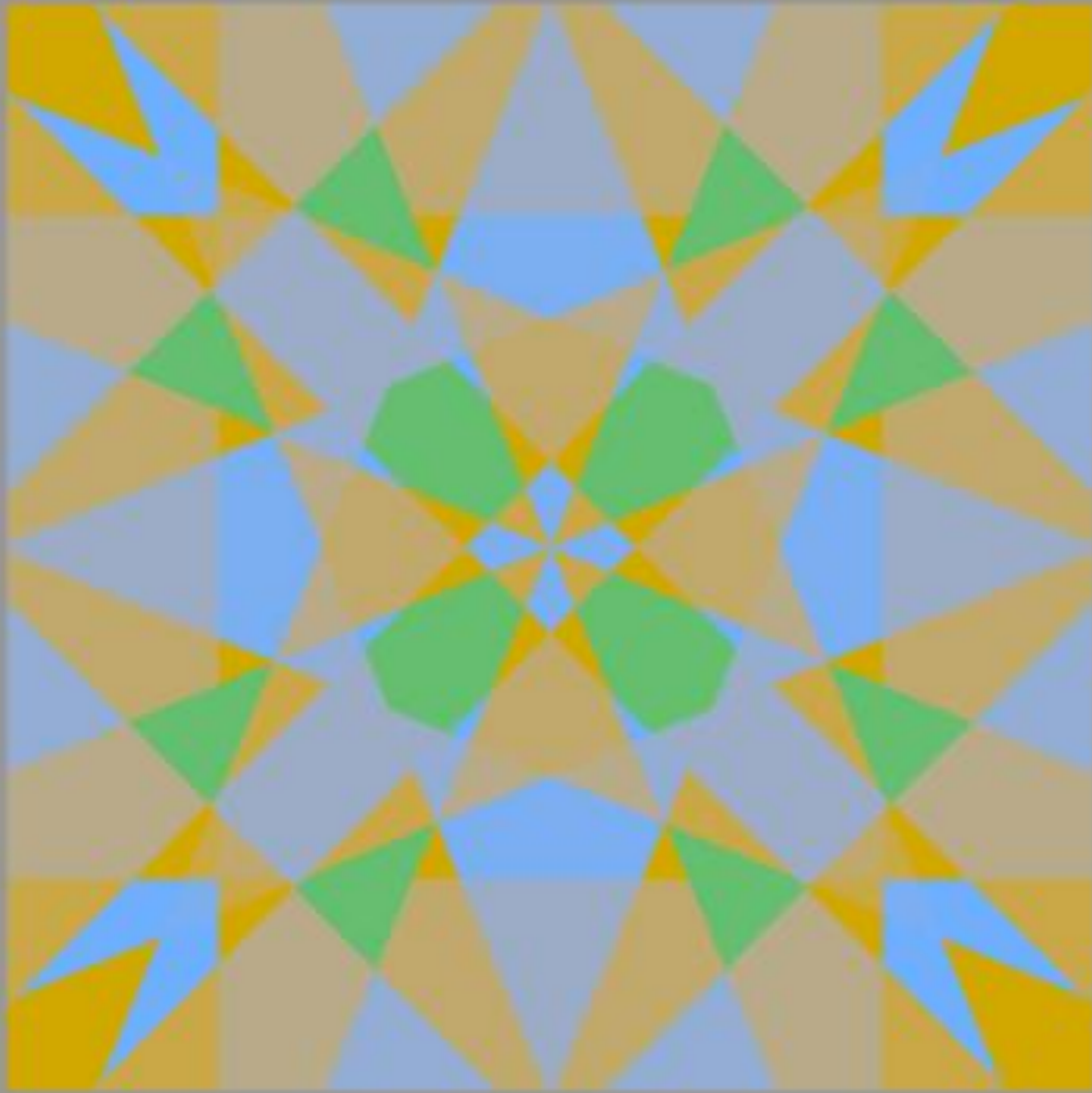
Retargeting Color Content: Color Issues in Tone Mapping

Alessandro Artusi

Cyprus Institute, CaSToRC, Cyprus

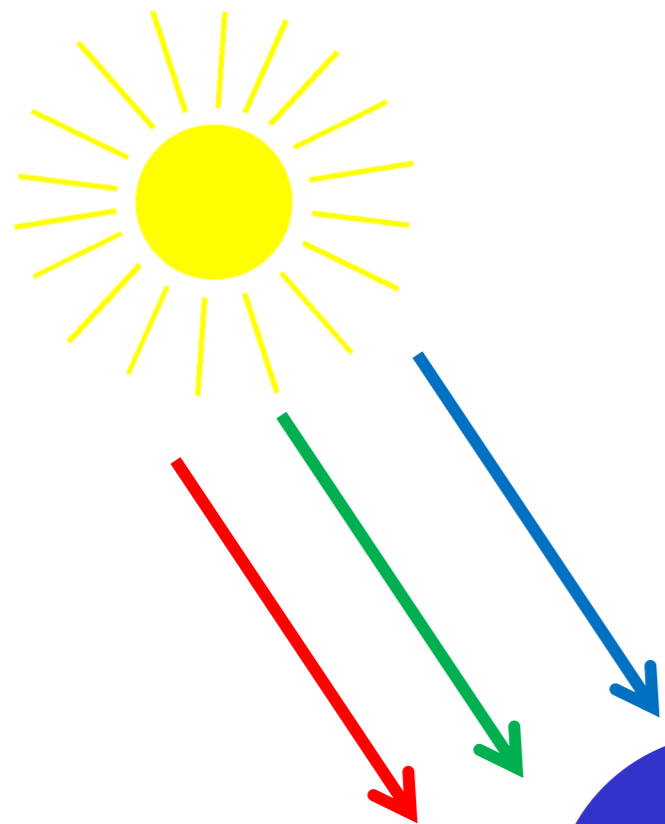


Introduction to Color



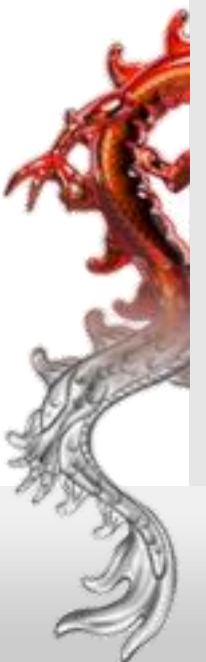
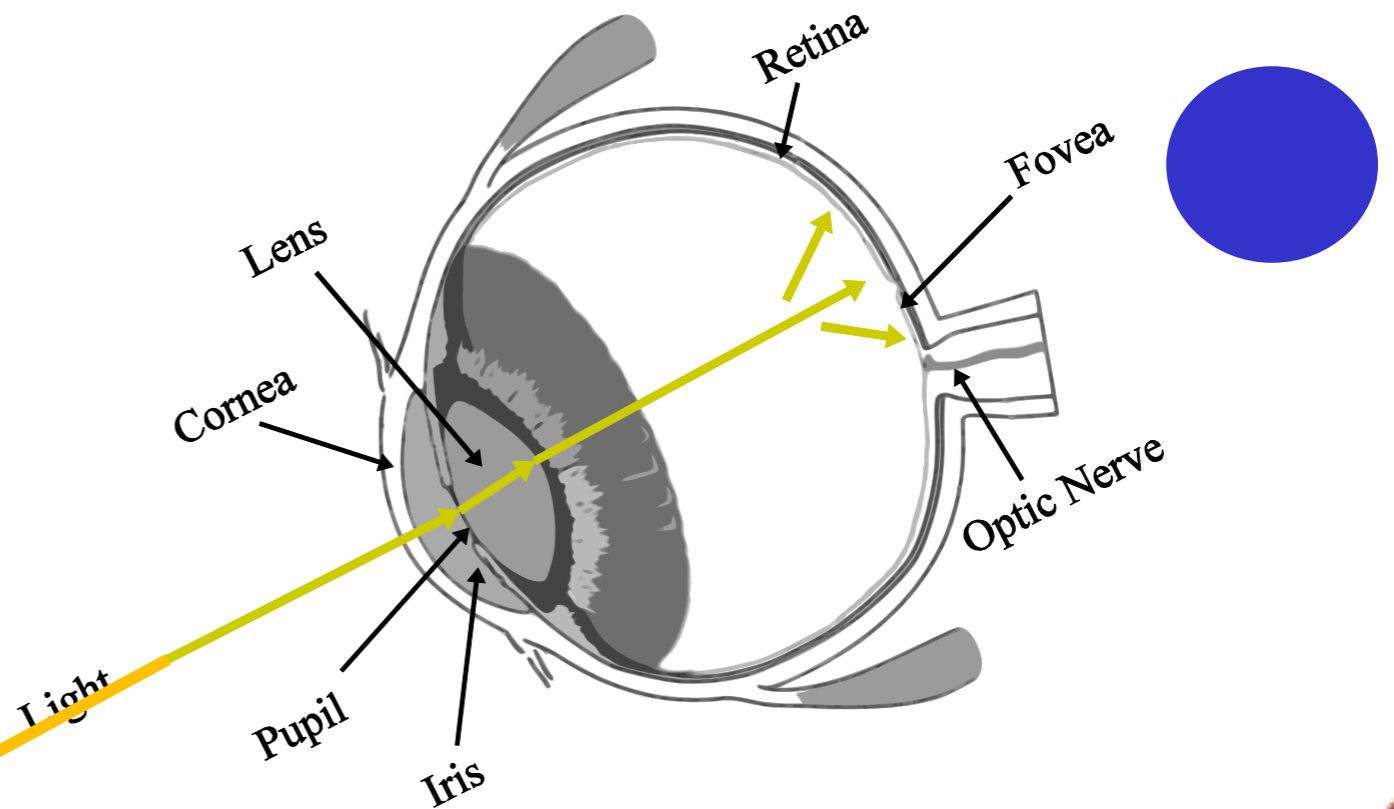
What is Color?

Source Light



Stimulus Object

Human Visual System



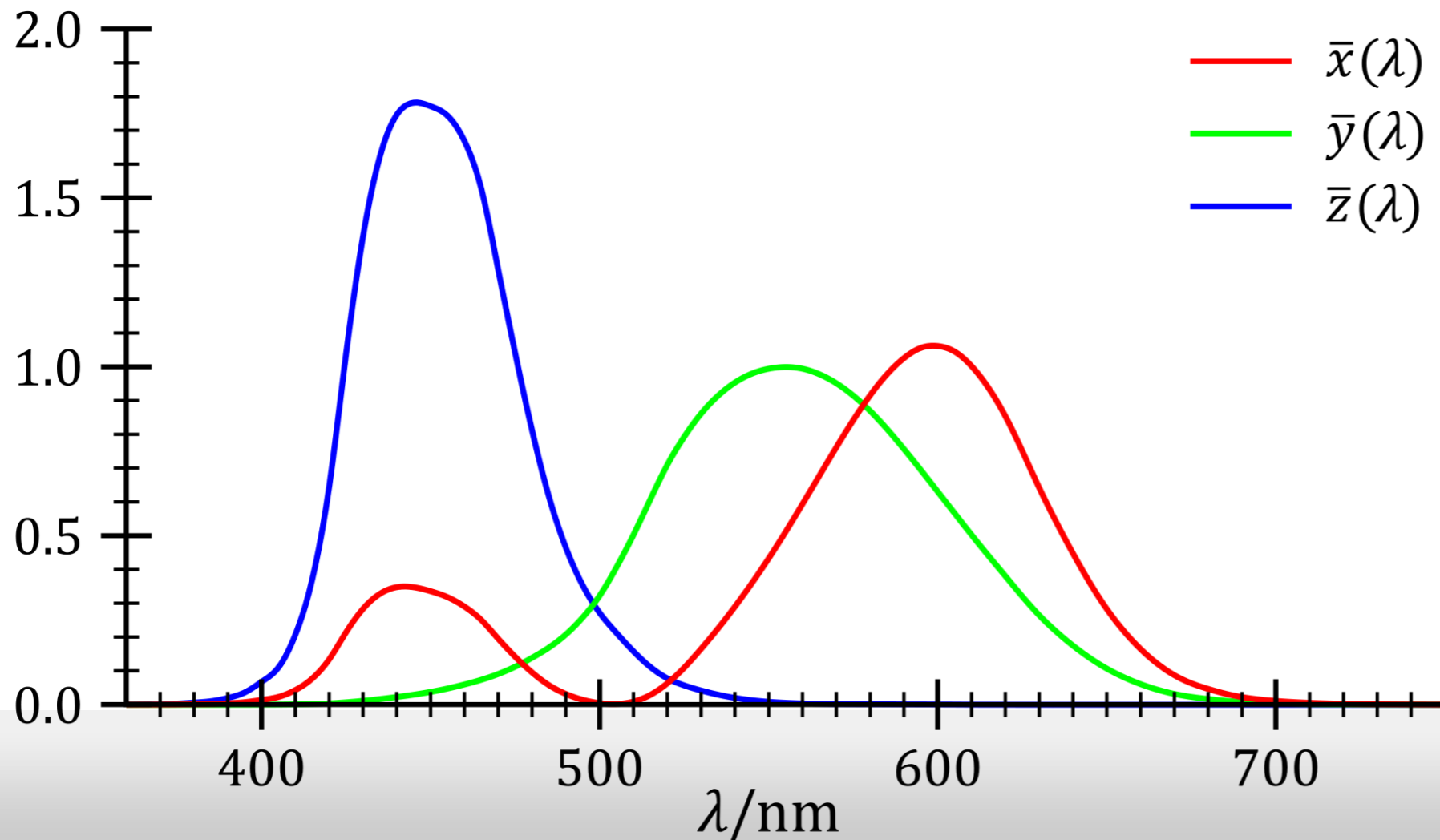
Quantifying Color

$I(\lambda)$ SPD of the light
 $\rho(\lambda)$ Reflectance of the object
 $\bar{x}, \bar{y}, \bar{z}(\lambda)$ CIE color matching functions

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

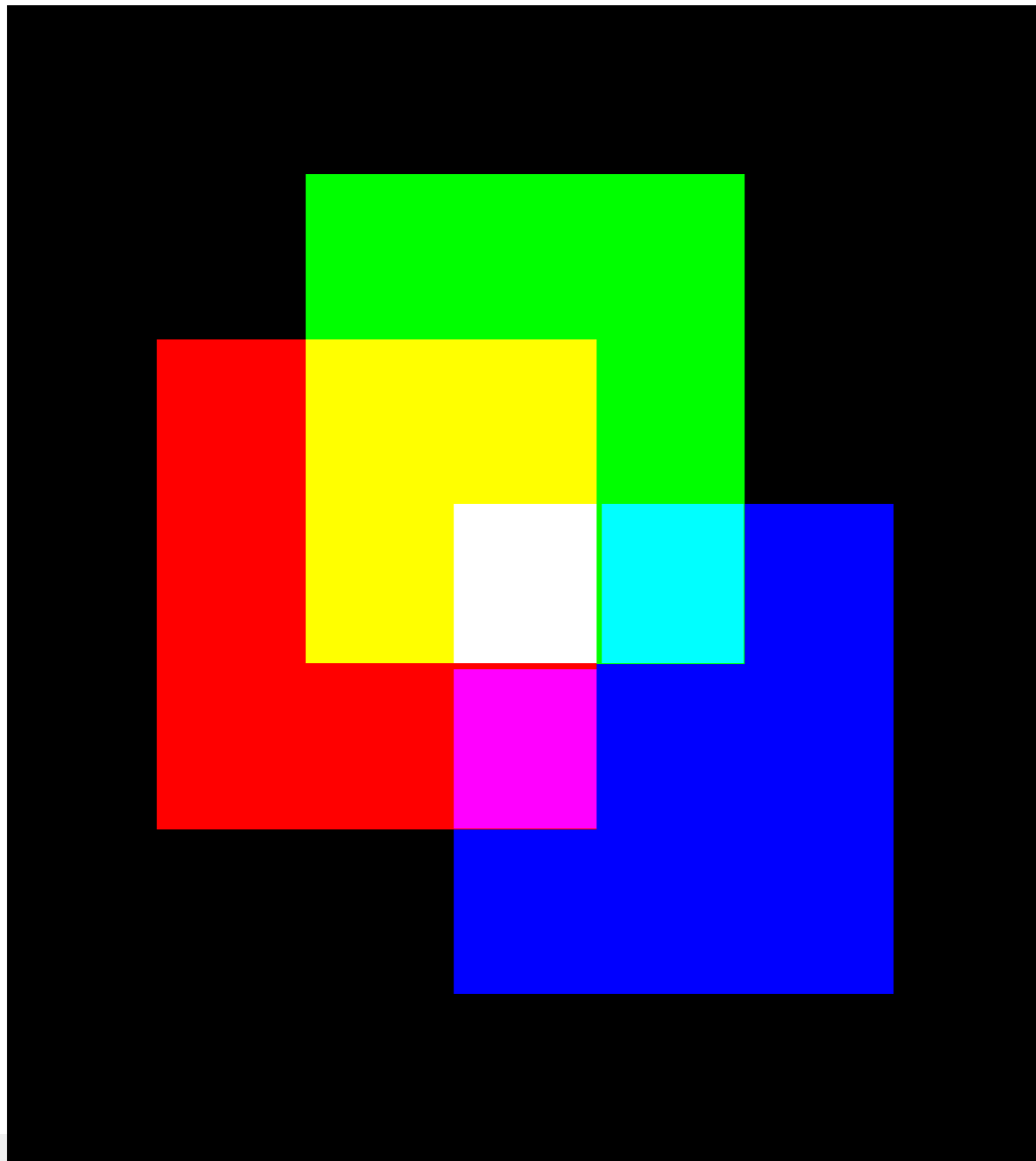
$$Y = \int_0^{\infty} I(\lambda) \rho(\lambda) \bar{y}(\lambda) d\lambda$$

