Master SIF - REP (Part 3)
Color Representation

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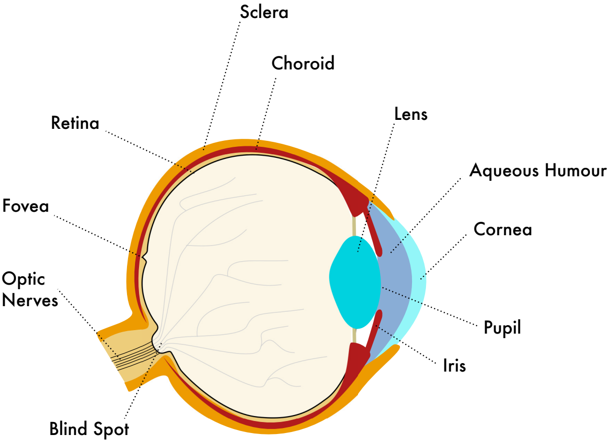
Table of Contents

Table of Contents

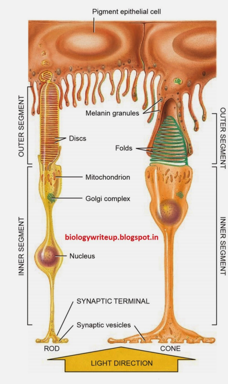
Eye structure



Photosensors

Two types of Photosensors on the retina:

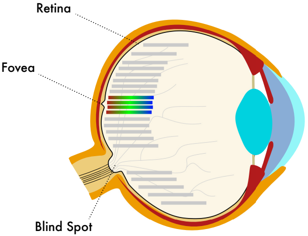
- **Rods**: achromatic vision
  - very sensitive to light intensity
  - night vision
  - low visual acuity
  - slow response to light
  - 120 millions in each retina
- **Cones**: color vision
  - not very sensitive to light intensity
  - high visual acuity
  - fast response to stimuli
  - 3 sorts of cones: Blue, Green, Red
  - 6 millions in each retina

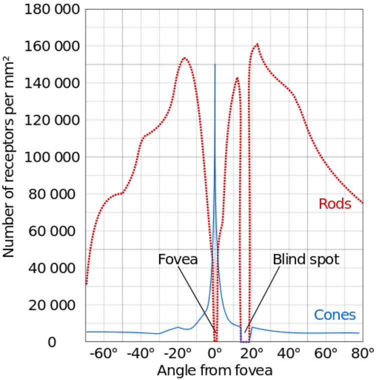


Photosensors Distribution

Cones in the fovea

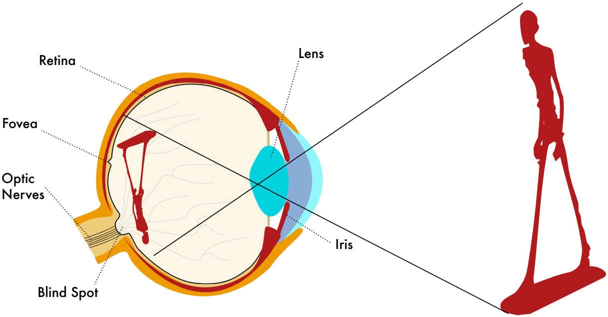
Rods in the retina





The Human vision is thus more sensible to light intensity than color.

Eye capture



Iris controls the quantity of light that enters in the eye (aperture)

Blind spot

Demonstration of the blind spot	
R	L

Instructions: Close one eye and focus the other on the appropriate letter (**R** for right or **L** for left). Place your eye a distance from the screen approximately equal to 3× the distance between the **R** and the **L**. Move your eye towards or away from the screen until you notice the other letter disappear. For example, close your right eye, look at the "L" with your left eye, and the "R" will disappear.

