Color Image Processing
SCC0251/5830 – Image Processing

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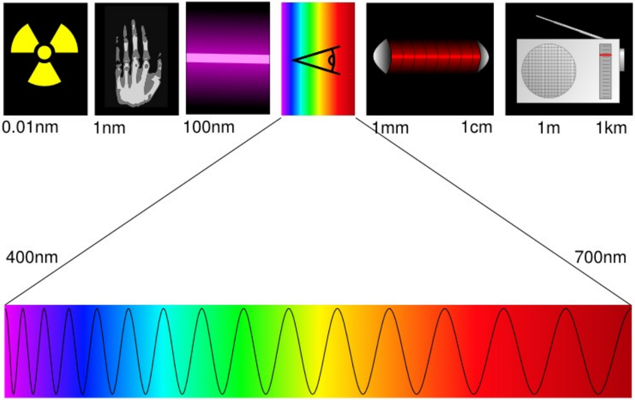
Agenda

Color

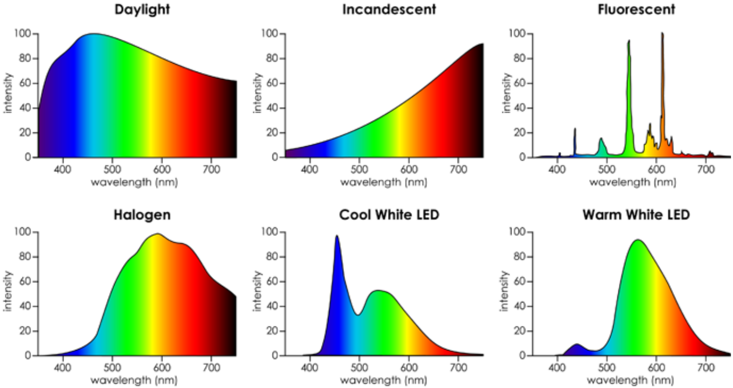
- Important descriptor for identification of elements in a scene
- Human visual system is able to see and distinguish millions of colors

Visible spectrum of light



Thanks to http://www.electricalfun.com/

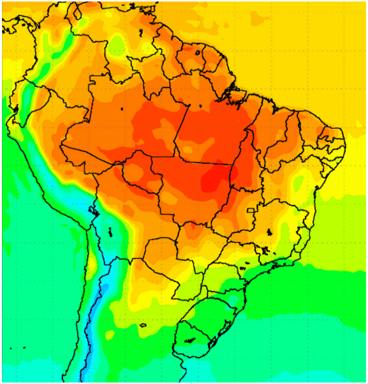
Spectral responses of light sources



Thanks to http://www.lightiningschool.eu/

Color vs Pseudocolor

Color image



Pseudocolor image

Color

- Achromatic light: a single attribute of *intensity* (or amplitude) without color separation,
- Chromatic light: selection of specific wavelengths.

Color

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- Chromatic light: selection of specific wavelengths.
- Cones are the color sensors of the eye, divided in red cones (65%), green cones (%33) and blue cones (2%).

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- Chromatic light: selection of specific wavelengths.
- Cones are the color sensors of the eye, divided in red cones (65%), green cones (%33) and blue cones (2%).
- The RGB (R, red), (G, green), (B, blue) scheme is inspired in this tri-stimulus color sensibility.

Color: composition

- Primary: blue, yellow and red (with paint/crayons):
  - blue+yellow =

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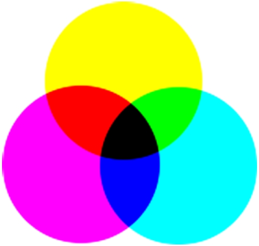
Color: composition

- Primary: blue, yellow and red (with paint/crayons):
  - blue+yellow = green
  - red+blue = purple
  - red+yellow = brown
- The primary colors are in fact: cyan, yellow and magenta.
- Can be understood as a **subtractive model**, in which pigments absorb some wavelengths and reflects the remaining ones.
- More pigment means more absorption and therefore a darker color.