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



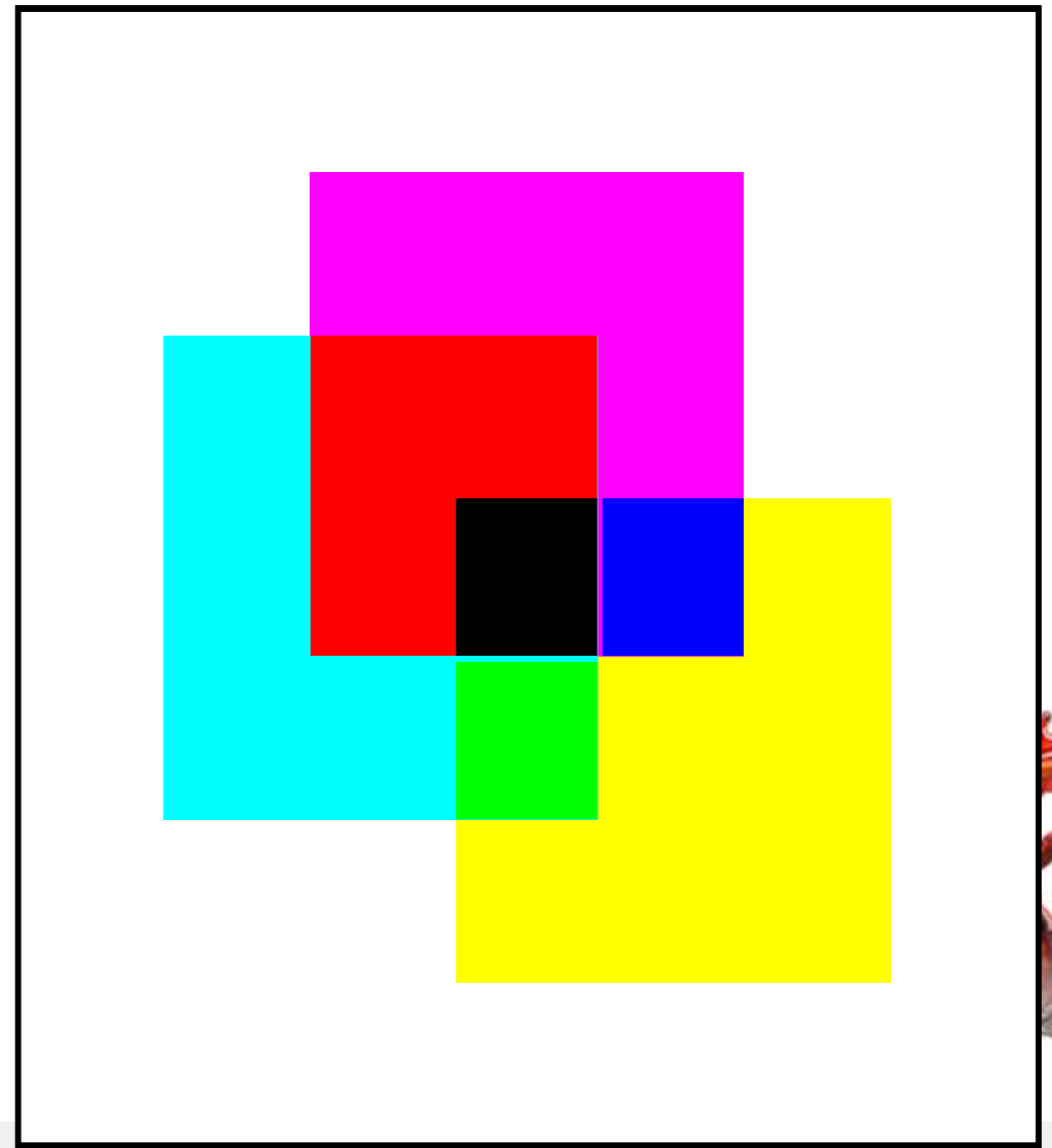
How Color is Produced?

Additive



(a)

Subtractive



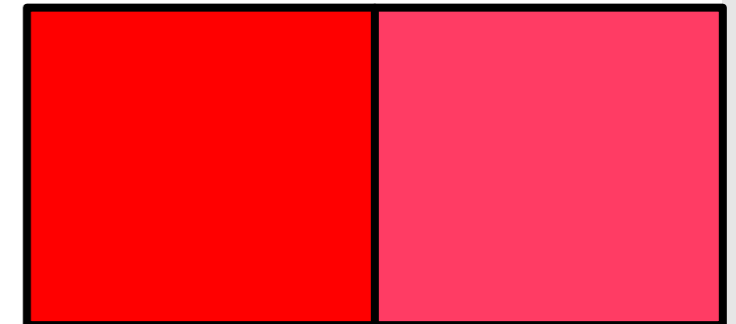
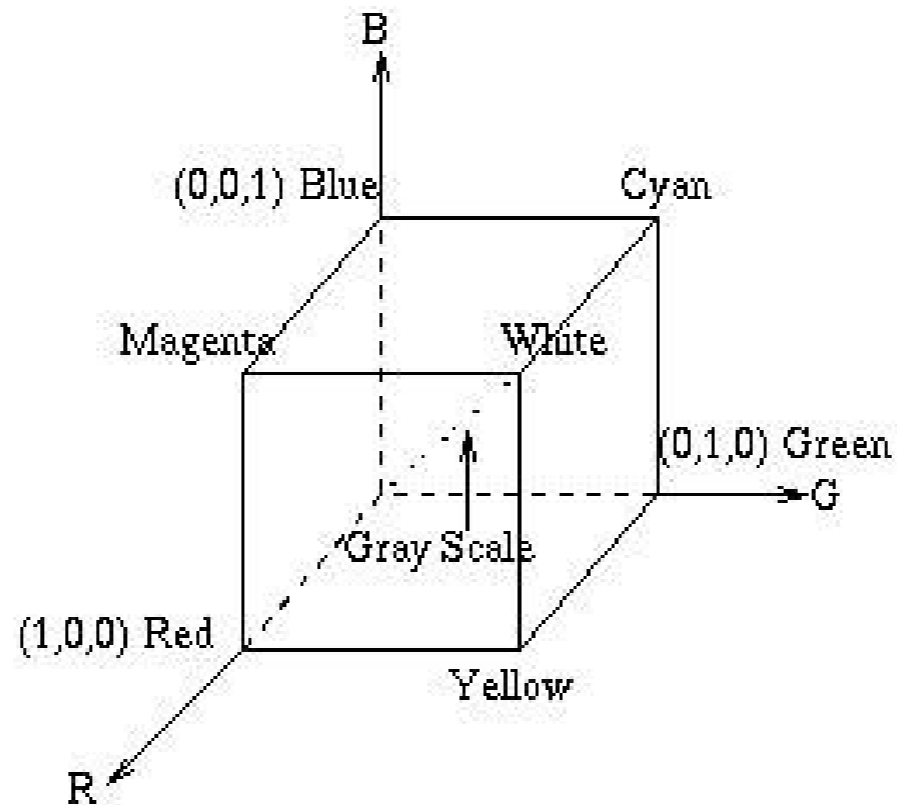
(b)



Color Space

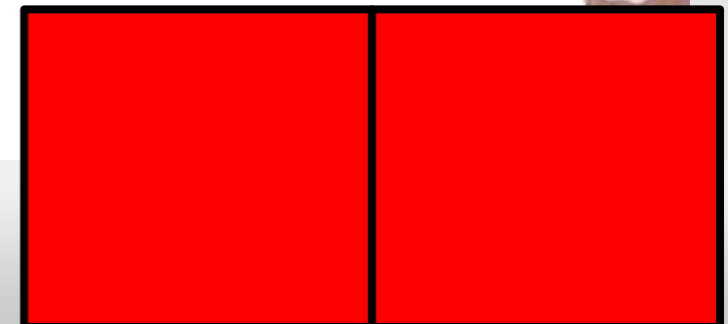
- Device dependent: the description of color information is related to the characteristics of a particular device

- 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...



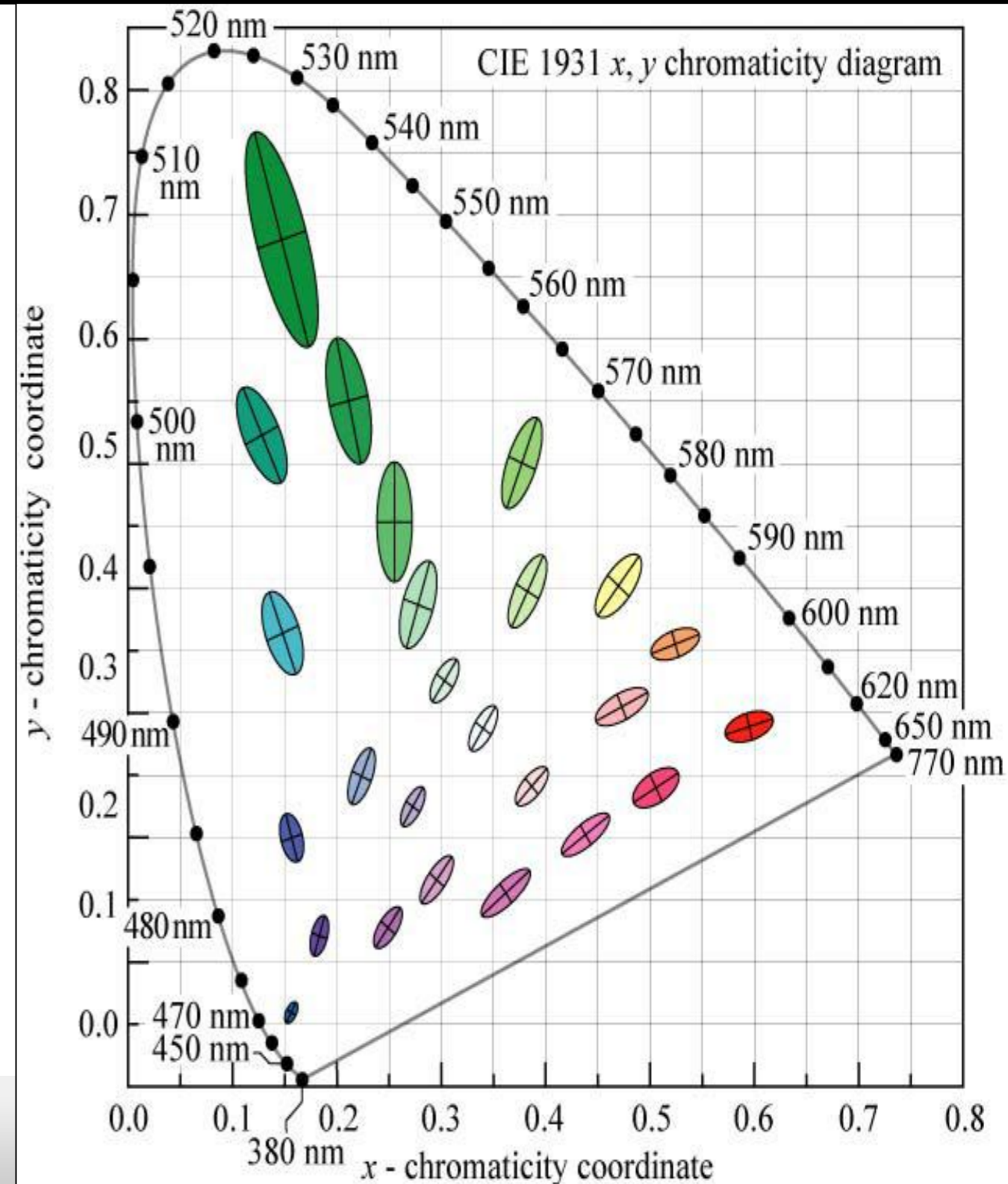
Chromaticity Diagram and MacAdam's Ellipses

MacAdam's Ellipses

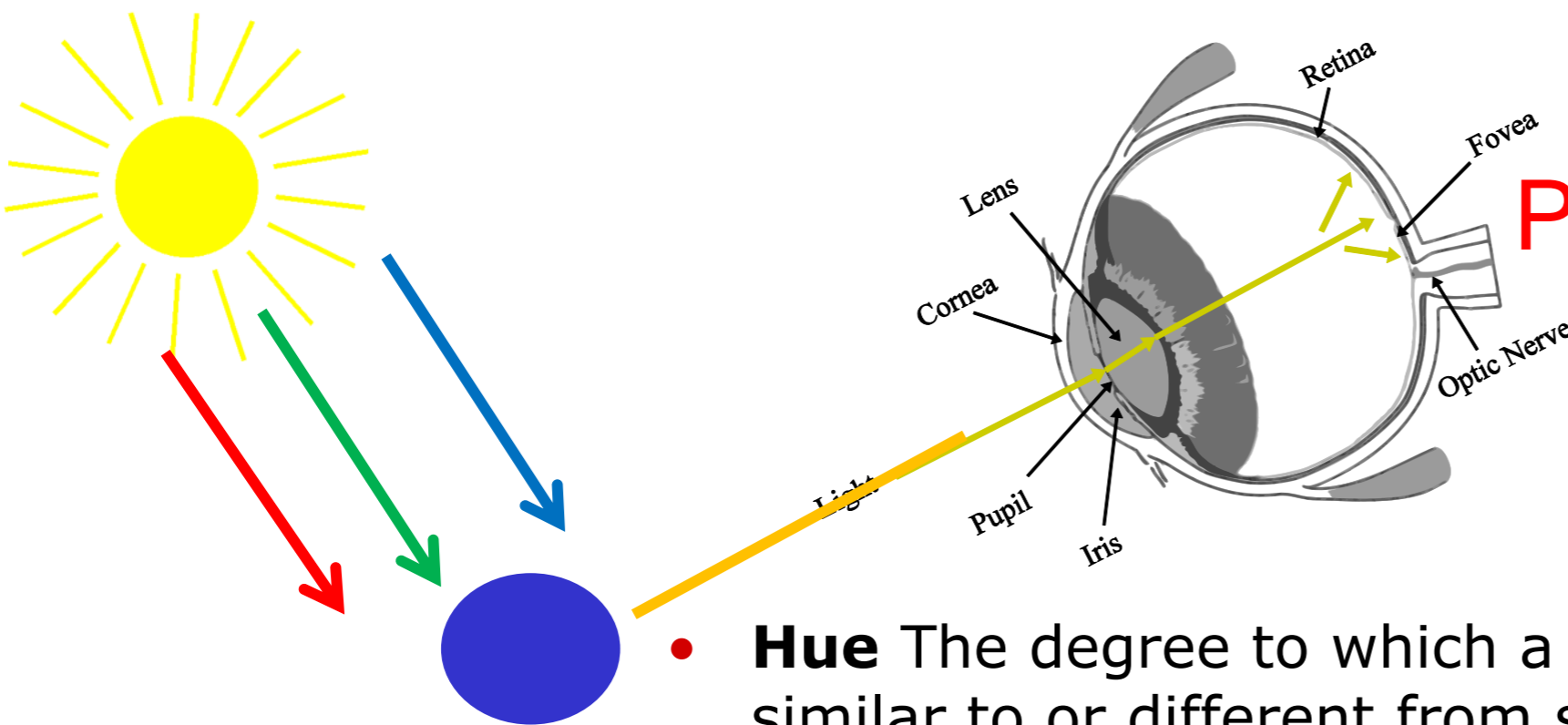
- contains all colors which are indistinguishable to an human observer from the color at the center of the ellipse
- the contour of the ellipse represents the just noticeable differences of chromaticity

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

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



Color Attributes by the CIE



- 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.

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



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



Color in High Dynamic Range

- Saturation Control (Thumblin and Turk 1999)

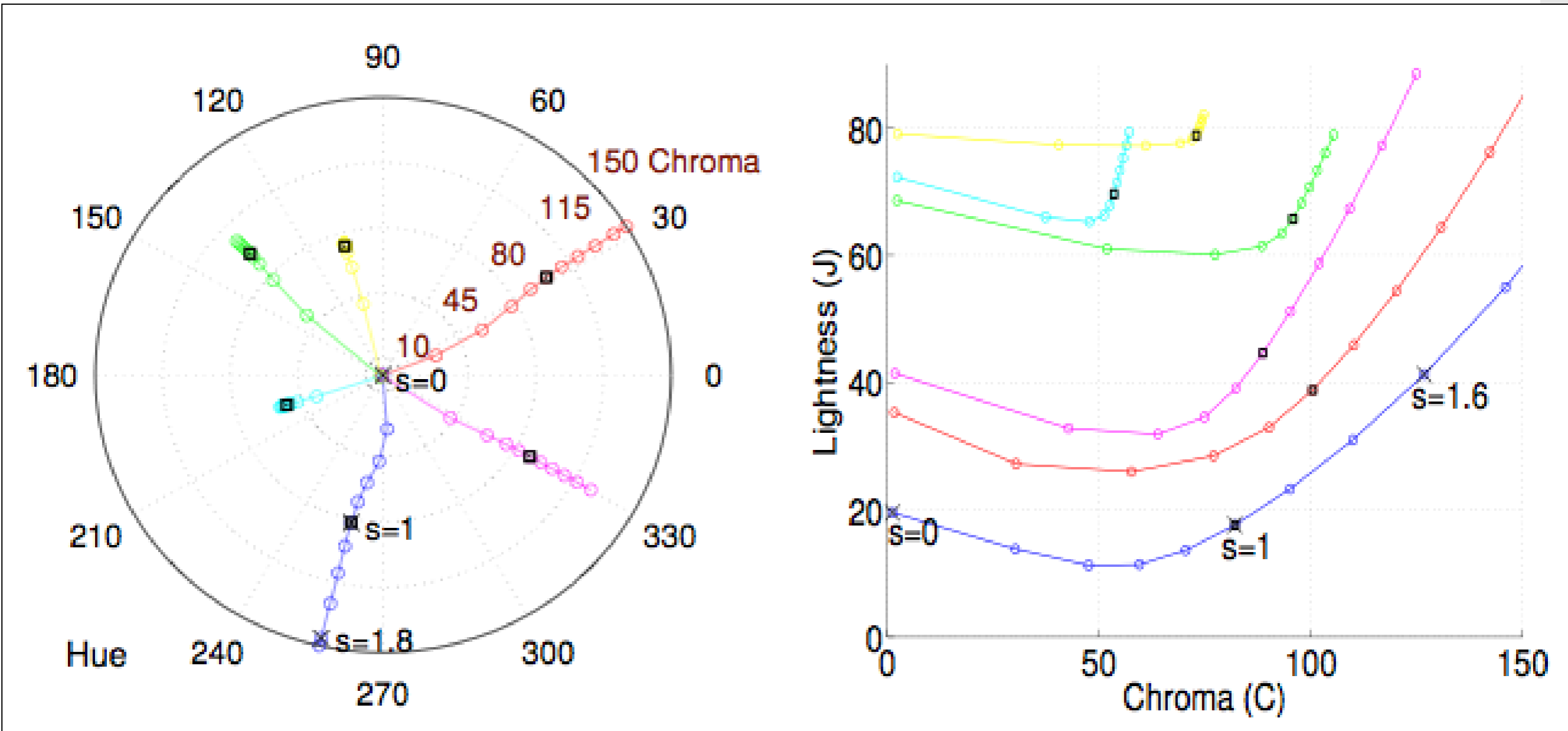
$$RGB_{out} = \left(\frac{RGB_{in}}{L_{in}} \right)^s L_{out}$$

s Saturation Parameter
 c Contrast Compression

Under-saturated colors for $S=C$.



