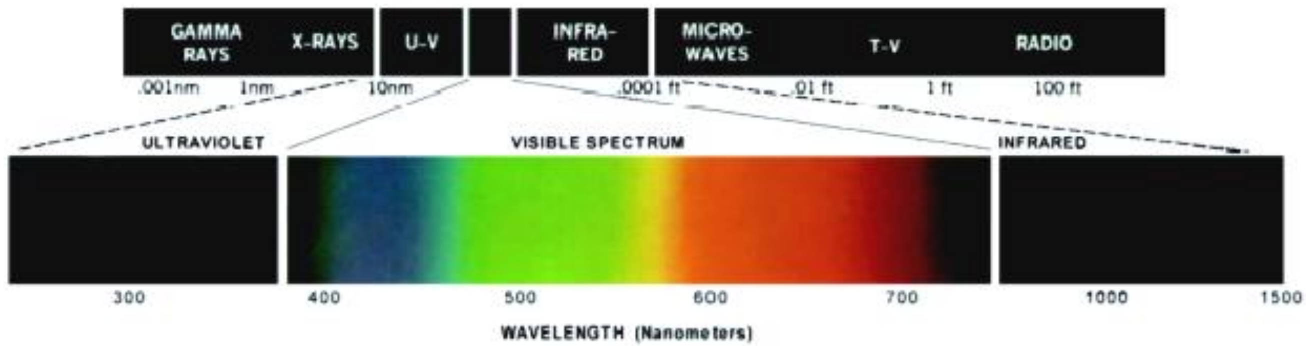
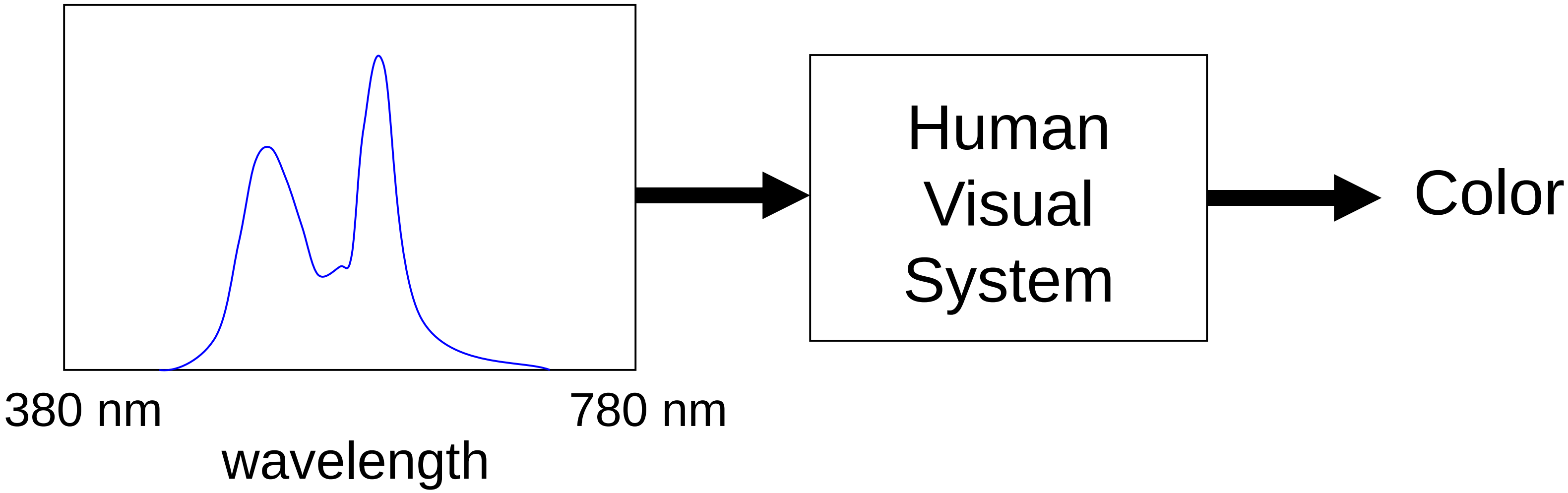
Color Image Processing