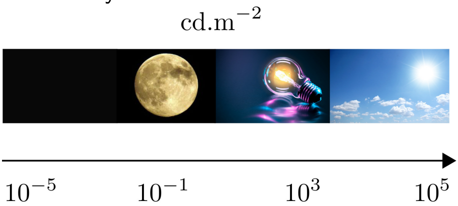
[Wikipedia]

Table of Contents

Measuring light

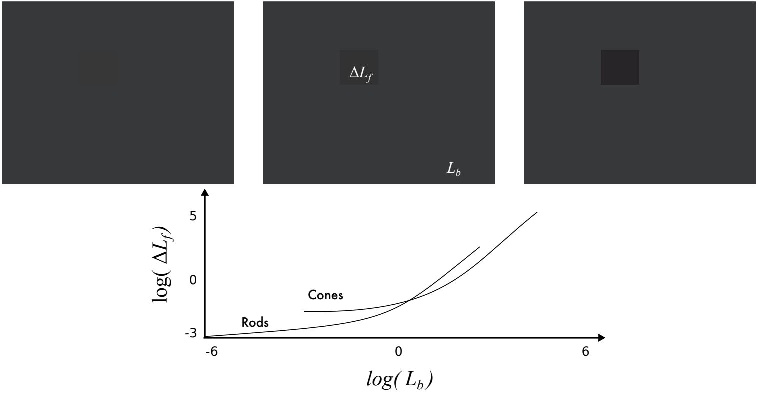
Brightness: Human's visual perception of "how much" a source is reflecting or radiating light.

Luminance: is the luminous intensity per unit area and is measured in cd.m^{-2}. It also corresponds to the photometric quantity of light arriving at the human eye.



Other physical measurment of light: light intensity (Candela), luminous flux (Lumen), illuminance or luminous emittance (Lux).

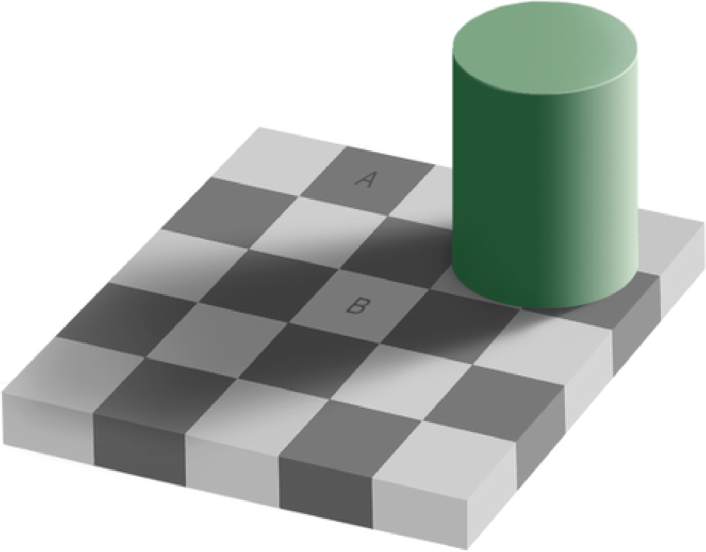
Brightness not straightforwardly linked to **Luminance**



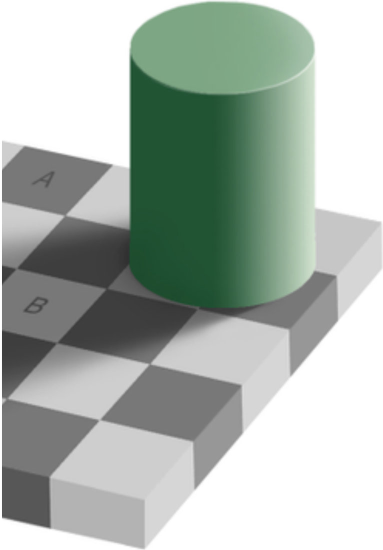
[Blackwell, H. (1981). An analytical model for describing the influence of lighting parameters upon visual performance, volume 1: Technical foundations.]