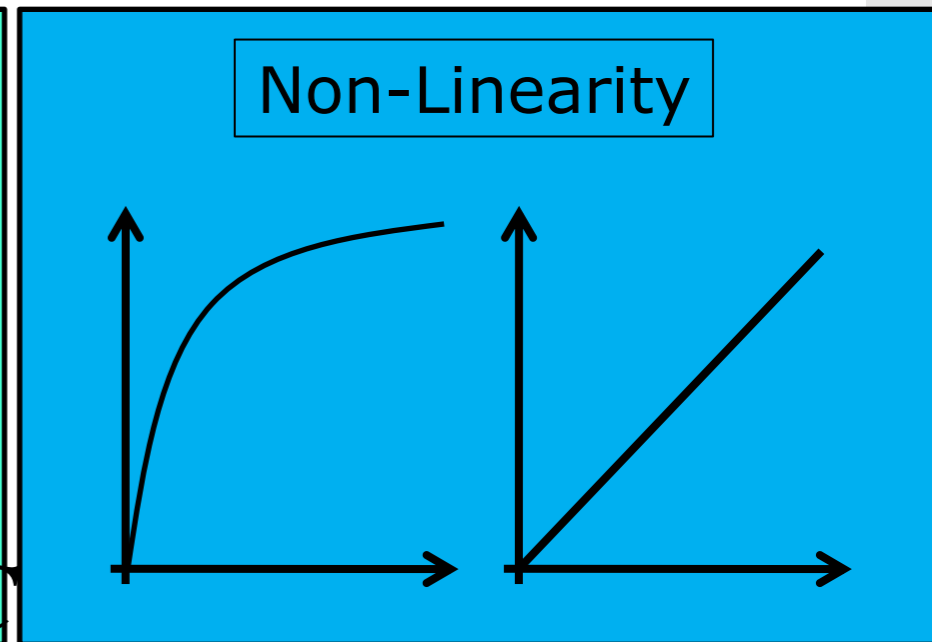
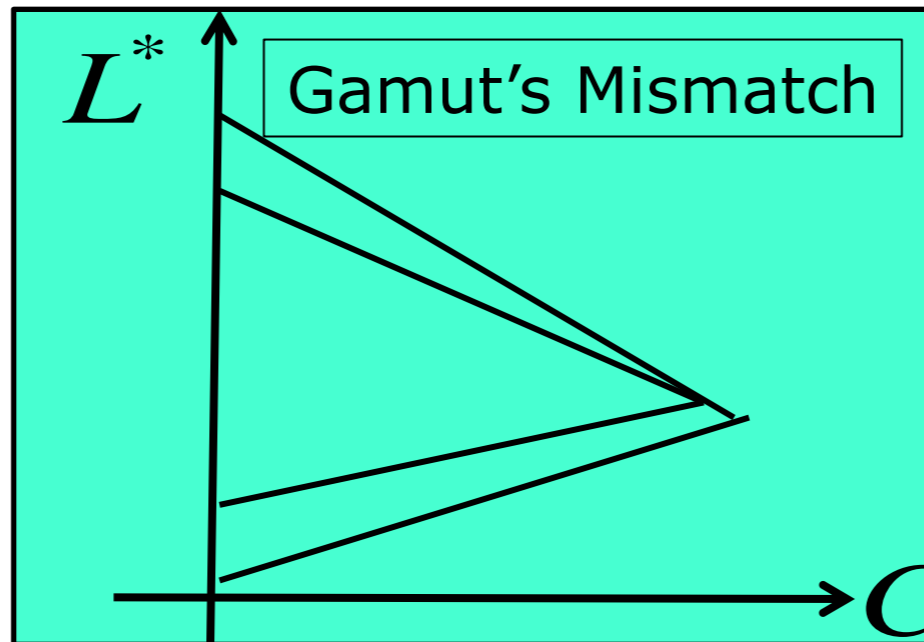
Color in High Dynamic Range



Color Rendering Pipeline (8 Bit)



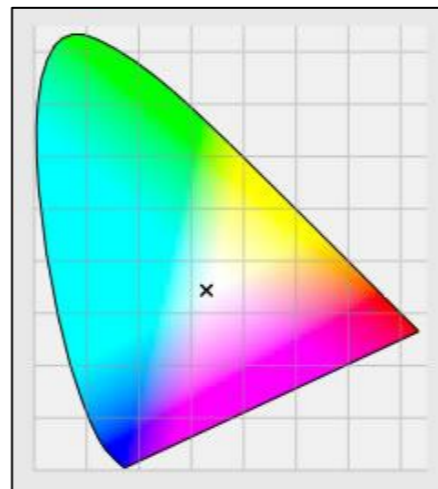
Image Acquisition



Displaying



Device Independent



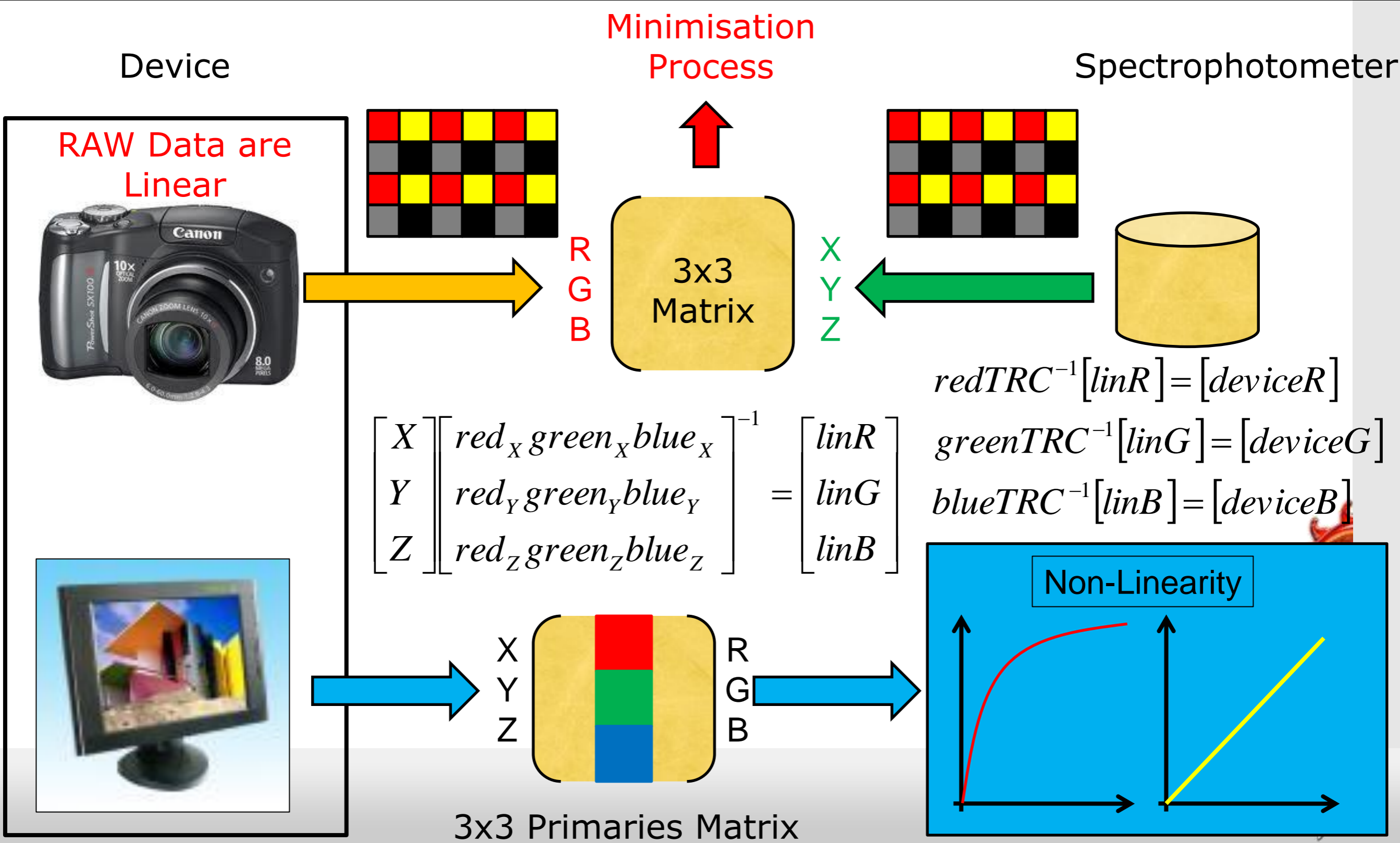
Device Dependent



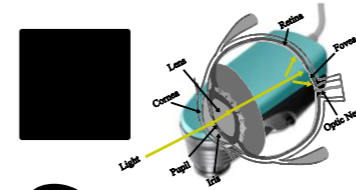
Colorimetric Characterization



Colorimetric Characterisation of a Device



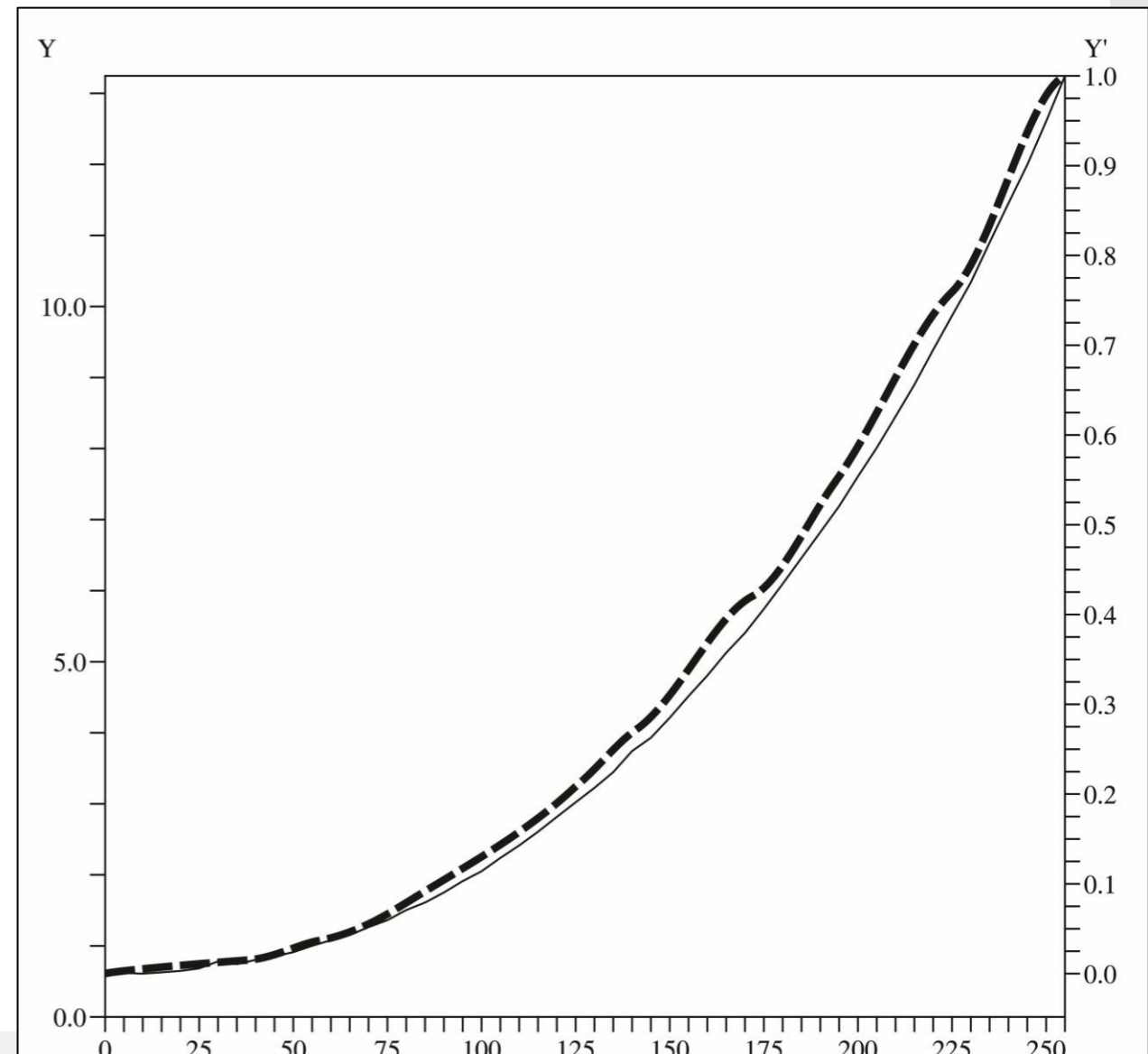
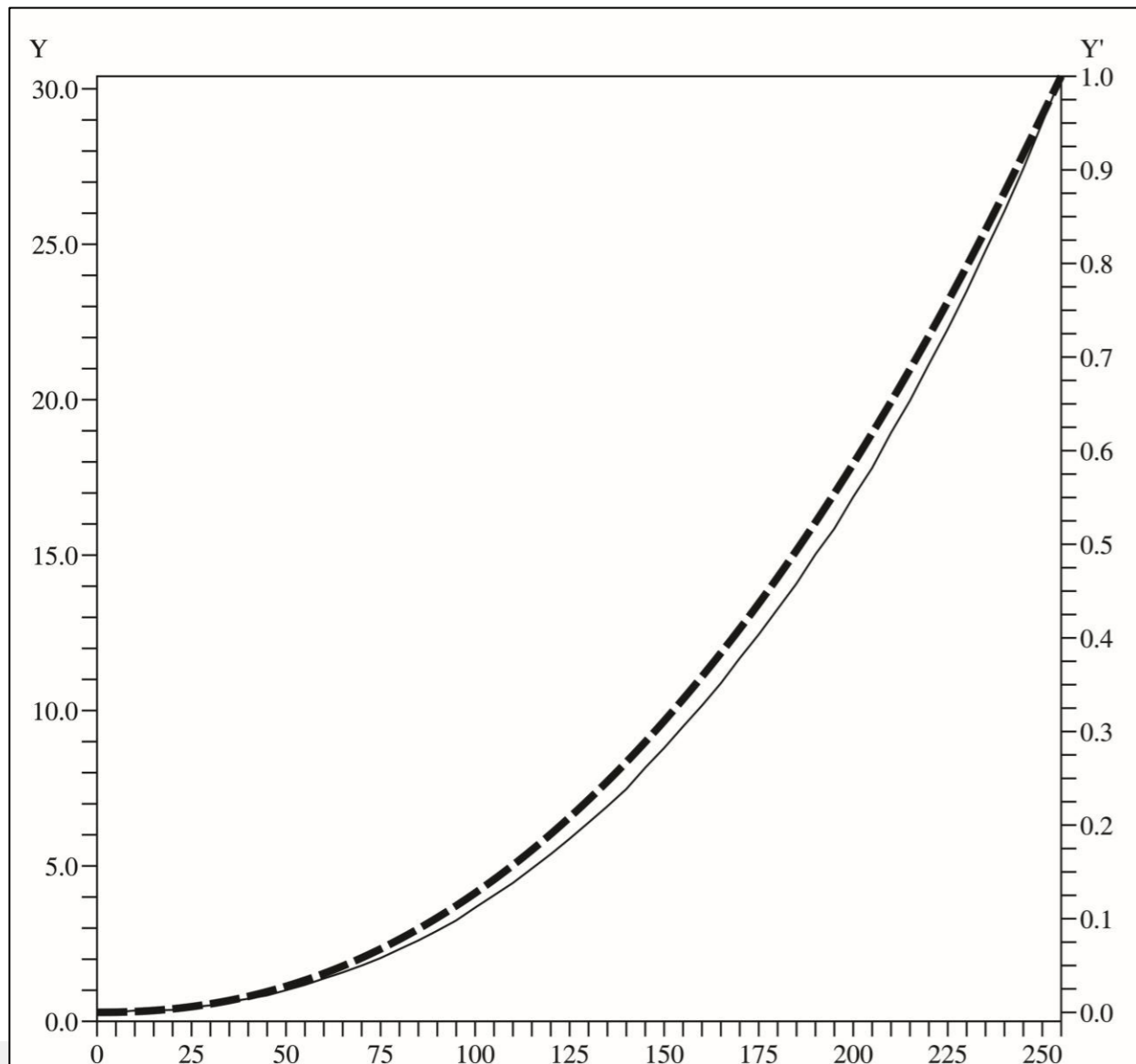
Gamma – Curve