Color Perception

Spectrum of EM waves:



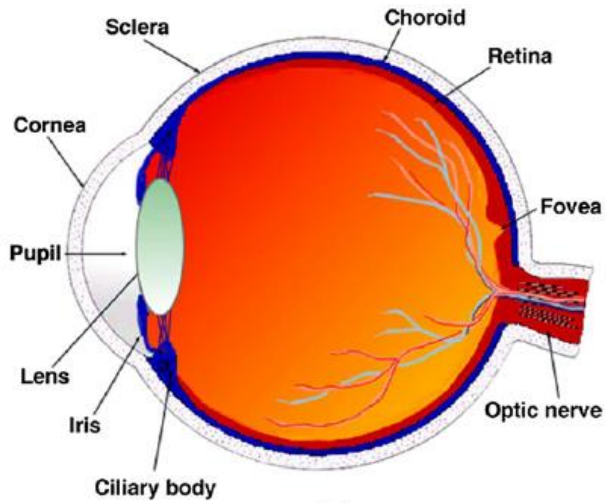
Color is not the underlying physical property (the spectrum of light is), but the human perception of it.



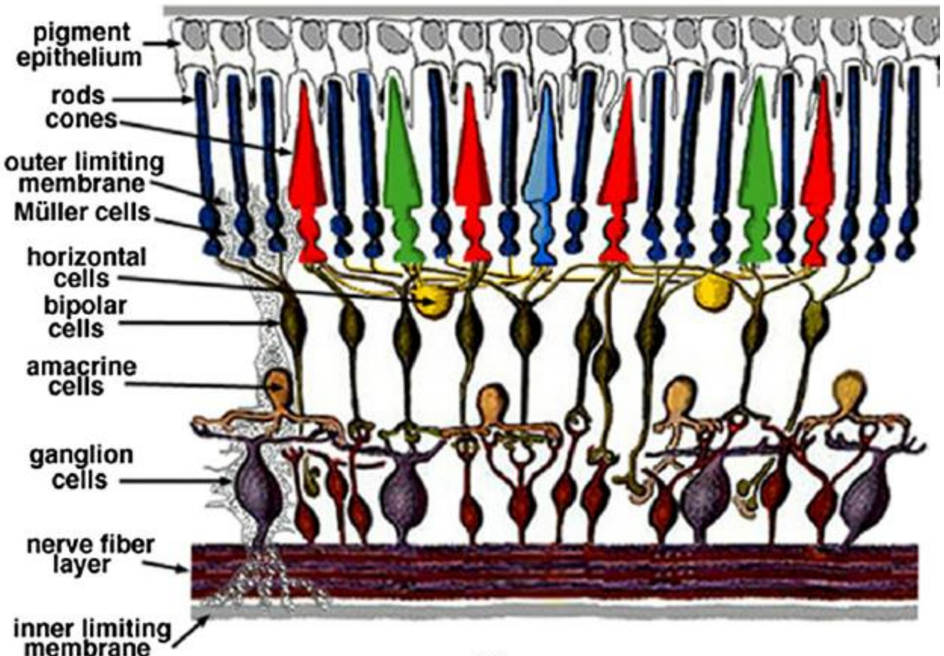
Color Perception

There are two types of cells in human retina that sense light:

- **Cones**: Bright light vision; 3 types; Color perception
- **Rods**: Low light vision



(a)