[Barten, P. G. J. (1992). Physical model for the contrast sensitivity of the human eye. In Rogowitz, B. E., editor, SPIE 1666, Human Vision, Visual Processing, and Digital Display III,, pages 5772.]

Context dependent interpretation



Context dependent interpretation



Context dependent interpretation

Context dependent interpretation

Context dependent interpretation

Color perception

Perception of color is also a mental construction of the brain

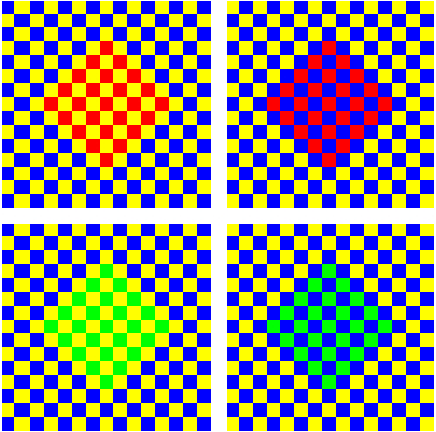
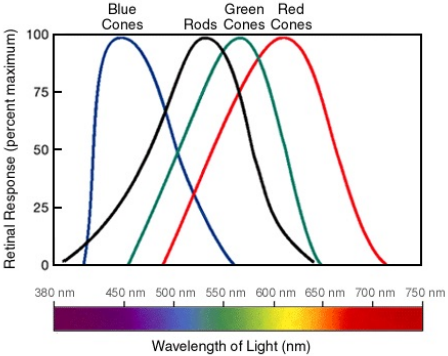


Table of Contents

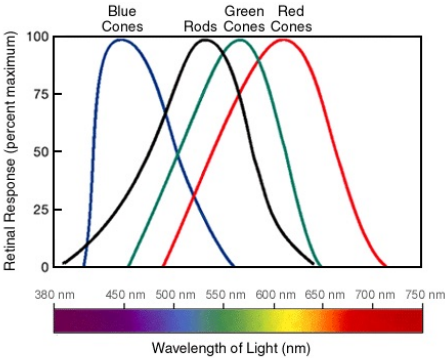
Color perception



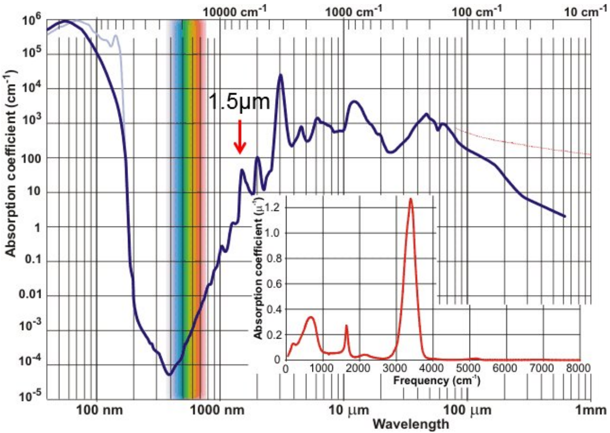
Three color channels filtered by the cones $\rightarrow$ trichromatic vision

Digression

Why the visible light spectrum is the visible light spectrum?



Water's absorption properties



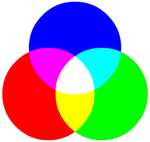
Colorimetry

Colorimetry is the field of assigning code values to perceived colors.

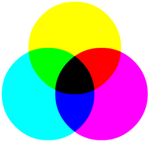
There are several ways to represent perceived colors using color spaces.

A **color space** is an abstract mathematical representation designed to describe the way color can be represented as a combination of code values (i.e. color components or color channels).

Synthesis: Additive



Substractive



The **Gamut** designates a complete range or scope of a color space.

RGB Color space

In 1931, the Commission Internationale de l'Eclairage (CIE) defined the standard CIE 1931 RGB color space.