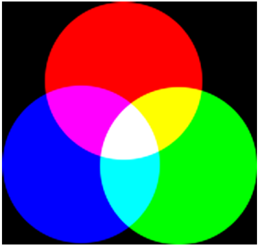


Color: composition

- In monitors, TVs and projectors, the model is **additive**

Color: composition

- In monitors, TVs and projectors, the model is **additive**
- By adding light in different wavelengths we have a mixture. More light results in a brighter color.
  - blue+green = cyan
  - red+blue = magenta
  - red+green = yellow



Color image acquisition

- Most cameras have an array of sensors sensible to red, blue and green individually, positioned in a regular pattern.
- Each color is defined by the real response measured and interpolated from the neighbors.

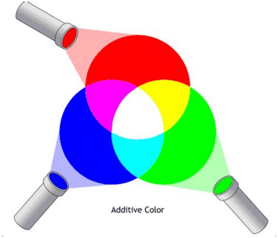
G	R	G	R
B	G	B	G
G	R	G	R
B	G	B	G

rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb
rGb	Rgb	rGb	Rgb
rgB	rGb	rgB	rGb

Agenda

Color models

- Comission Internationale d'Eclairage (CIE) in 1931 decided to create a standard for color
- a standard was necessary to, among others, represent and interpret well color in plane and ship navigation



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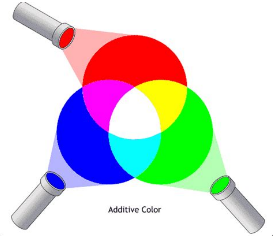

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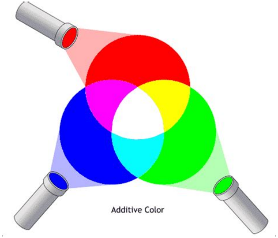

- a color space: a space of sources of color that, when combined, form another color
- allows to do math with colors that match real life representation

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- Comission Internationale d'Eclairage (CIE) in 1931 created a tri-stimulus standard (CIE 1931 XYZ color space).
- Tri-stimulus comes from the three rod cells present on human retina.
  - three sources of light with different combinations of wavelength will produce the same stimulus.

Color models

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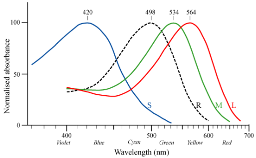
It contains colors that are represented in all other models:

- **Lab**, **Luv** were developed from that to a better adaptation of human vision..
- **RGB** is used for light, **CMY** and **CMYK** are often used in printers.
- **HSV** separates the color into luminance, chroma and saturation.

XYZ

- Values of XYZ are related but not equal to the LMS cones.
- Y was defined as Luminance (brightness), Z related to blue and X a mixture (linear combination) so that we don't have non-negative values.



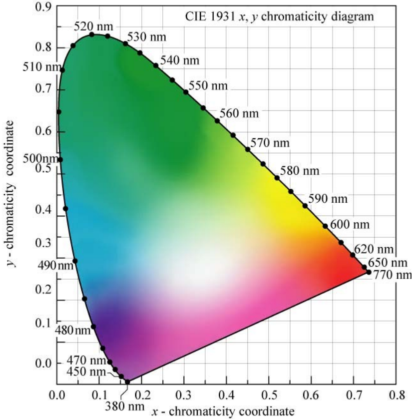
XYZ

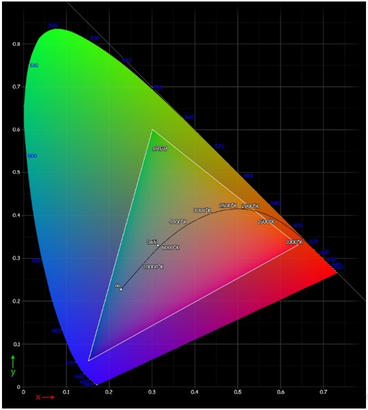
$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

- The *color space* (representation) is CIE xyY, used to visualize and specify colors in practice

XYZ

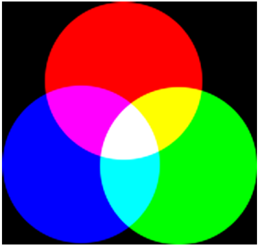
- The diagram representing all visible chromatic space
- All mixtures of any two colors are given by the line connecting them





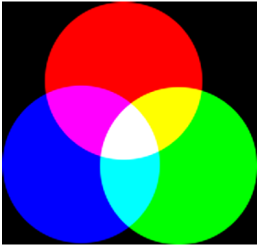
RGB

- The addition of red, green and blue colors produces the color (light color)



RGB

- The addition of red, green and blue colors produces the color (light color)
- There is a subset sRGB used as a standard for system compatibility – however it is not linear, so math is yields incorrect real-world light!