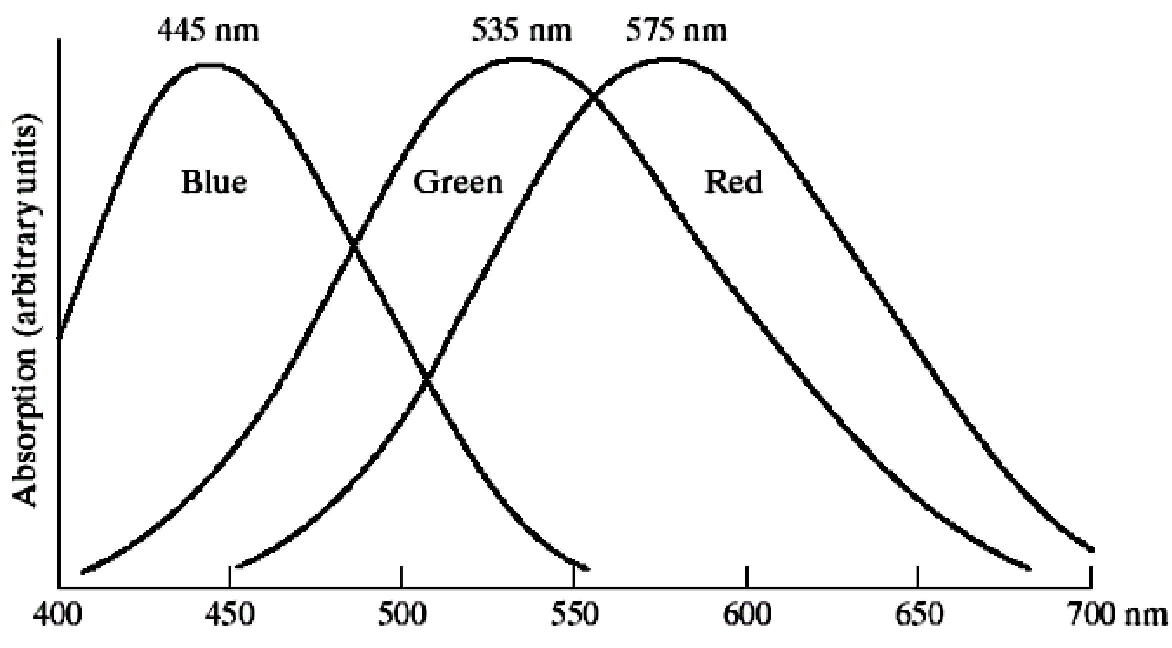


(b)

https://www.researchgate.net/publication/263289543_Retinal_Imaging_as_a_Source_of_Biomarkers_for_Diagnosis_Characterisation_and_Prognosis_of_Chronic_Illness_or_Long-Term_Conditions/figures?lo=1