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

Gamma Response for RED

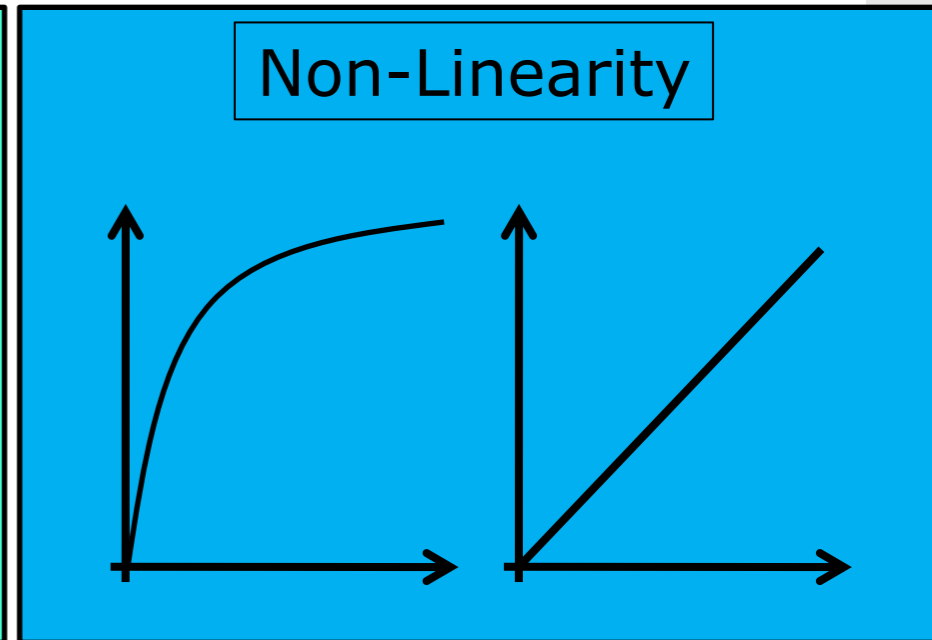
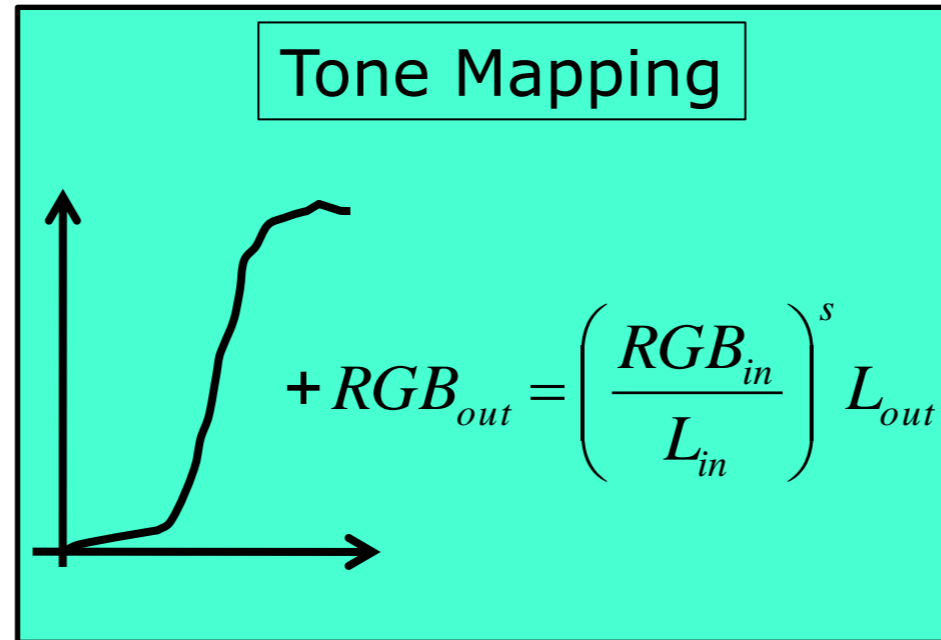
Gamma Response for BLUE



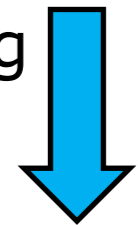
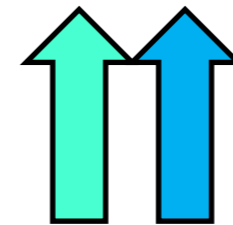
Color Rendering Pipeline in HDR