RGB

R

G

B

XYZ / RGB

From RGB to XYZ:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{0.17697} \cdot \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$L^* a^* b^*$

- Space based on oponent colors, separating brightness in L^*
- Created to be easily computed from XYZ and to be "perceptually smooth":
  - a change in a similar value in different colors must produce a visual change of similar magnitude,
  - good for data visualization and color interpolation.

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  - good for data visualization and color interpolation.
- Codifies visible and virtual colors, containing the spaces RGB e CMYK.
- Needs 16 bits/pixel for storage

Interpretation

- $L^* = 0$ black, $L^* = 100$ difuse white;
- $a^* < 0$ color approaches green, and $a^* > 0$ color approaches magenta;
- $b^* < 0$ color approaches blue, and $b^* > 0$ color approaches yellow.

$L^* a^* b^*$

- L^*, a^* and b^* computed from XYZ.

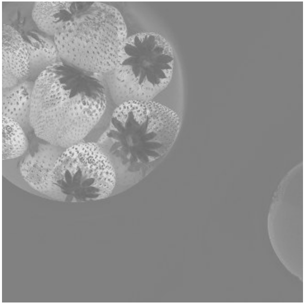
$$
\begin{aligned}
L^* &= 116 f(Y/Y_n) - 16 \\
a^* &= 500\left[f(X/X_n) - f(Y/Y_n)\right] \\
b^* &= 200\left[f(Y/Y_n) - f(Z/Z_n)\right],
\end{aligned}
$$

$$
f(t) = \begin{cases} t^{1/3} & \text{if } t > (6/29)^3 \\ 1/3(29/6)^2 t + 4/29 & \text{otherwise} \end{cases}
$$

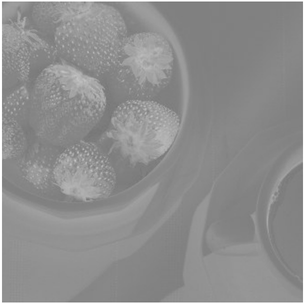
- $L^* u^* v^*$ is a similar system (L^* is the same)

RGB

L^*



a^*

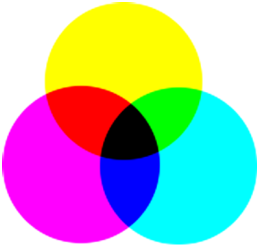


b^*

CMY/CMYK

Subtractive systems, to define colors for printing (pigment color). Can be computed from RGB as:

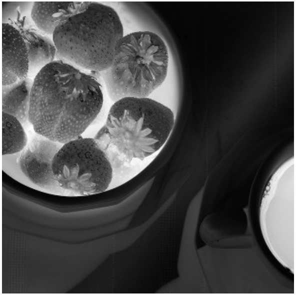
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



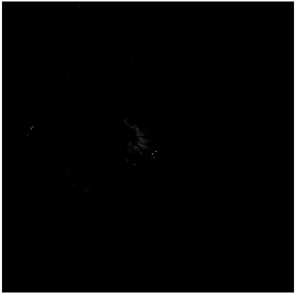
CMY / CMYK

- From this system we can observe that cyan does not reflect red $C = 1 - R$, similarly, magenta does not reflect green and yellow does not reflect blue.
- Converting directly from RGB to CMY creates inconsistences with respect to dark colors (brown, black).
- CMYK is an attempt to fix this issue by adding a black channel K.

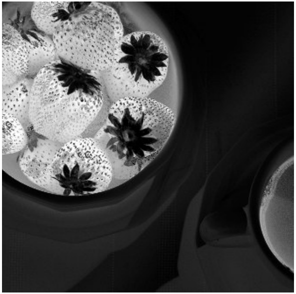
RGB



K



C



M

Y

HSV

- If we could define a color channel so that each value codifies the hue (the chromatic component) of each pixel, then we would have the circle as below.