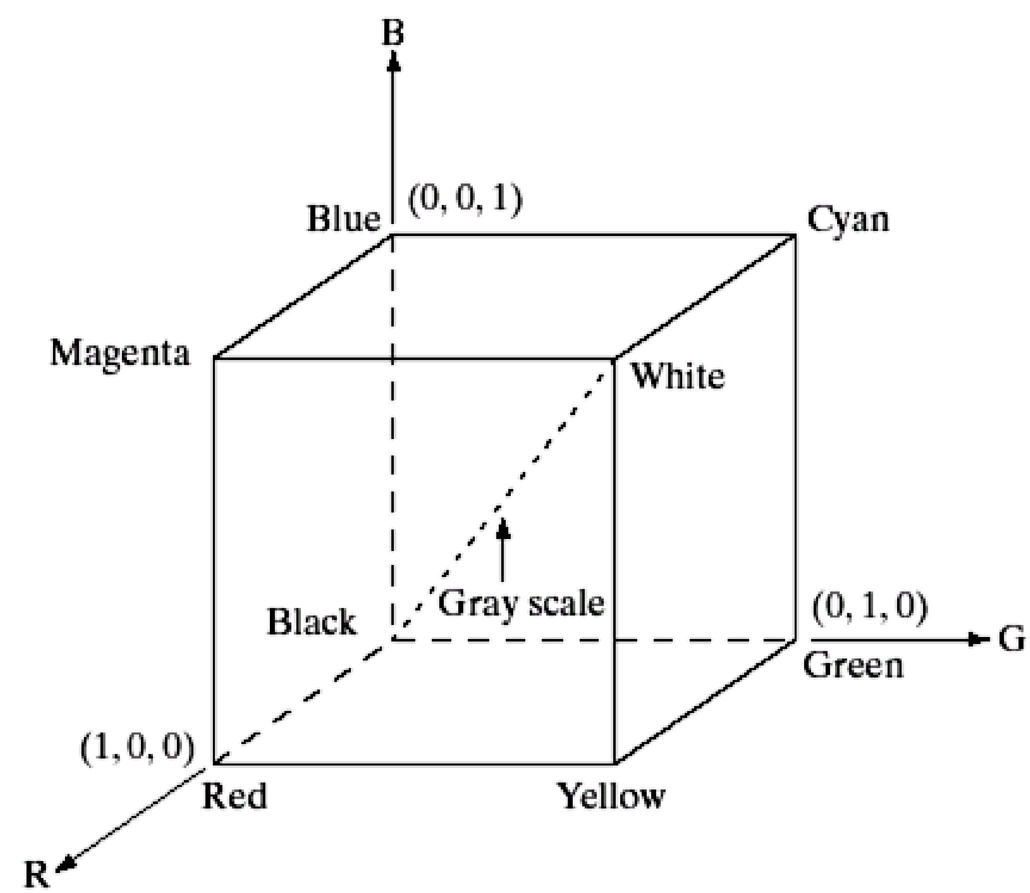
Color Perception

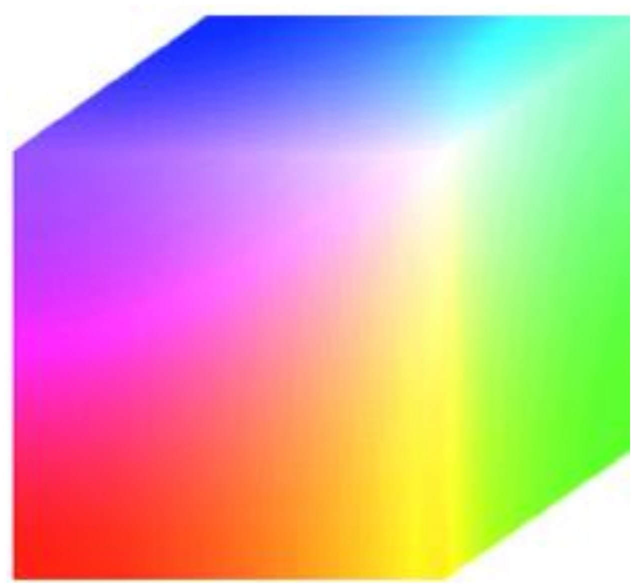
- The reason we use three components (e.g., RGB) to represent colors is because there are three types of cone cells in human retinas.
- The human visual system converts the outputs of the 3 types of cones (3 color components) into one **luminance** and two **chrominance** values.



RGB Color Model

- Corresponding to the cones in human retina
- Representing the "content of light"
- Common for displays