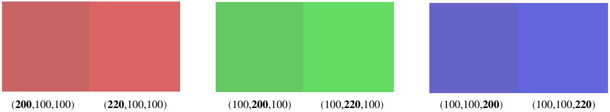
Color vectorial space of dimension 3 (additive colors)

$\lambda_R = 700nm$, $\lambda_G = 546.1nm$, $\lambda_B = 435.8nm$

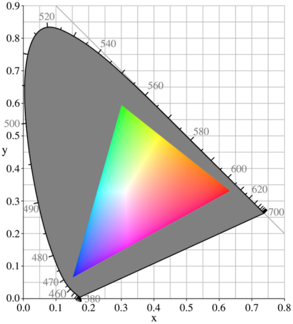
[Smith, T. and Guild, J. (1931). The c.i.e. colorimetric standards and their use. Transactions of the Optical Society, 33(3):73]

RGB drawbacks

- Relative luminance
- The eye/brain does not respond equally between the channels



- The full gamut is achievable only with negative values.



XYZ Color space

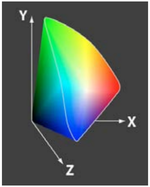
In 1931, the CIE defined the standard CIE 1931 XYZ color space which includes all of the visible gamut.

Y = Luminance

Z = the response of the “blue” cone

X = linear combination of “green” and “red” cones

Given a Y, the plan XZ gives all the chromaticities at the given luminance.



$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.7689 & 1.7517 & 1.1302 \\ 1.0000 & 4.5907 & 0.0601 \\ 0.0000 & 0.056508 & 5.5943 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

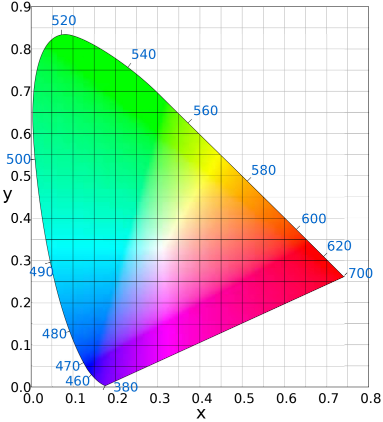
Chromaticity diagram

Chrominance

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

Chromaticity diagram

- Pure color: "outside" border
- $x = y = 1/3$ white
- a line define the linear combination between two colors

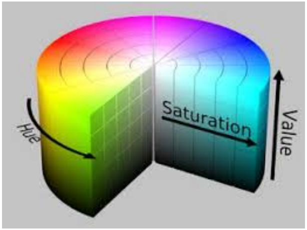


Limits: still not perfectly matching the color perception

HSV color space

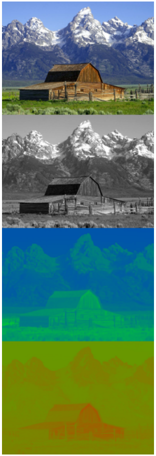
- H = "hue"
  Color identity on the wheel

- S = Saturation
  Color intensity
- V = value
  Color luminance



YUV color space

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51498 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



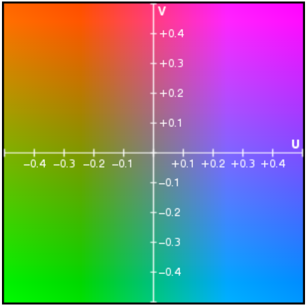
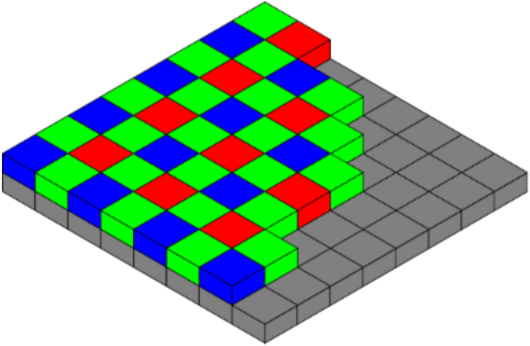
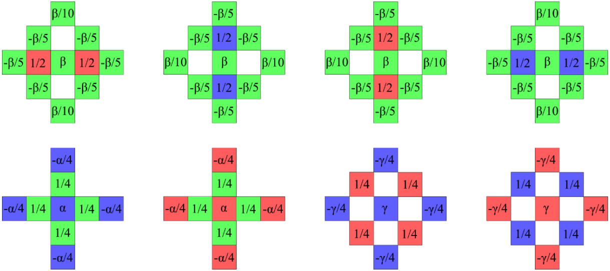