HSV

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- In this circle, oposite colors are called **complementary**: its mixture creates a grayscale.

HSV

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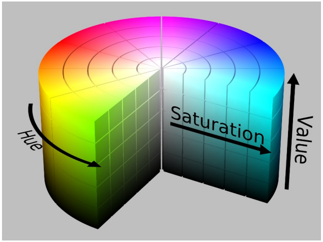
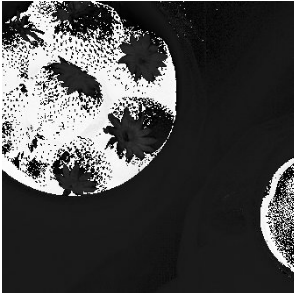
- In this circle, oposite colors are called **complementary**: its mixture creates a grayscale.
- In order to create colors, two other channels are defined: saturation (S) and value/brightness (V).

HSV

- Hue: defines the color component, and its position along the circle
- Saturation: the degree of purity of some color, allow to make a color to appear pale (low saturation) or vivid (high saturation).
- Value: defines the amount of light in the mixture.





RGB H

S V

RGB

Maximum saturation

Maximum value

Change in hue

RGB

Maximum saturation

Maximum value

Change in hue

RGB

Maximum saturation

Maximum value

Change in hue


RGB


Maximum saturation


Maximum value


Change in hue

RGB to HSV

Considering each RGB is a value between 0.0 and 1.0:

$$H = \begin{cases} 60 \times \frac{G-B}{MAX-MIN} + 0 & \text{if } MAX = R \text{ and } G \geq B \\ 60 \times \frac{G-B}{MAX-MIN} + 360 & \text{if } MAX = R \text{ and } G < B \\ 60 \times \frac{B-R}{MAX-MIN} + 120 & \text{if } MAX = G \\ 60 \times \frac{R-G}{MAX-MIN} + 240 & \text{if } MAX = B \end{cases}$$

$$S = \frac{MAX - MIN}{MAX}$$

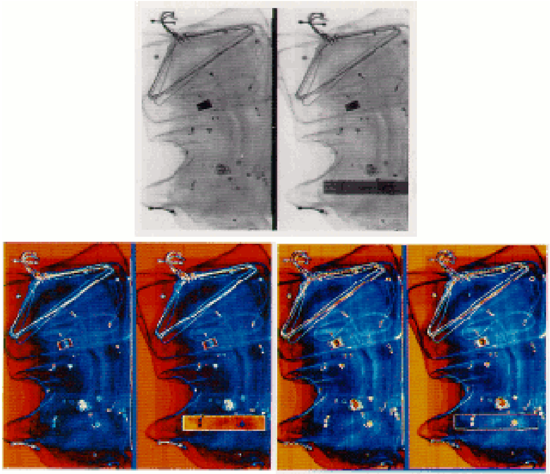
$$V = MAX$$

Agenda

Pseudocolors

- In some applications the response that must generate the image is not the intensity of visible light and color.
- In this scenarions, the color is not meaningful as we see, but we can assign colors to make it easier to visualize.
  - Weather forecast or analysis: map is overlayed with colors relative to temperature for a given region (e.g. between $-80.0°$ and $+60.0°$ C)
  - X-ray security: the response of some energies is enhances with colors in order to make it easier to identify weapons, explosives and dangerous objects

Pseudocolors



Pseudocolors

- A easy way to obtain pseudocolors is to use the input as the Hue (from HSV system), and defining Saturation and Value as needed.

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Processing color images

- The naive approach to process color images is to apply the same operation in each sRGB channel.
  - convert sRGB to linear RGB by inverting the gamma-correction (the standard value is $\gamma = 1/2.2$)

Processing color images

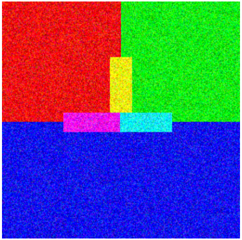
- The naive approach to process color images is to apply the same operation in each sRGB channel.
  - convert sRGB to linear RGB by inverting the gamma-correction (the standard value is $\gamma = 1/2.2$)
- Another way is to process only the V channel of the HSV system.
  - In this case the results are better since we process in a separate way the luminance and chrominance components.