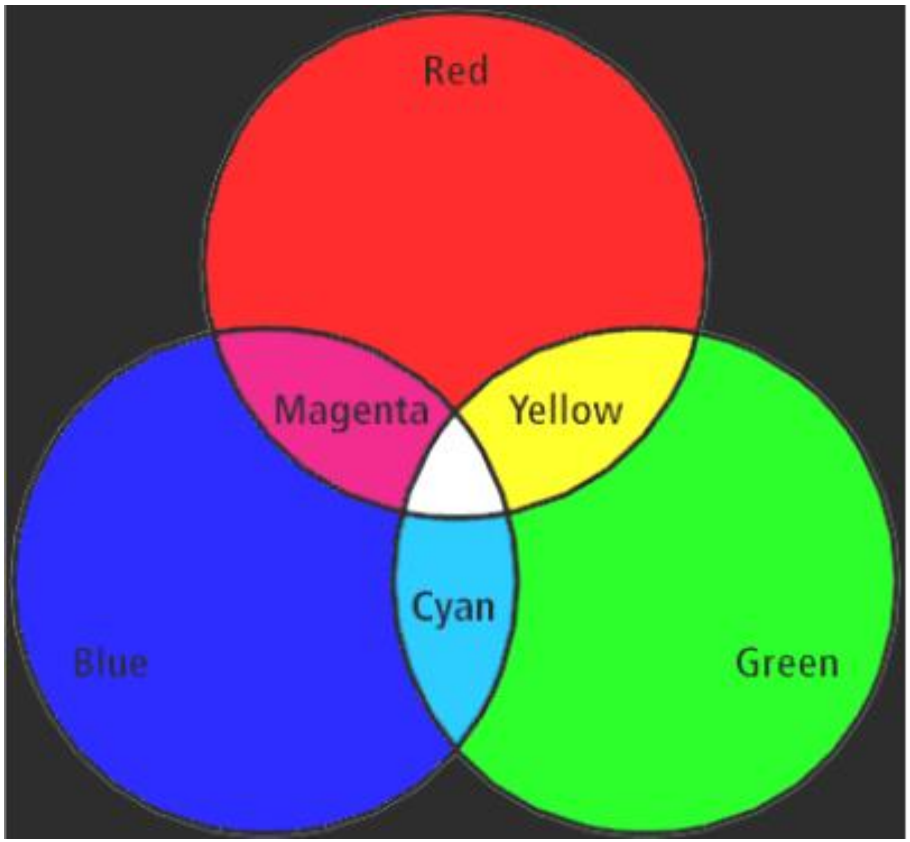
CMY / CMYK Color Models

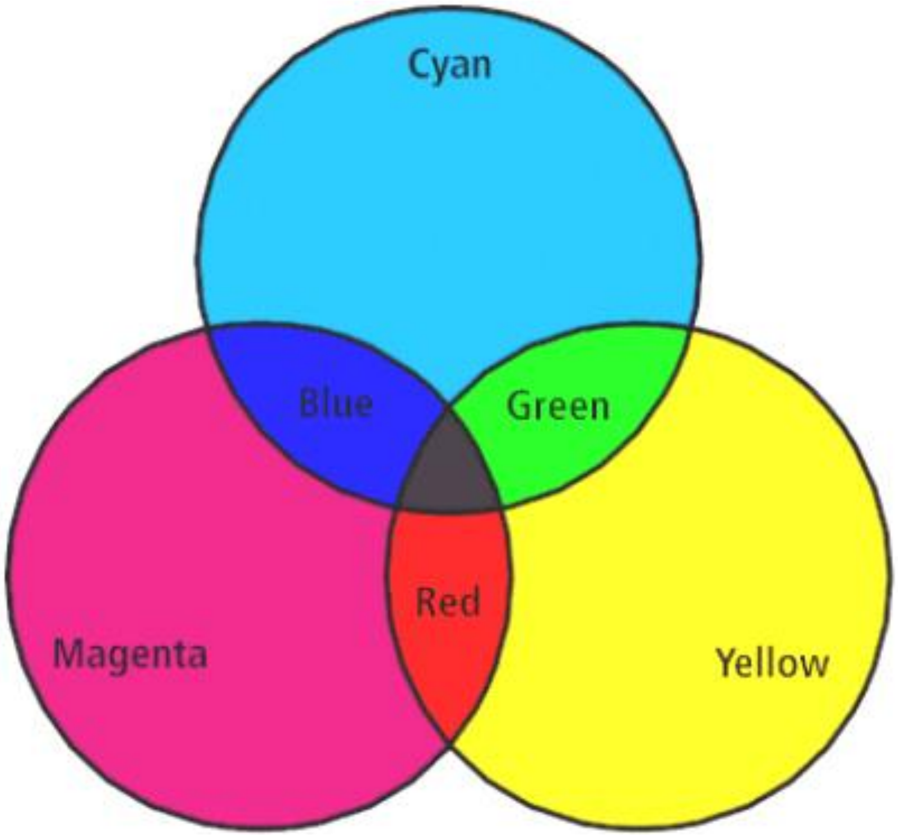
$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Opposite (complement) of RGB
- Used for altering the content of light by changing how a surface reflects light
- Common for color printing devices
- CMYK = CMY + black

$$C \leftarrow (C - K)/(1 - K)$$
$$M \leftarrow (M - K)/(1 - K)$$
$$Y \leftarrow (Y - K)/(1 - K)$$
$$C, M, Y \leftarrow 0 \quad \text{if } K = 1$$