Table of Contents

Capture with Bayer pattern



Demoisacking



Retrieve the green component at a red location:

$$\hat{G}(i,j) = \frac{1}{4}\left(G(i-1,j) + G(i+1,j) + G(i,j-1) + G(i,j+1)\right) + \alpha \Delta R(i,j)$$

and

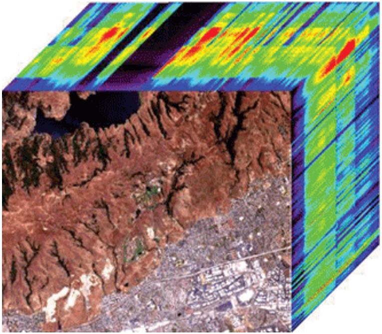
$$\Delta R(i,j) = R(i,j) - \frac{1}{4}\left(R(i-2,j) + R(i+2,j) + R(i,j-2) + R(i,j+2)\right)$$

with $\alpha = 1/2$, $\beta = 5/8$, $\gamma = 3/4$

Table of Contents

Hyperspectral Imaging

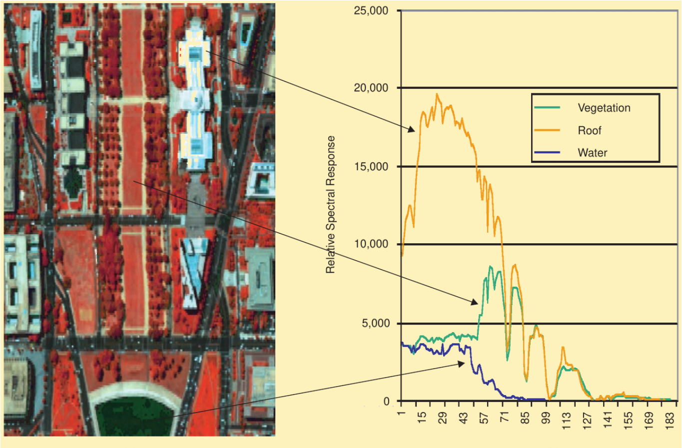
One image per band:



The image is now a tensor of dimension 3.

[Ziph Schatzberg, L. (2014). Hyperspectral imaging enables industrial applications. Industrial Photonic.]

Hyperspectral Imaging



[Landgrebe, D. (2002). Hyperspectral image data analysis. IEEE Signal processing magazine, 19(1), 17-28.]

Table of Contents

Color Transfer example

Given a reference image (b)

Modify an input image (a)

Such that the resulting image (c) has the color of (b)

[Reinhard, E., Adhikhmin, M., Gooch, B., Shirley, P. (2001). Color transfer between images. IEEE Computer graphics and applications, 21(5), 34-41.]

Taxonomy

General concept of Color transfer:

- Find a good representation of the color
- Transfer the characteristics of the reference image into the input one

What is a good representation ? Different answers in the literature

- Different color space
- Parametric / non parameteric
- Global / local

Choice of Colorspace

Need of having decorrelated color channels

RGB:

RG : cc = 0.72 RB : cc = 0.51 BG : cc = 0.80

Not a good choice

YUV, XYZ, HUV: less correlated but still not satisfying

Example

Caracteristics: $l\alpha\beta$ color space / parametric / global

Color space conversion (RGB) $\rightarrow$ (LMS- cones' response) $\rightarrow$ ($l\alpha\beta$)