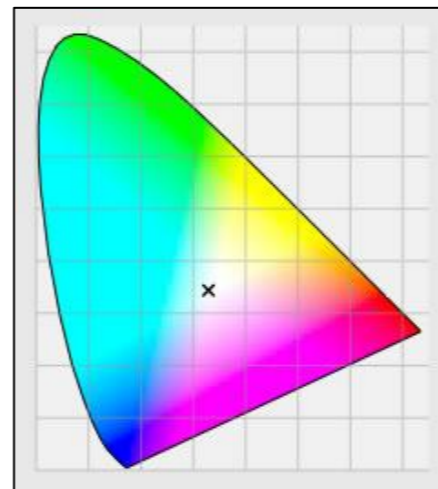
HDR Image Acquisition



Displaying



Device Independent



Device Dependent

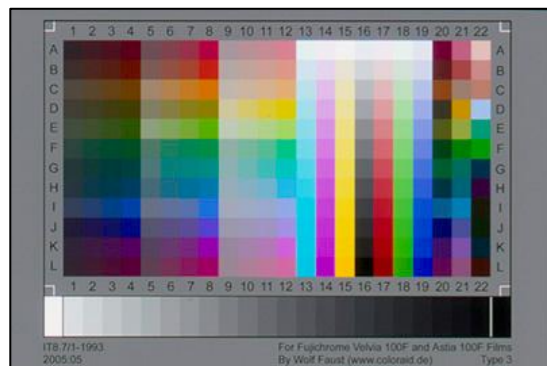


Colorimetric Characterization

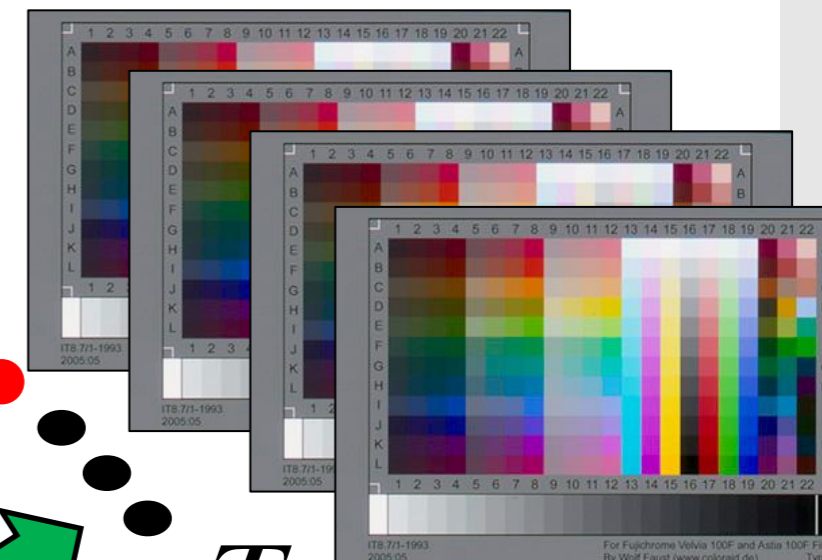


HDR ICC Profile

Target



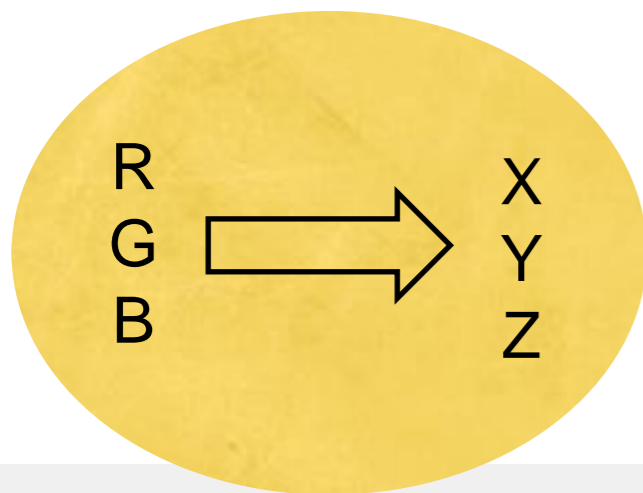
T_1



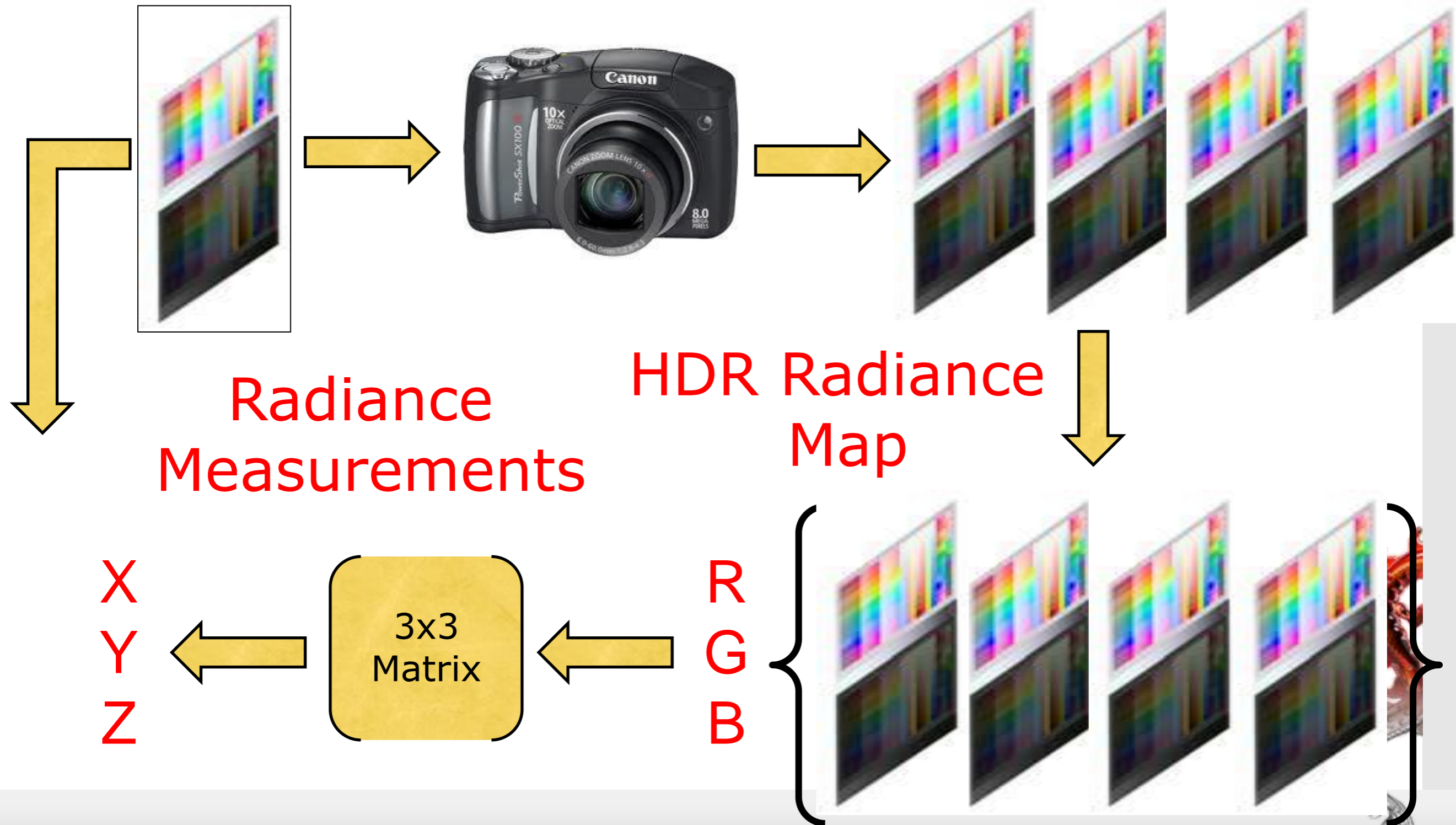
T_n

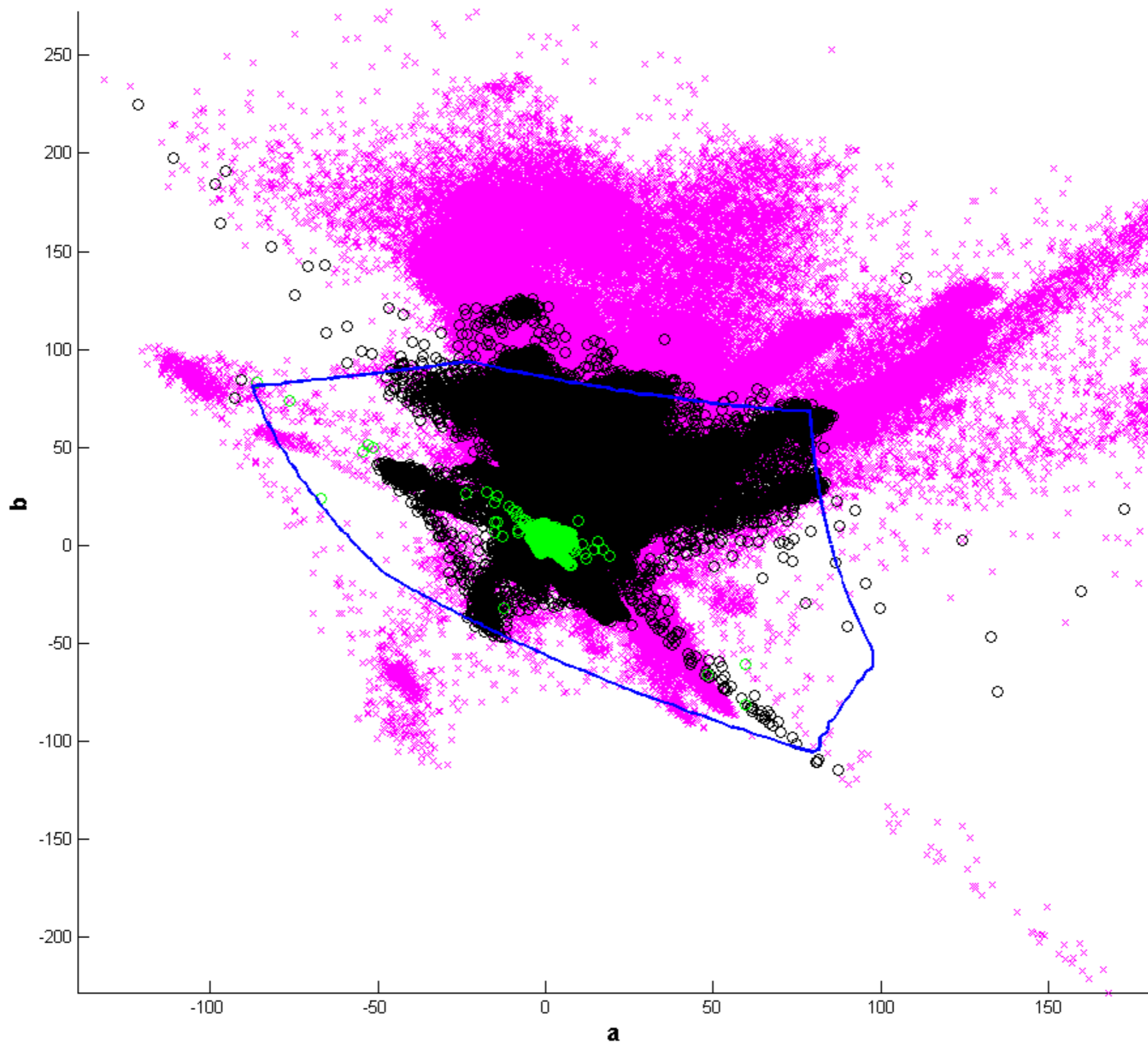
- Best Exposure Image

ICC Profile

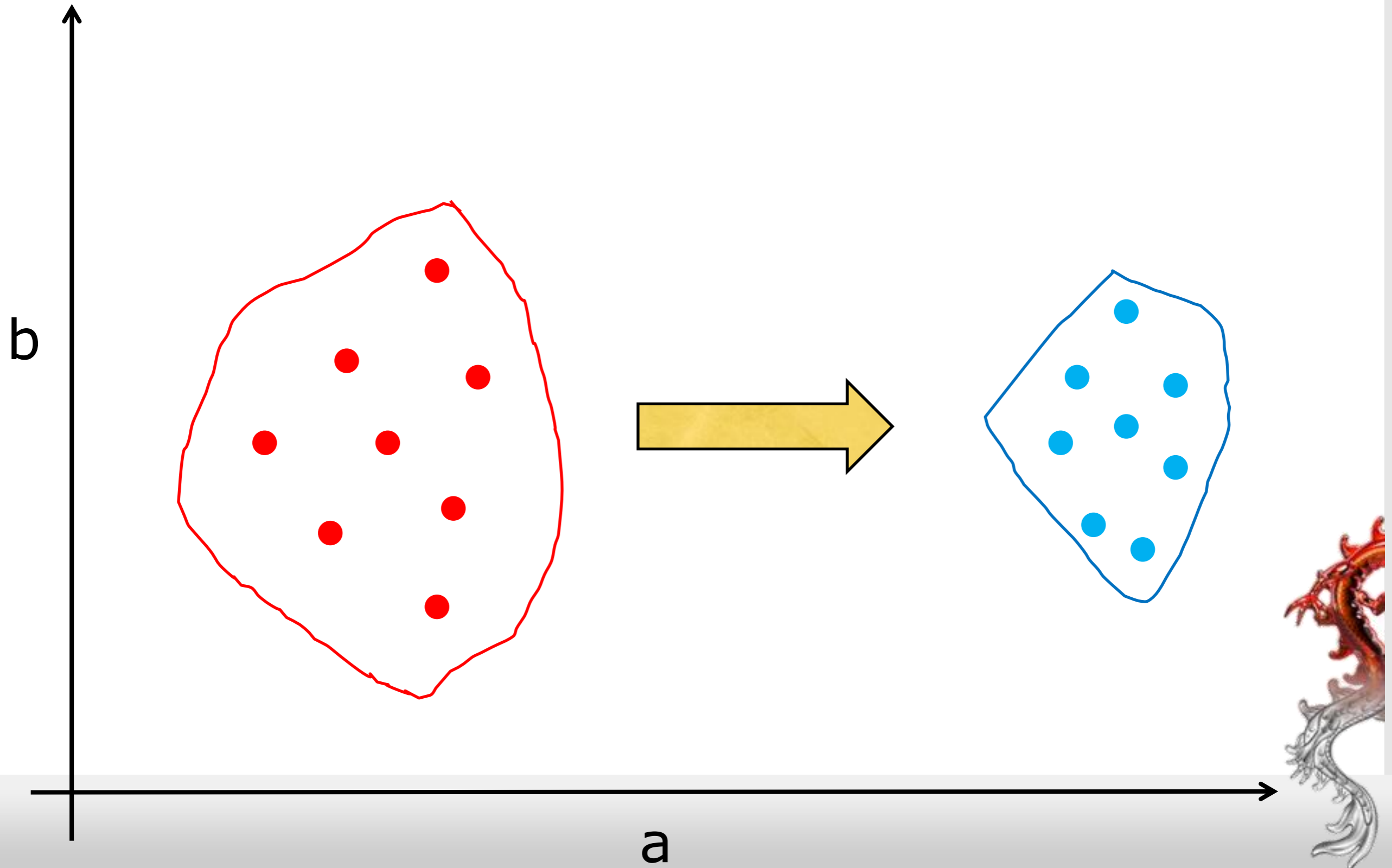


HDR Colorimetric Camera Characterization

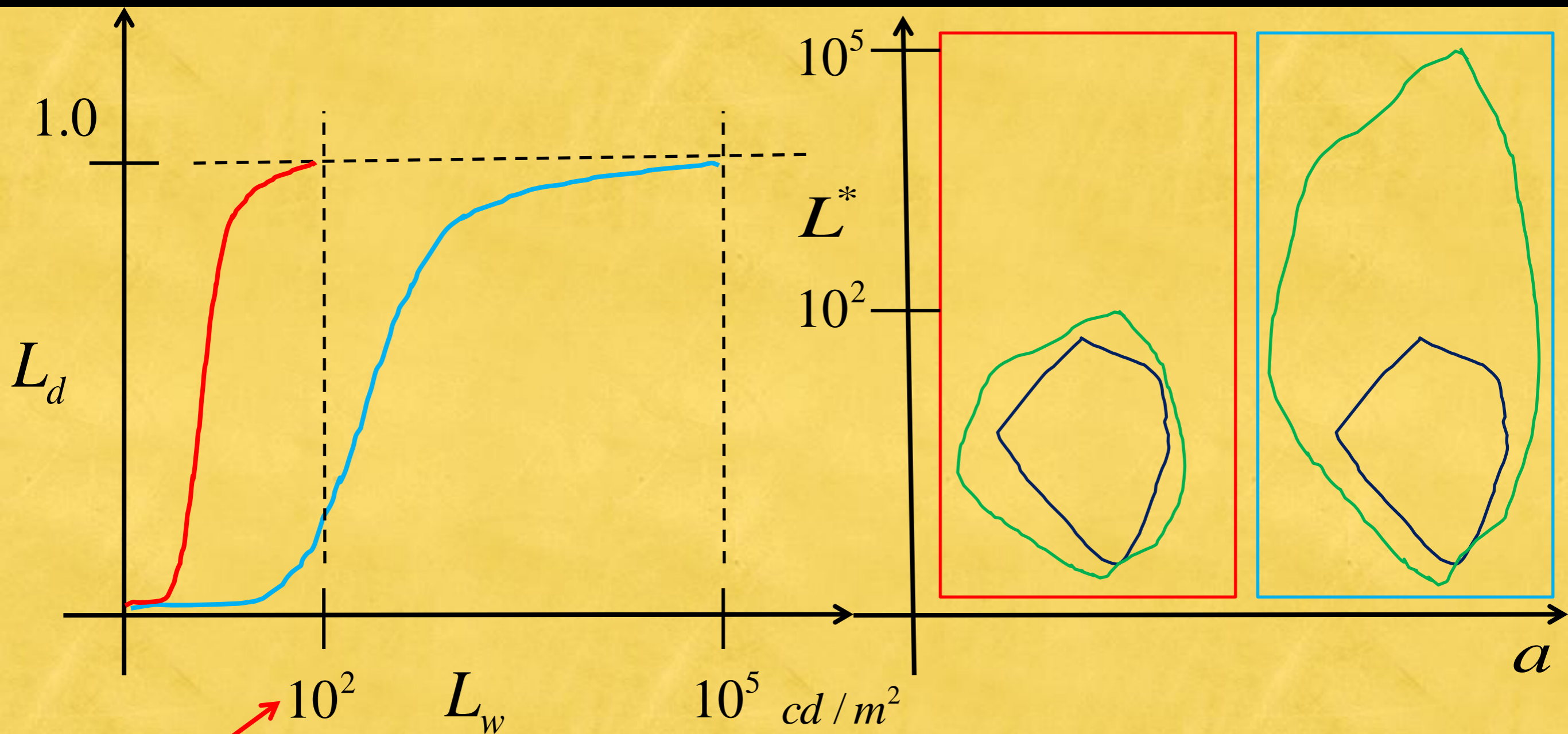




Gamut Mapping



Gamut vs. Tone Mapping

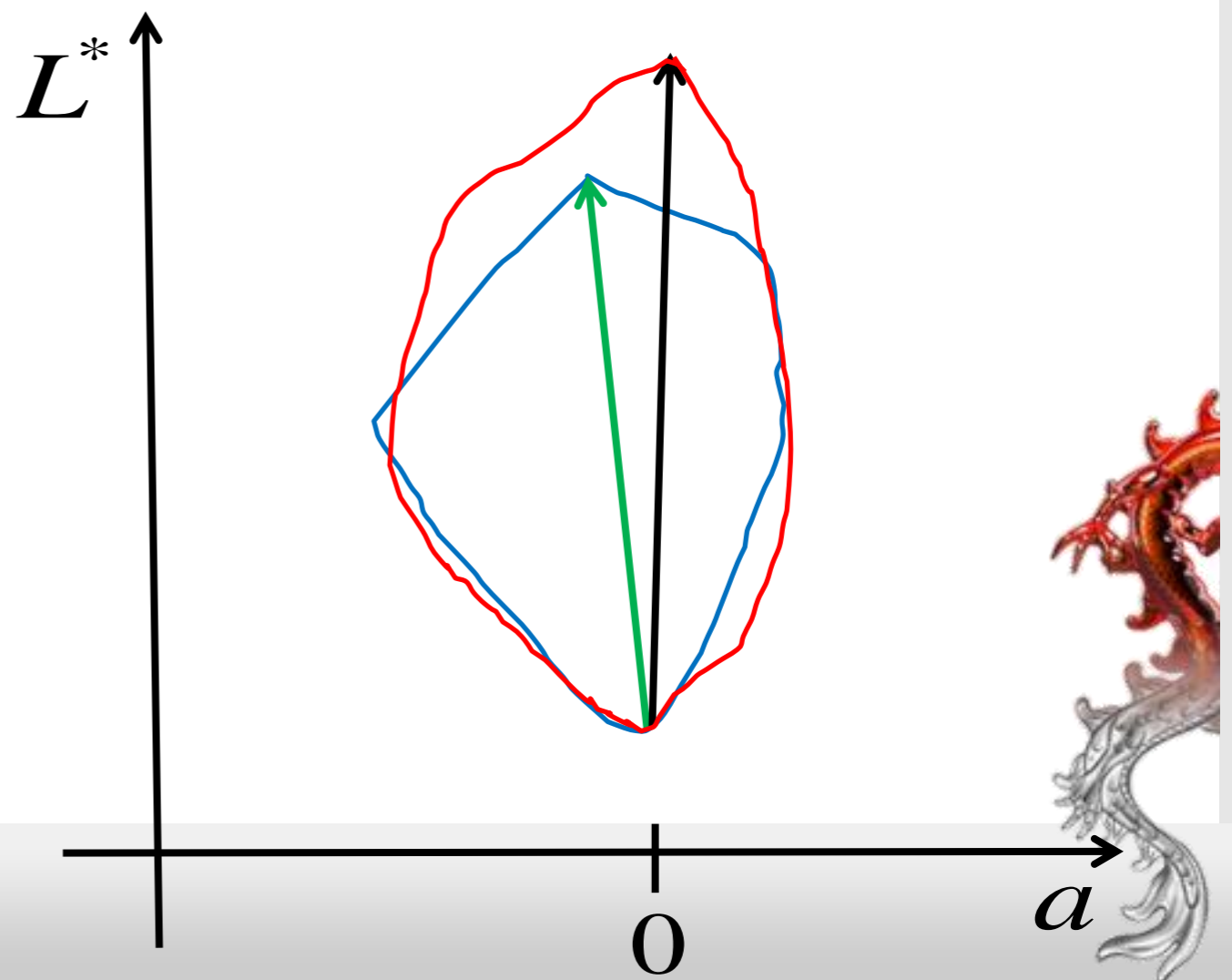
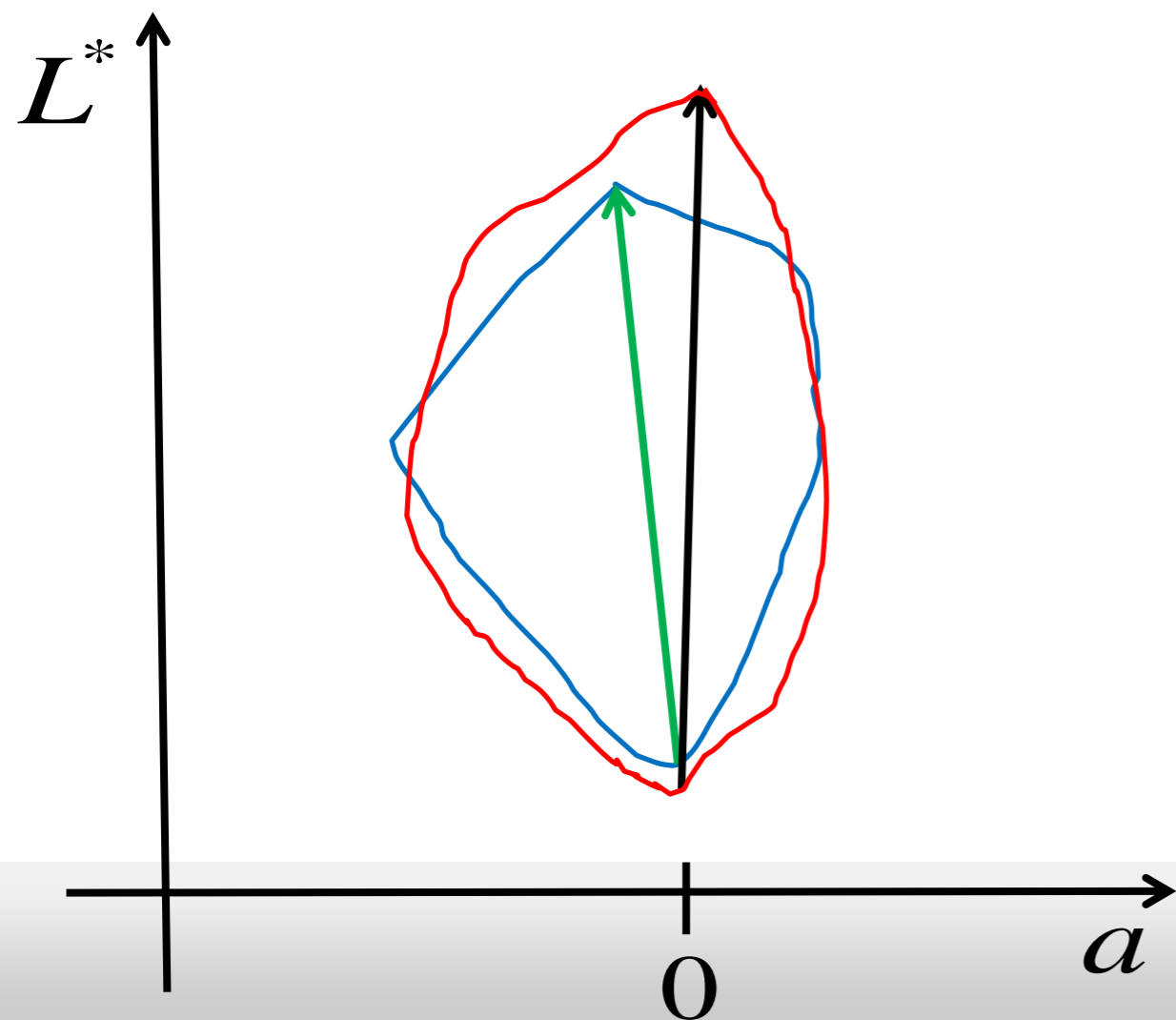


Not HDR Content



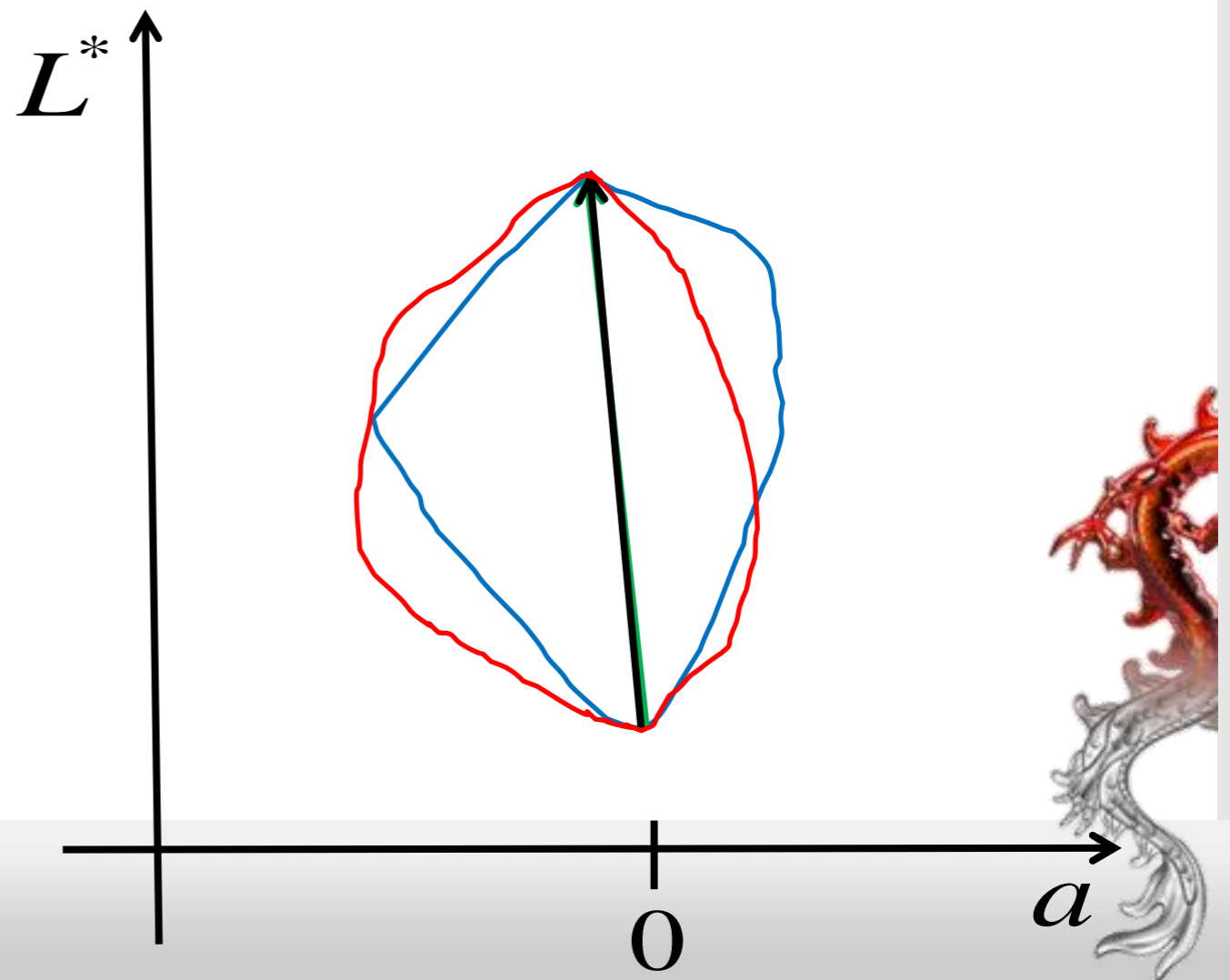
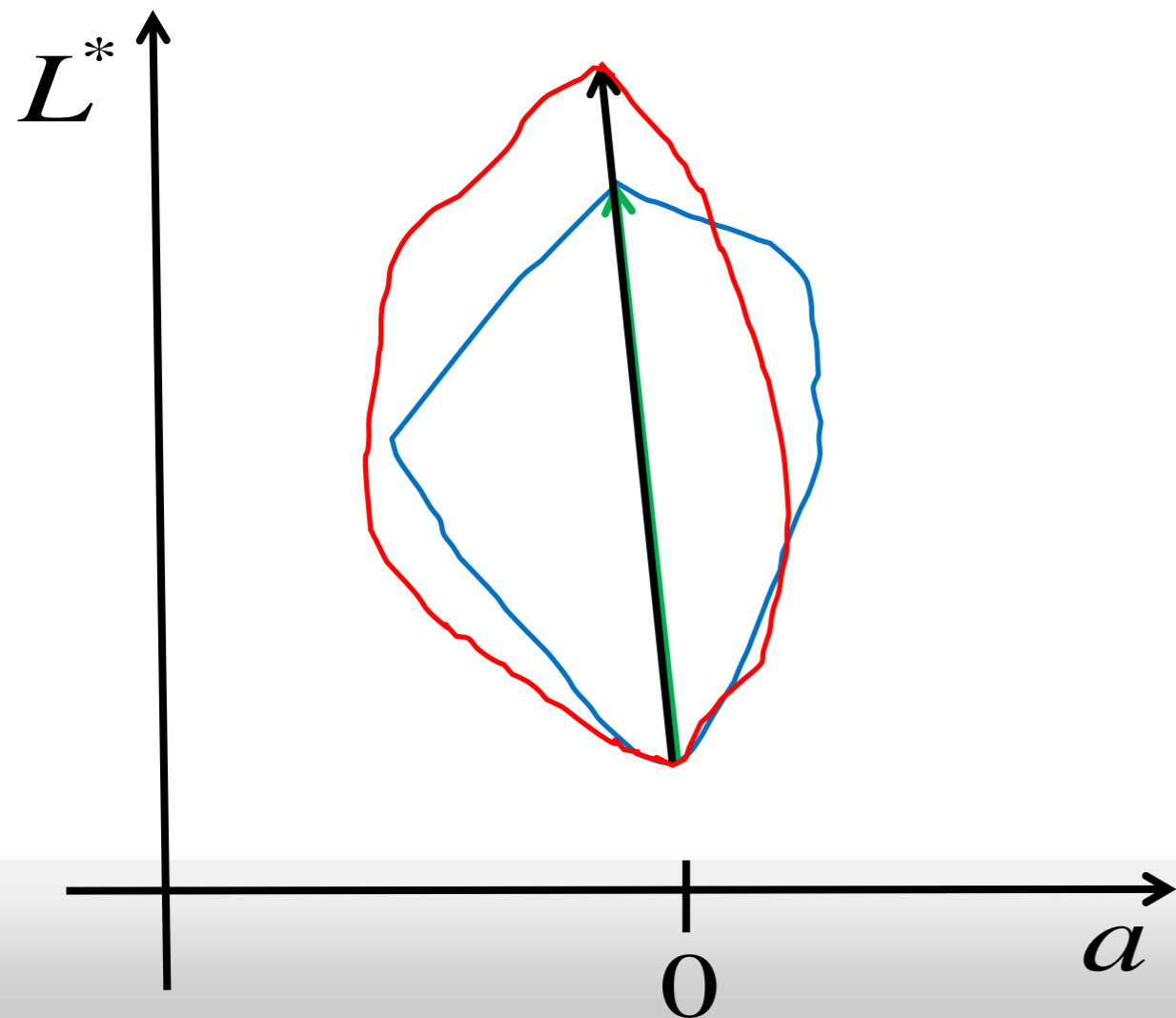
Gamut Mapping Aims (CS)