RGB and CMY Colors





Luminance+Chrominance Models

- Color models that have one luminance component and two chrominance components
- This matches better with how human understand and process colors.
- Human visual system does not respond to luminance and chrominance, or even different colors, equally.
- Transform to luminance and chrominance helps to provide the best human viewing quality with limited resources (data storage and transmission bandwidth).
  - In lossy image/video compression, chrominance is usually subsampled relative to luminance. For example, MPEG-1/2 uses 4:2:0 chrominance subsampling (only 1/4 chrominance samples).

Luminance+Chrominance Models

Types of Luminance/Chrominance Specifications:

- HSI (hue, saturation, intensity), HSV, HSL
- YUV and YIQ (analog TV standards)
- YC_bC_r (digital TV, JPEG compression)

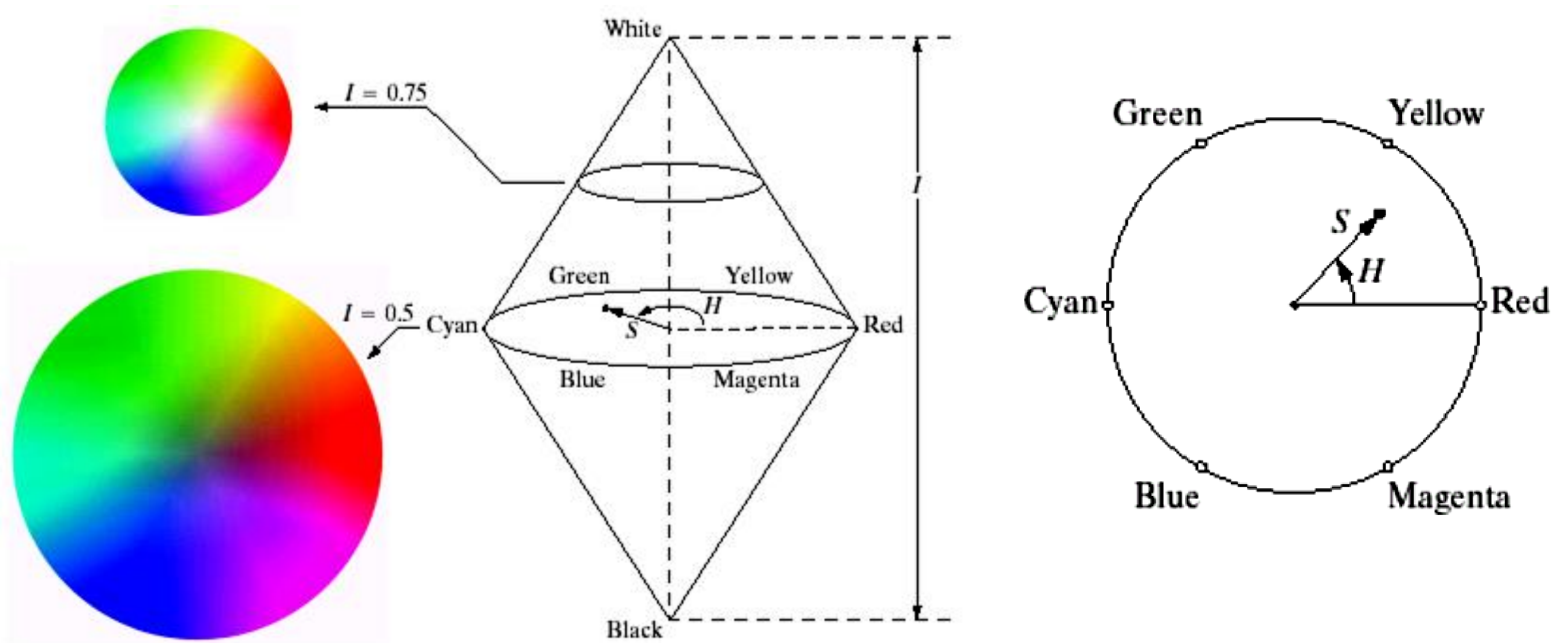
Transformation between Y** and RGB is linear. For example:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} \tilde{R} \\ \tilde{G} \\ \tilde{B} \end{bmatrix}$$