Example: linear contrast adjustment

RGB

Only using V from HSV

Example: mean filter to reduce noise



Noisy image

sRGB filtering

linear RGB filtering

Agenda

Color histogram

Examples of histogram-based descriptors

- Global Color Histogram (GCH): computes a single histogram for the image, using the frequency values as descriptor.
- Border/Interior Classification (BIC): computes two histograms – one for pixels considered as interior (a given pixel is interior if their neighbors have the same color), and another for pixels considered as border (otherwise).

Those methods generate a vector of values that tries to "describe" color in a given image or image region.

Descriptors are often designed with a distance function that allows the comparison between them.

Color descriptors

Euclidean distance (circular/radial kernel):

$$dEuclid(q, d) = \sqrt{\sum_{i=0}^{M} (q[i] - d[i])^2}, \qquad (1)$$

Log distance:

$$dLog(q, d) = \sum_{i=0}^{i<M} |f(q[i]) - f(d[i])| \qquad (2)$$

where

$$f(x) = \begin{cases} 0, & \text{if } x = 0 \\ 1, & \text{if } 0 < x < 1 \\ \lceil \log_2 x \rceil + 1, & \text{otherwise} \end{cases}, \qquad (3)$$

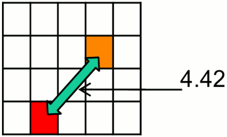
- reduces the influence of dominant colors in a histogram.
- histogram normalized before applying the log function.

Color correlogram

Describes the global distribution of spatial co-occurence of colors.

- A table of pairs of colors $P(c_i, c_j, d)$: each point specifies the probability of finding a pixel with a color c_j that distances from a value of k from another pixel with color c_i in the image.

Example: $P(\text{'red'}, \text{'orange'}, 4.42)$ is the probability of existing:



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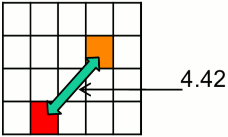


- An **autocorrelogram** captures the spatial correlation between identical colors (it is a subset of a correlogram: the diagonal of the correlogram matrix).

Color autocorrelogram

Given a pixel p_1 of color c_i in an image f, and another pixel p_2 at a distance k from p_1.

- What is the probability that p_2 also have the color c_i?

Color autocorrelogram

Given a pixel p_1 of color c_i in an image f, and another pixel p_2 at a distance k from p_1.

- What is the probability that p_2 also have the color c_i?
- The autocorrelogram considering a series of distances $k \in [d]$:

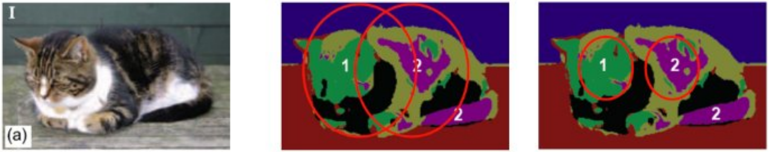
$$\gamma_{c_i}^{k}(f) \equiv Pr(|p1 - p2| = k, p_2 \in f_{c_i} | p_1 \in f_{c_i}), \quad (4)$$

or also:

$$\Gamma_{c_i}^{k}(f) \equiv | \{p_2 \in f_{c_i}, p_1 \in f_{c_i} \mid |p1 - p2| = k\} |, \quad (5)$$

a simple algorithm considers each $p_1 \in f$ of color c_i; for each $k \in [d]$, counts all $p_2 \in f$ of color c_i, with $|p1 - p2| = k$.

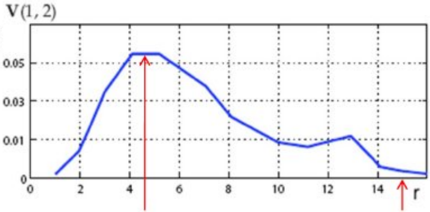
Color autocorrelogram



radius r = distance between regions

other radii

Correlation = pixel match between two regions covered by kernel



Maximum Correlation: (radius of kernel r = distance between regions)

Correlation decreases as difference between radius and distance increase

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