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



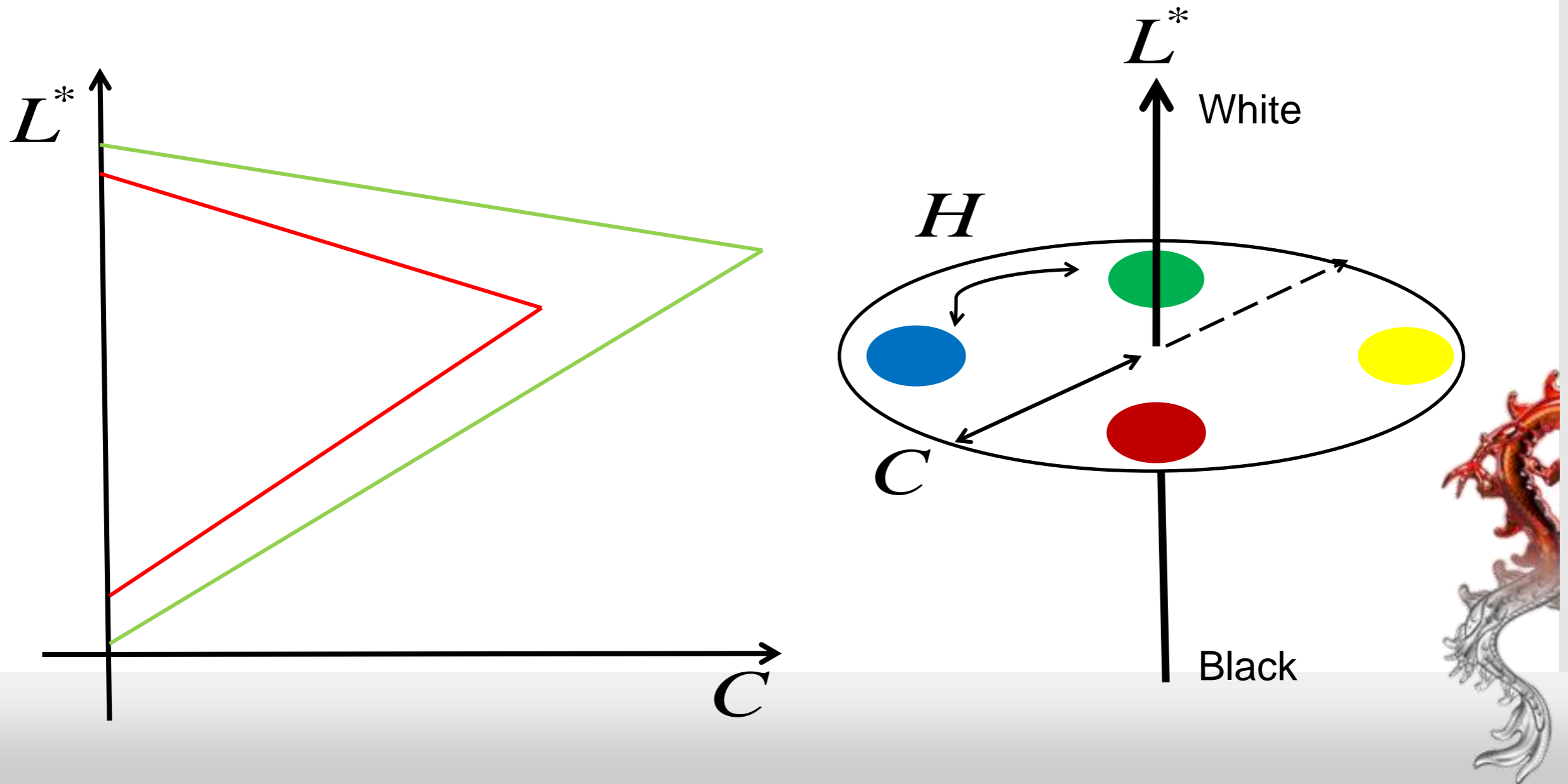
Gamut Mapping Aims (CS)

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



Gamut Mapping Aims (CS)

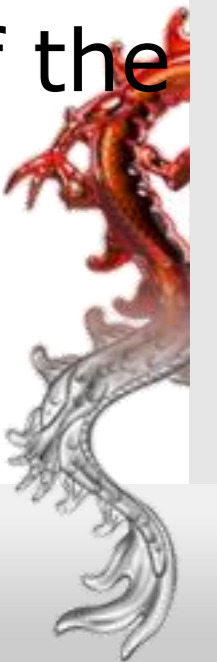
- Unchanged the Hue shift, will keep the overall image appearance



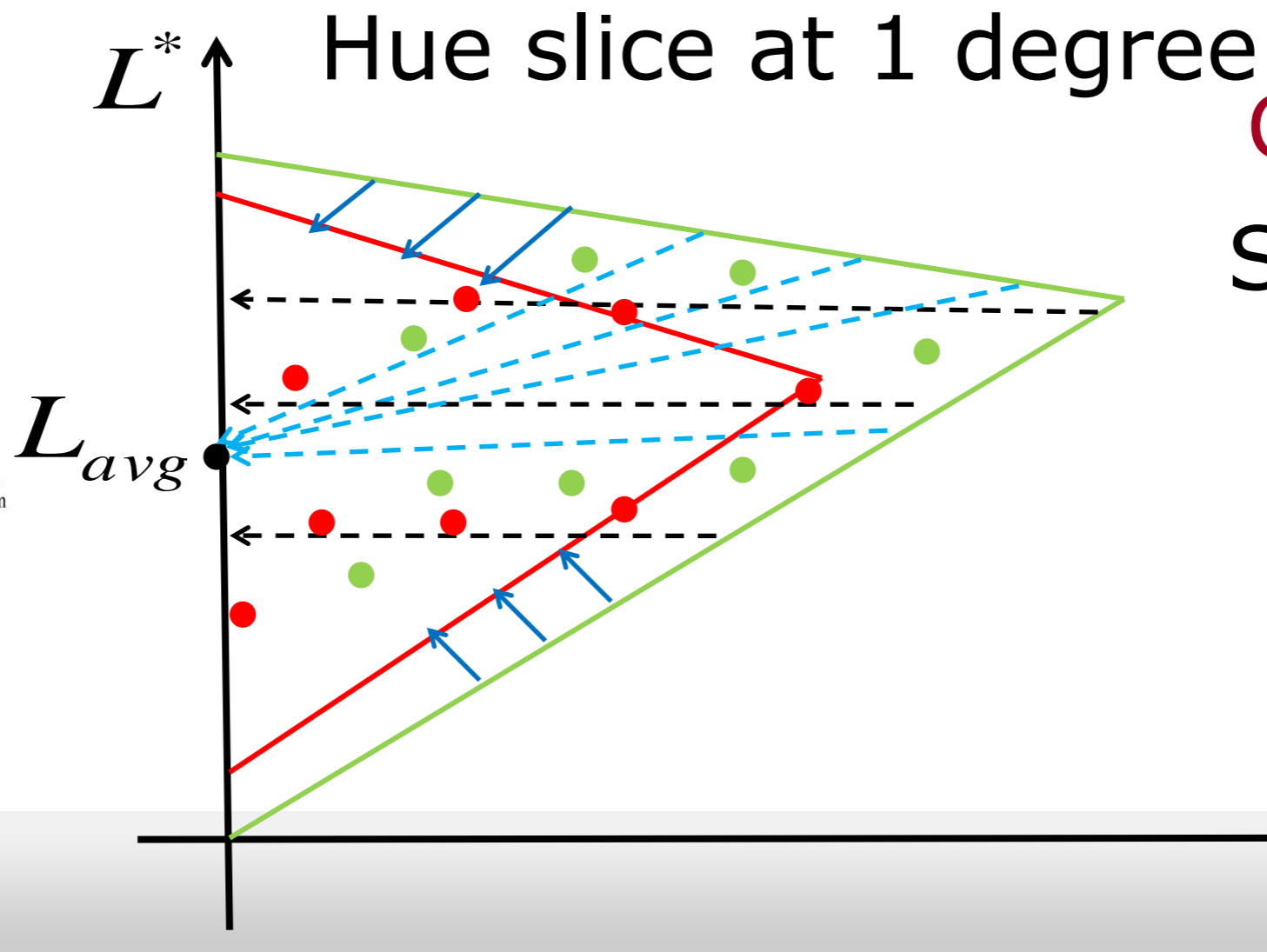
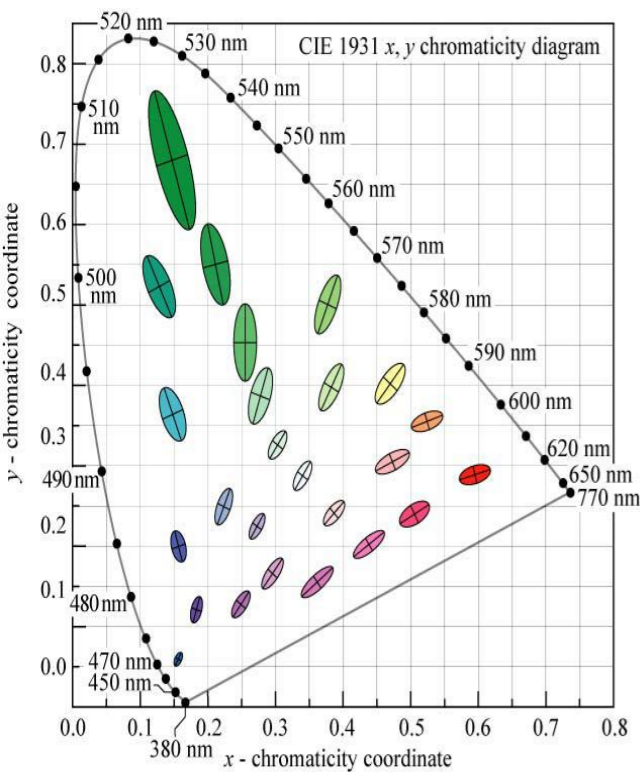
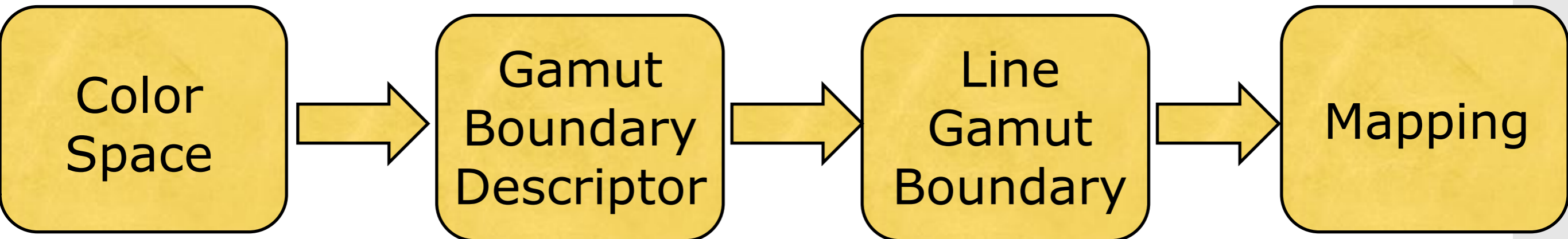
Gamut Mapping Aims (CS)



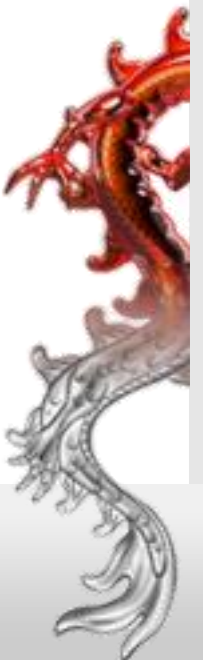
- Limiting out of gamut colours
 - Soft clipping can be afterwards adopted to eliminate these extremes
- Increase Image saturation
 - Destination gamut has reduced saturation
 - Helps maintaining the original chroma differences of the input Image