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.257 & 0.504 & 0.098 \\ -0.148 & -0.291 & 0.439 \\ 0.439 & -0.368 & -0.071 \end{bmatrix} \begin{bmatrix} 255\tilde{R} \\ 255\tilde{G} \\ 255\tilde{B} \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$

HSI Color Model

- **Hue**: The pure-color component
- **Saturation**: How pure the color is
- Intensity: A measure of brightness



HSI Color Model

RGB to HSI conversion:

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360^\circ - \theta & \text{if } B > G \end{cases}$$

$$\theta = \cos^{-1}\left\{ \frac{[(R-G)+(R-B)]/2}{\sqrt{(R-G)^2+(R-B)(G-B)}} \right\}$$

$$S = 1 - \frac{3}{R+G+B}\min(R,G,B)$$

$$I = (R+G+B)/3$$

HSI Color Model

HSI to RGB conversion (only RG sector shown):

$$B = I(1 - S)$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right] \qquad \text{when } 0^\circ \le H < 120^\circ$$

(RG sector)

$$G = 3I - (R + B)$$

Formulae for the GB and BR sectors can be derived similarly.

HSV and HSL Color Models

Similar to HSI in terms of meanings, but the actual numbers are different. These are more commonly used in actual systems.

$$MIN = \min(R, G, B) \qquad MAX = \max(R, G, B)$$

$$H = \begin{cases} \text{undefined}, & \text{if } MAX = MIN \\ 60^\circ \times \dfrac{G - B}{MAX - MIN}, & \text{if } MAX = R \text{ and } G \geq B \\ 60^\circ \times \dfrac{G - B}{MAX - MIN} + 360^\circ, & \text{if } MAX = R \text{ and } G < B \\ 60^\circ \times \dfrac{B - R}{MAX - MIN} + 120^\circ, & \text{if } MAX = G \\ 60^\circ \times \dfrac{R - G}{MAX - MIN} + 240^\circ, & \text{if } MAX = B \end{cases}$$

HSV and HSL Color Models

HSV (V=value):

$$V = MAX \qquad S = 1 - \frac{MIN}{MAX}$$

HSL (L=Luminance):

$$L = (MAX + MIN)/2$$

$$S = \begin{cases} 0 & \text{if } L = 0 \\ (MAX - MIN)/(2L) & \text{if } 0 < L \leq 0.5 \\ (MAX - MIN)/(2 - 2L) & \text{if } L > 0.5 \end{cases}$$

HSV/HSL to RGB

HSV: $$MAX = V, \quad MIN = (1-S)V$$

HSL:
$$L = 0 \quad \Rightarrow \quad MAX = MIN = 0$$
$$0 < L \leq 0.5 \quad \Rightarrow \quad MAX = L(1+S), \quad MIN = L(1-S)$$
$$L > 0.5 \quad \Rightarrow \quad MAX = L + (1-L)S, \quad MIN = L - (1-L)S$$

- In these two color spaces, we are ensured that any combination of V (or L) and S values in $[0,1]$ results in valid RGB values (in $[0,1]$). This is not the case for the HSI color space.
  - For example, MS PowerPoint provides HSL, and MATLAB provides HSV.
- Need to use Hue as well as the MAX and MIN values to compute RGB values.