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.3811 & 0.5783 & 0.0402 \\ 0.1967 & 0.7244 & 0.0782 \\ 0.0241 & 0.1288 & 0.8444 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

then

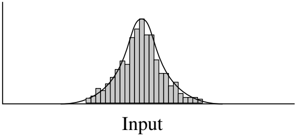
$$\begin{bmatrix} l \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} \frac{1}{\sqrt{3}} & 0 & \\ 0 & \frac{1}{\sqrt{6}} & 0 \\ 0 & 0 & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & -2 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} \log L \\ \log M \\ \log S \end{bmatrix}$$

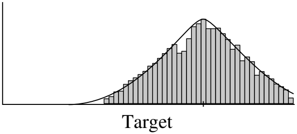
$l\alpha\beta$ channels are decorrelated and very close to human's perception
$\rightarrow$ the three channels are treated separately

[Reinhard, E., Adhikhmin, M., Gooch, B., Shirley, P. (2001). Color transfer between images. IEEE Computer graphics and applications, 21(5), 34-41.]

Algorithm

The distribution is assumed to be Gaussian





Remove the mean of each channel:

$$l^* = l_{\text{in}} - \bar{l}_{\text{in}}$$
$$\alpha^* = \alpha_{\text{in}} - \bar{\alpha}_{\text{in}}$$
$$\beta^* = \beta_{\text{in}} - \bar{\beta}_{\text{in}}$$

Adjust the variance and the mean of each channel:

$$l' = \frac{\sigma^l_{\text{ref}}}{\sigma^l_{\text{in}}} l^* + \bar{l}_{\text{ref}}$$
$$\alpha' = \frac{\sigma^\alpha_{\text{ref}}}{\sigma^\alpha_{\text{in}}} \alpha^* + \bar{\alpha}_{\text{ref}}$$
$$\beta' = \frac{\sigma^\beta_{\text{ref}}}{\sigma^\beta_{\text{in}}} \beta^* + \bar{\beta}_{\text{ref}}$$

Results

Input

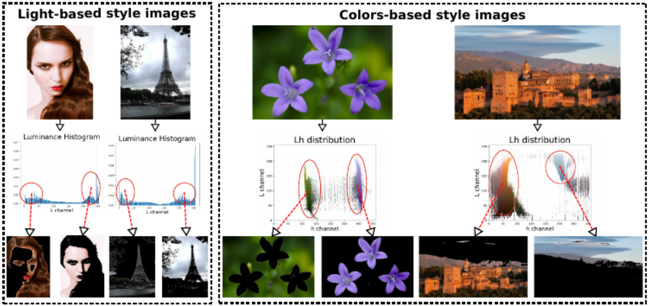
Color Transfer in RGB

Reference

Color Transfer in $l\alpha\beta$

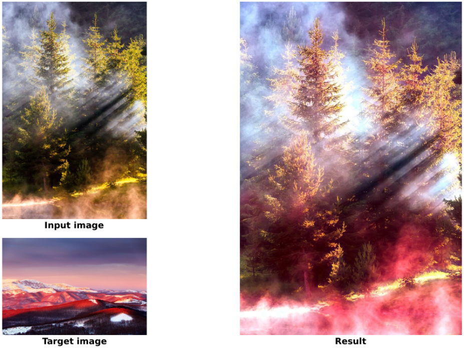
Other approaches

- Local: bright/dark regions, color clusters



- Parametric: more complex distributions
- Non-parametric: histogram alignment, optimal transport
- Smart transfer: gradient, style

Some results



[Hristova, H., Le Meur, O., Cozot, R., Bouatouch, K. (2015, June). Style-aware robust color transfer. In Computational Aesthetics (pp. 67-77).]

Table of Contents

References

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- Hristova Hristina. Example-guided image editing. Engineering Sciences. Université de Rennes 1 [UR1], 2017.