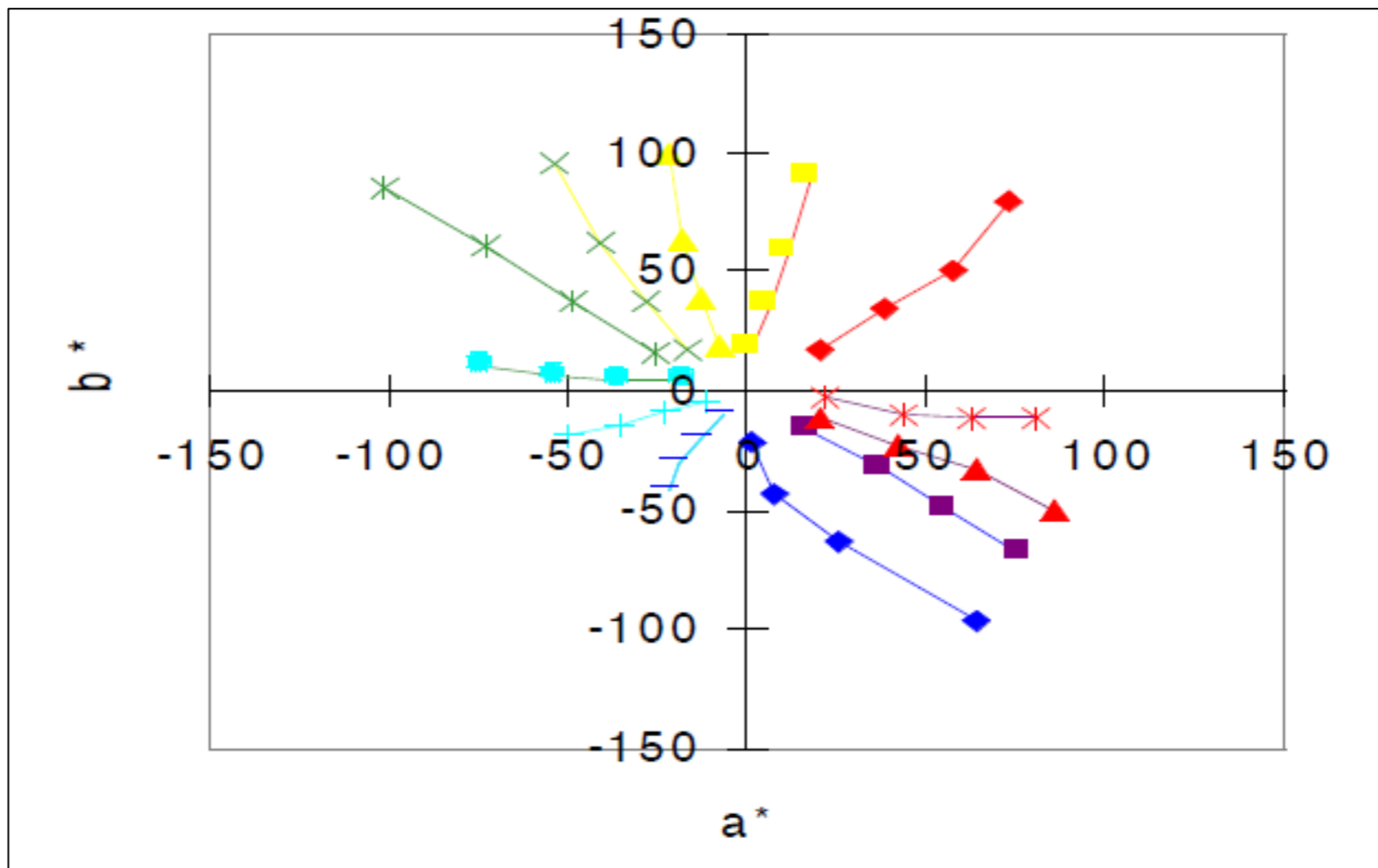
Gamut Mapping Pipeline



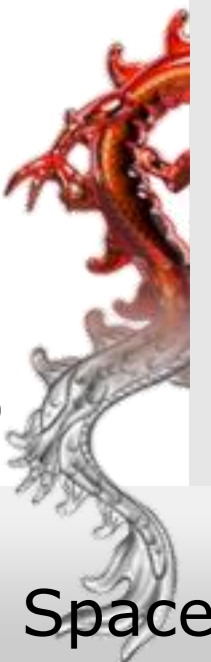
Clipping
Compression
Spatial GMAs



Color Space Issue



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



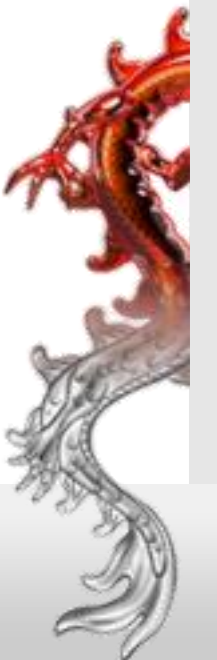
Point-wise Gamut Mapping Techniques



- **Clipping**

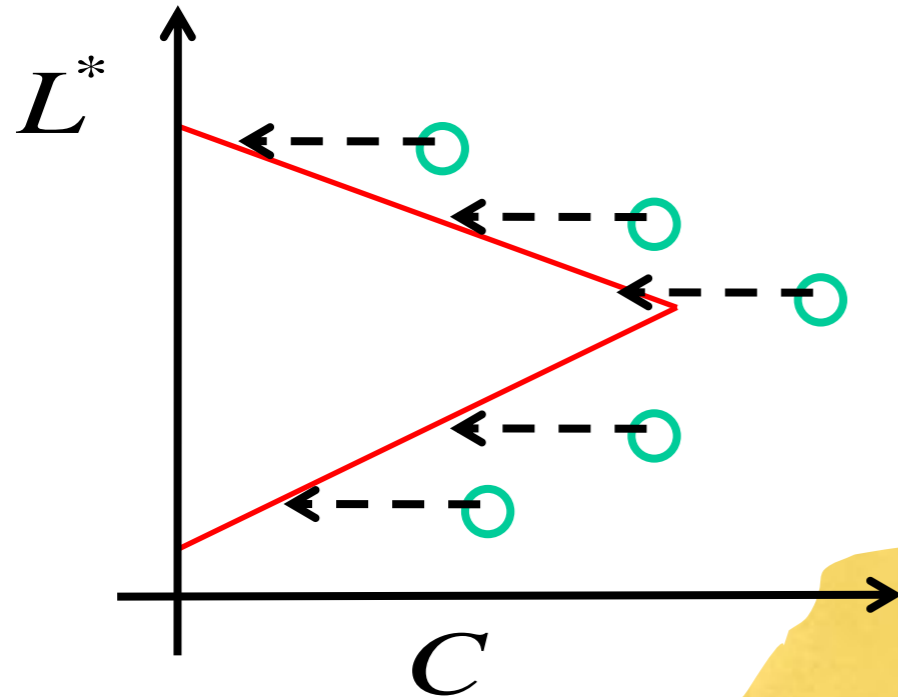
It changes colours which are outside of the destination gamut, mapping them on the boundaries of the destination gamut

- **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**)

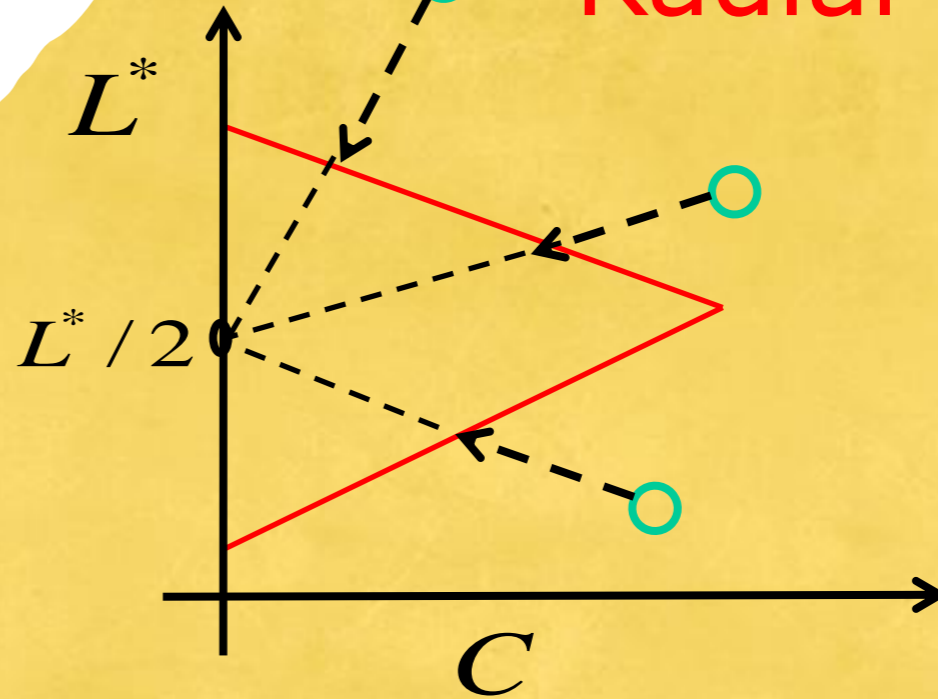


Clipping

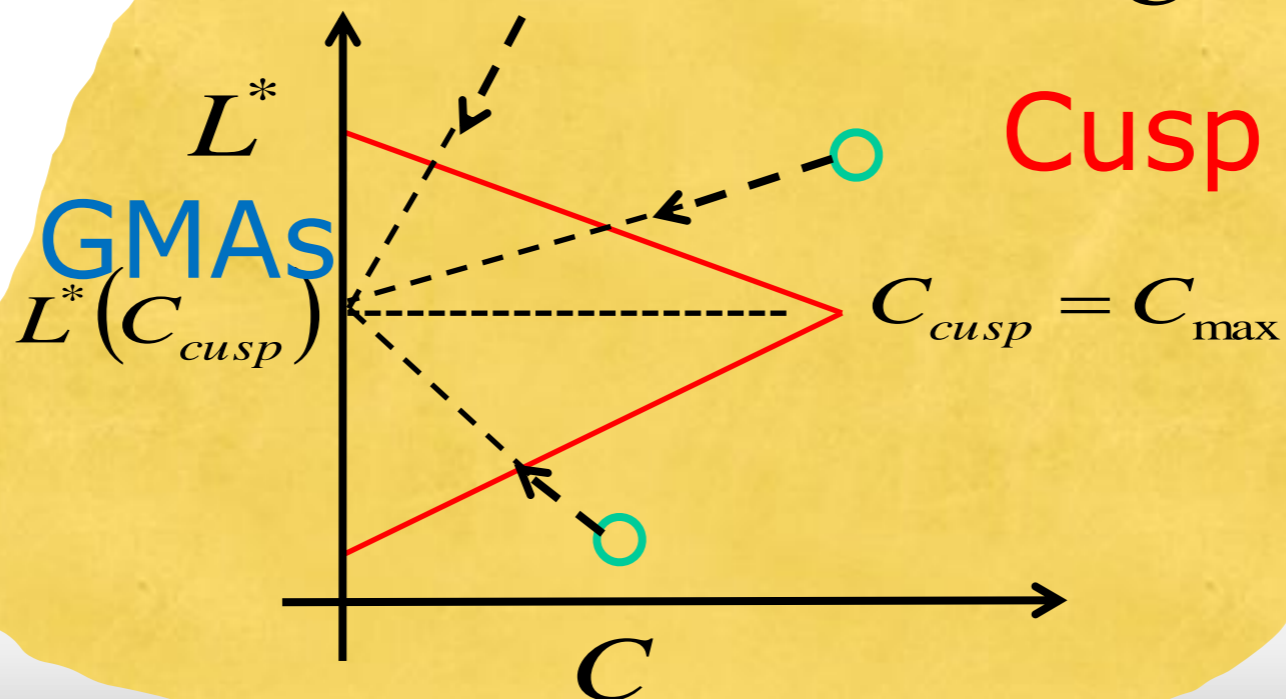
L^* Preservation



Radial to $L^*/2$



Cusp Radial

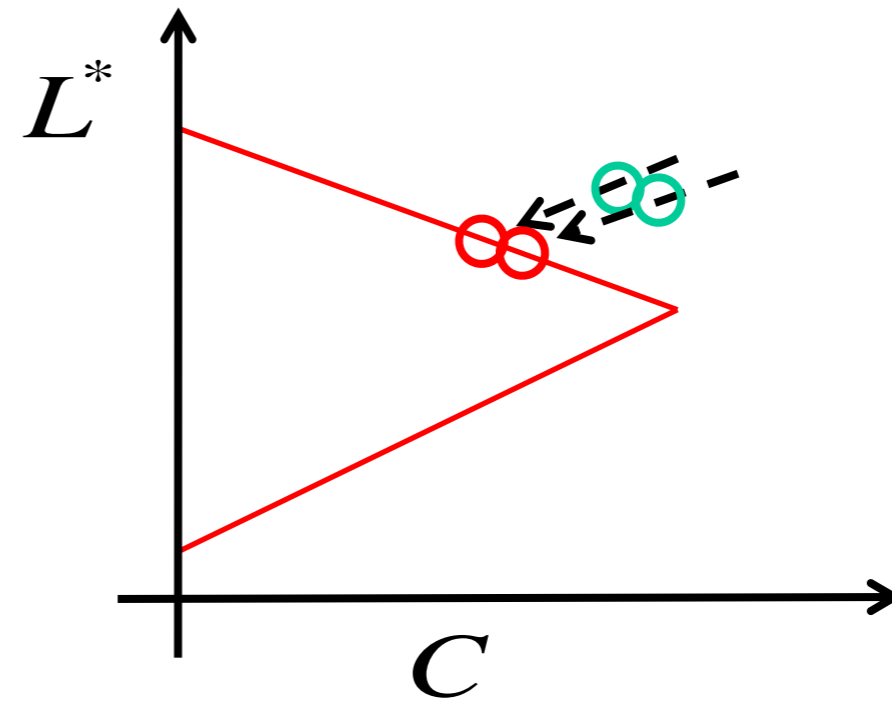
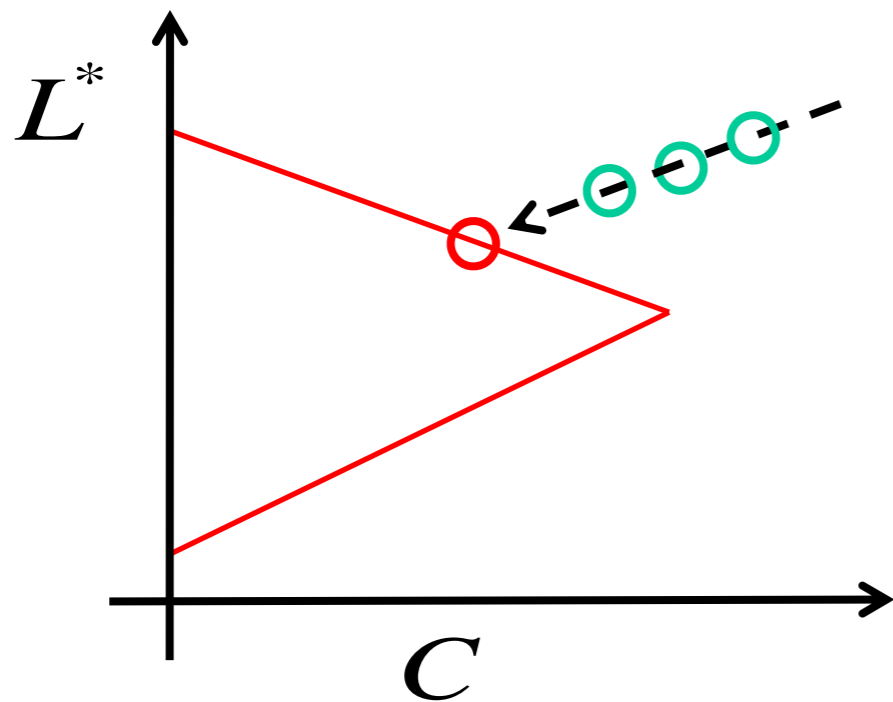


Simultaneous GMAs

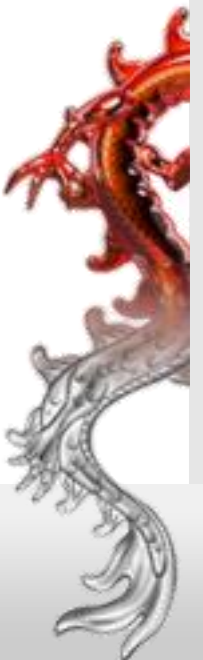


Clipping – Major Drawbacks

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 .

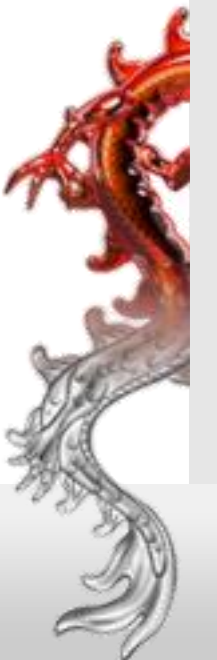
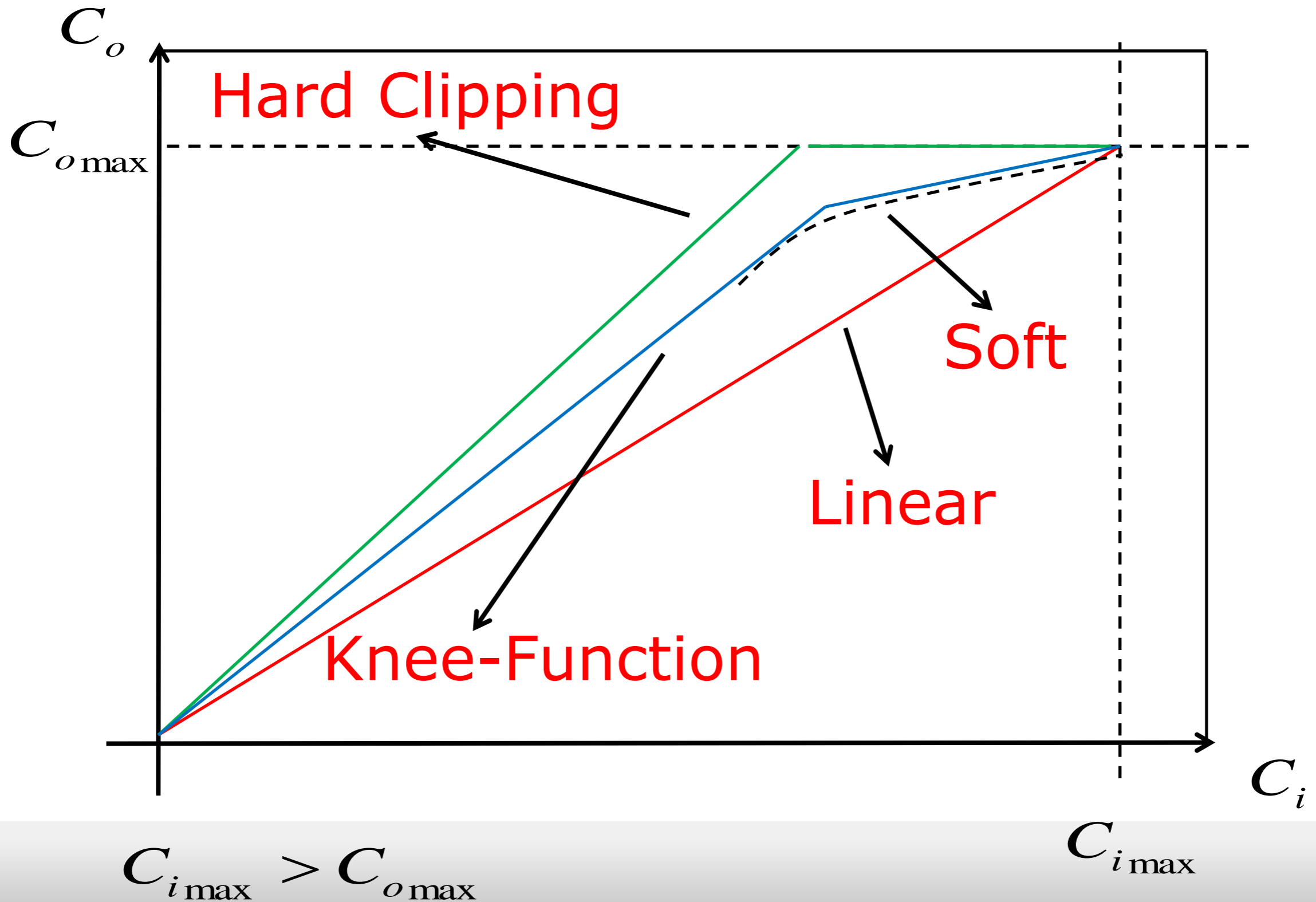
- **Linear**
- **Sigmoid**
- **Knee-function**

- **Parametric**

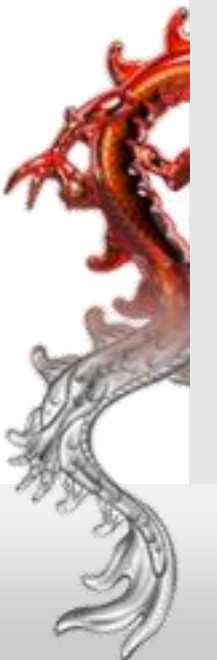
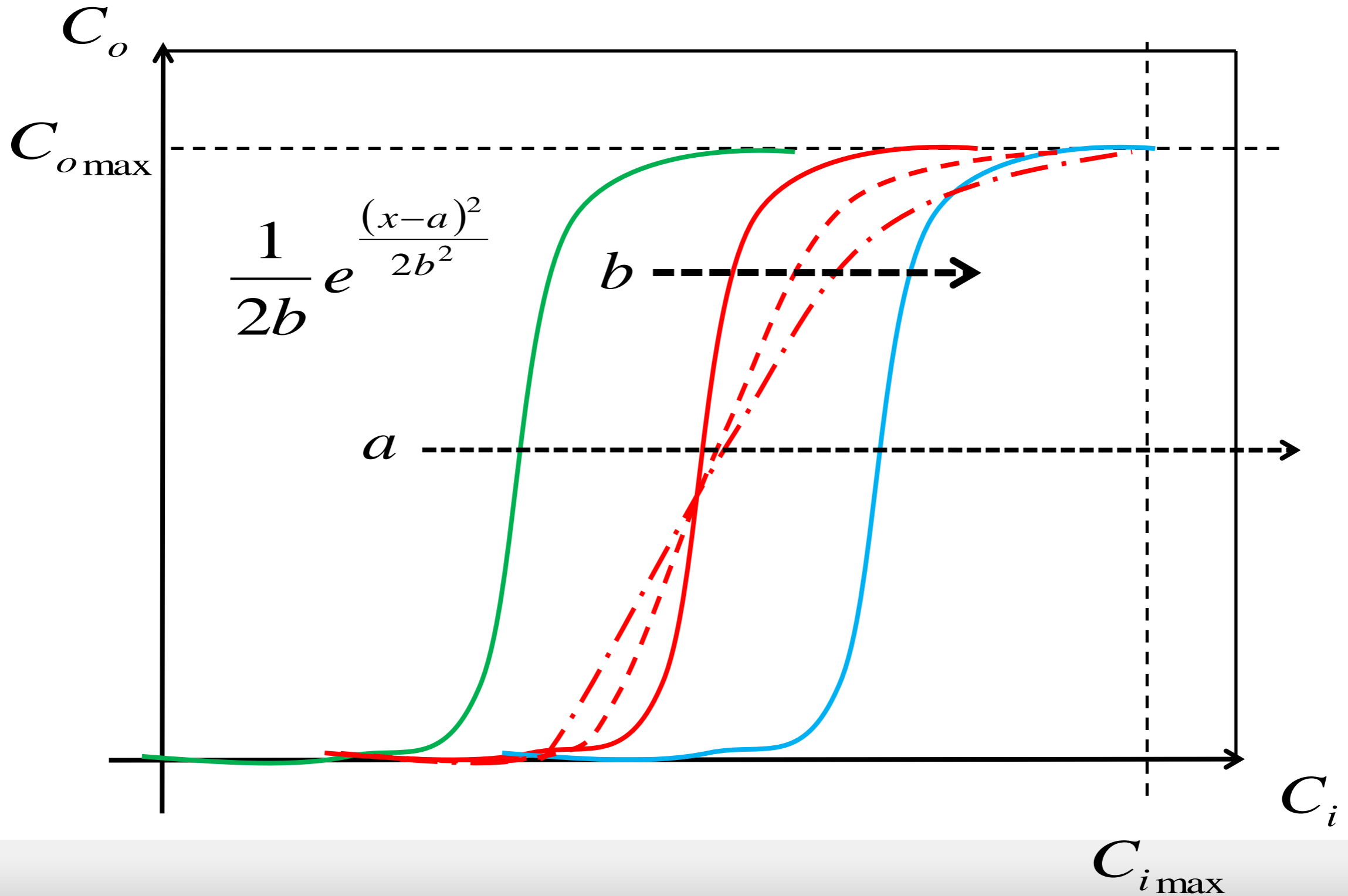
The behaviour change based on the shapes of the two gamut's (source and destination) at the hue angle, or it depends from user parameters. (Clipping and Compression)



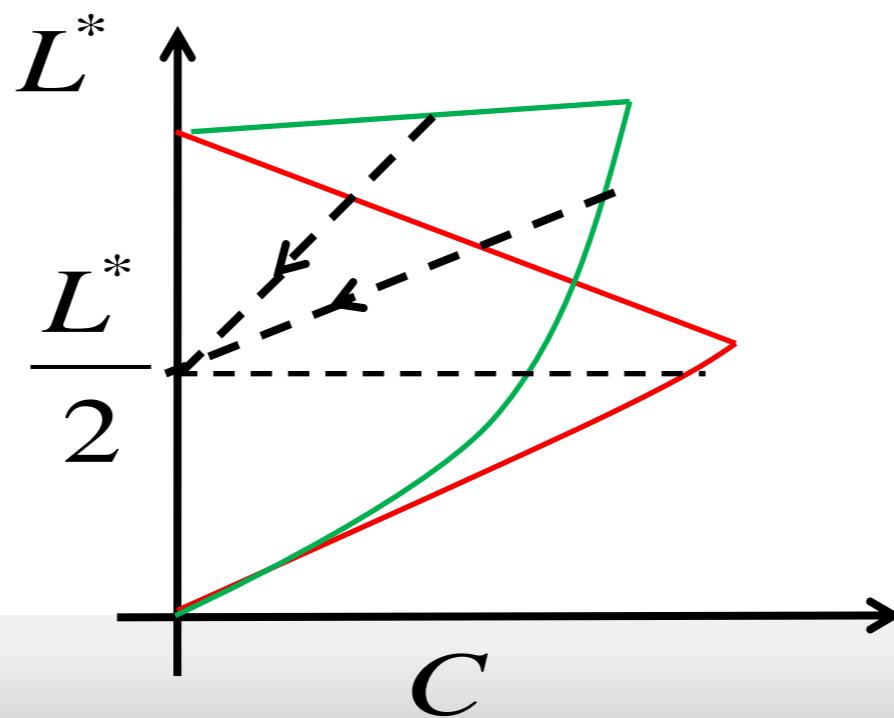
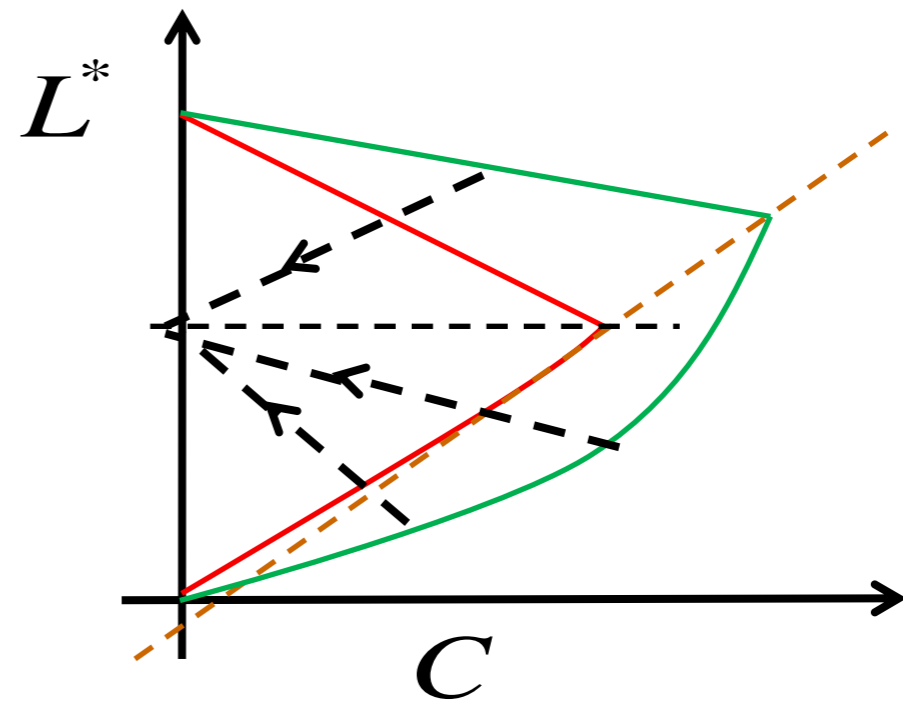
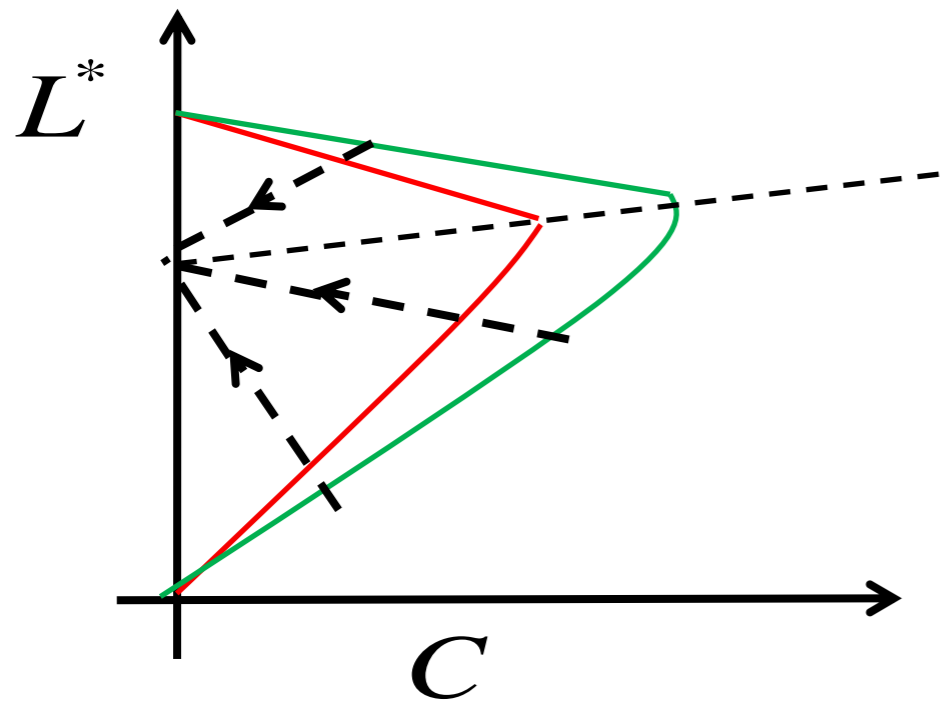
Compression



Compression



Parametric



Preservation of Spatial Details



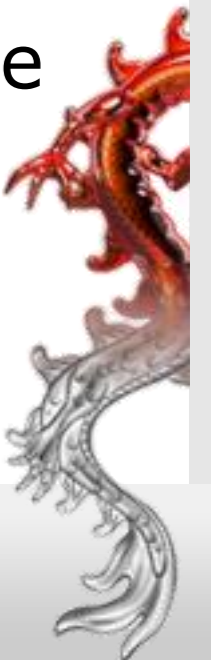
- **Optimization**

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

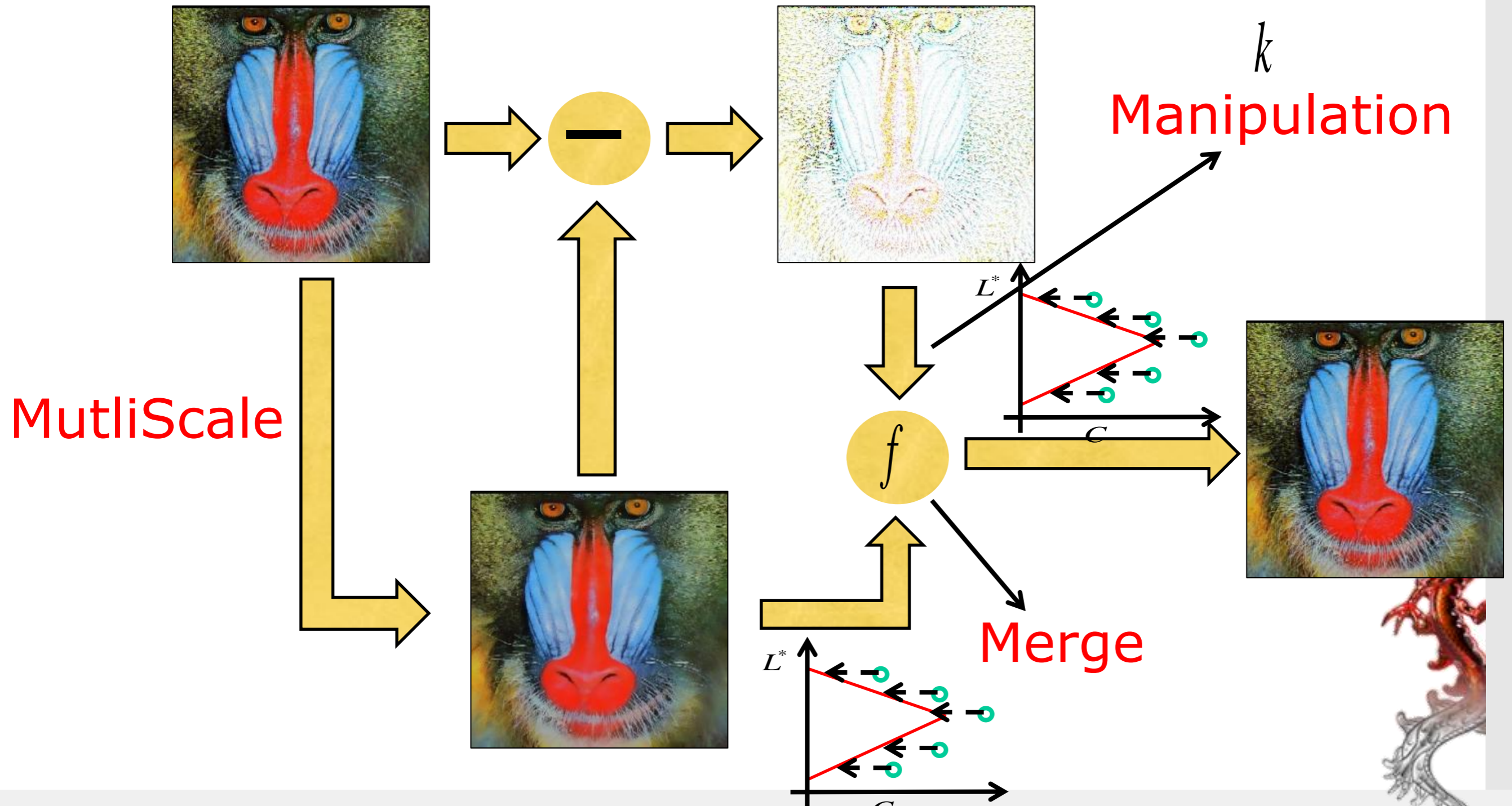
- **Multiscale**

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



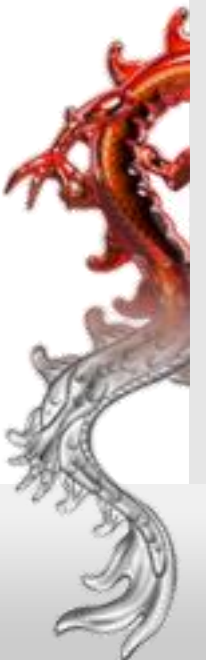
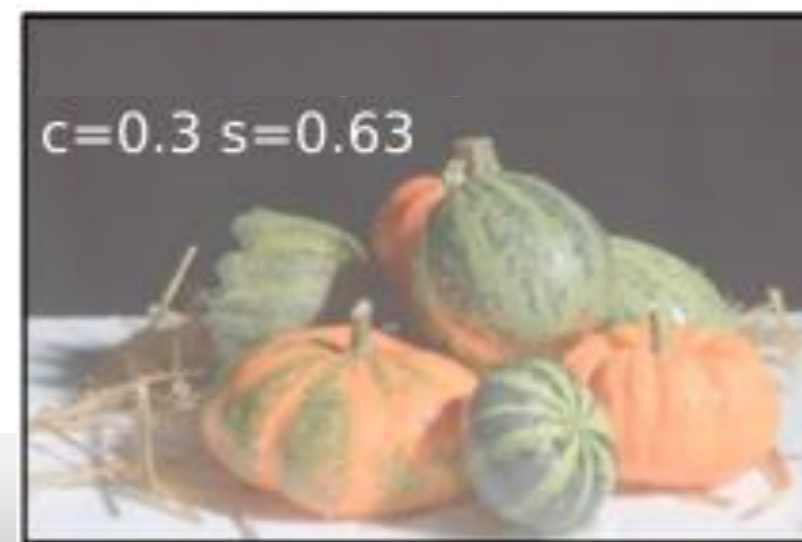
Mantiuk et al. "Color Correction for Tone Mapping"

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

$$C_{out} = \left(\frac{C_{in}}{L_{in}} \right)^s L_{out} \quad \xrightarrow{\quad} \quad s(c) = \frac{(1 + k_1) c^{k_2}}{1 + k_1 c^{k_2}}$$

$k_1=2.3892, k_2=0.8552$

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



Mantiuk et al. "Color Correction for Tone Mapping"

$$\text{luminance}(C_{in}) = \text{luminance}(C_{out})$$

$$C_{out} = \left(\left(\frac{C_{in}}{L_{in}} - 1 \right) s + 1 \right)^{k_1} L_{out} \quad k_1=2.3892, k_2=0.8552$$

**Unchanged luminance value after color correction
(luminance preserving solution)**

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



Conclusions

- 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 appearance
- 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 be 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



- Image IM2-Color (slide 2) Courtesy of Laszlo Neumann
- Material from the paper "Color Correction for Tone Mapping" Courtesy of Rafal Mantiuk
- Image Bottles (slides 12 and 15) Courtesy of Francesco Banterle
- Images (slides 18, 30 and 41) Courtesy of Ela Sikudova
- HDR Image s(skide 18) Martin Cadik