HSV Components

Original

Hue

Saturation

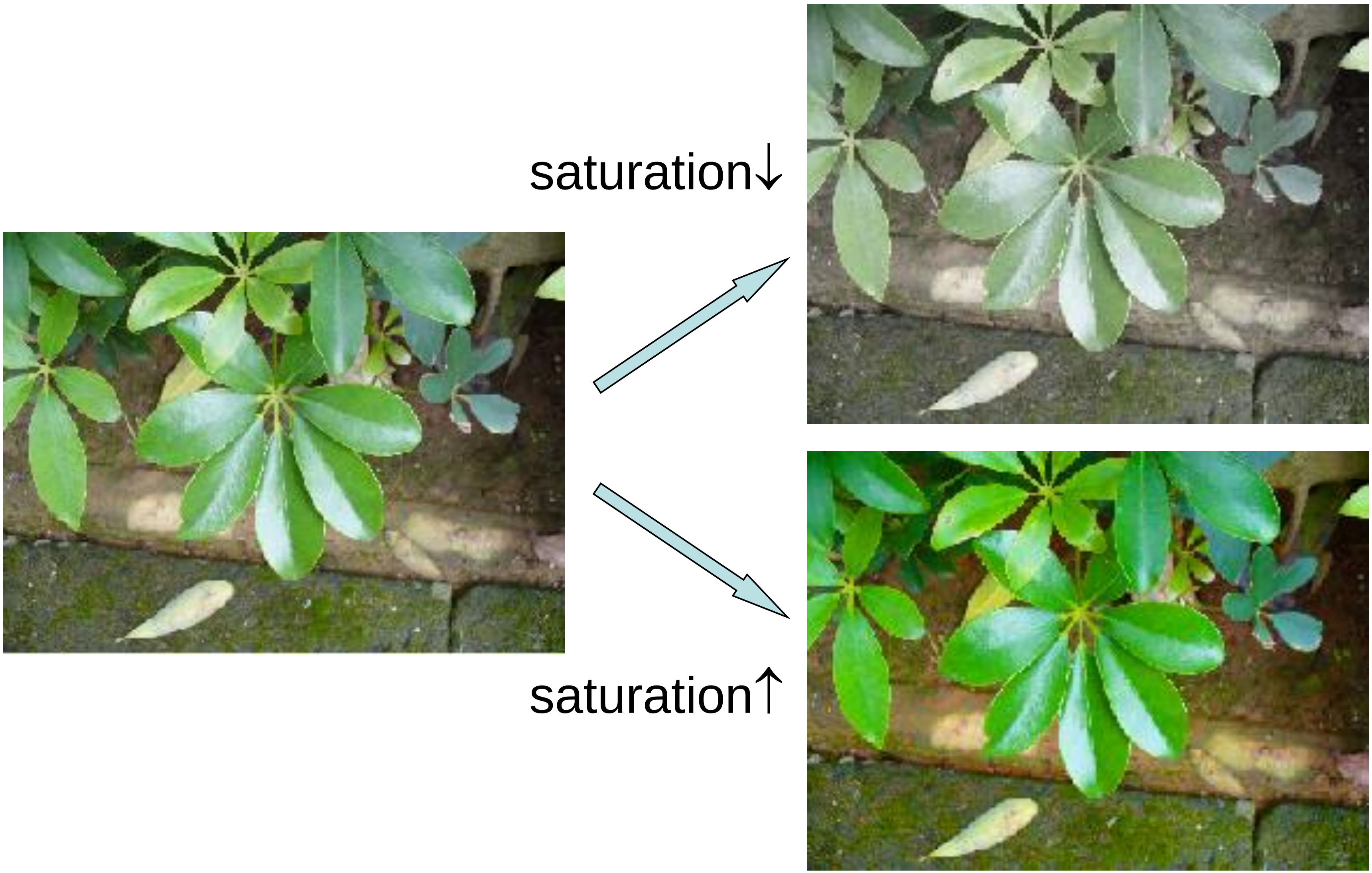
Value

Manipulating HSV Components

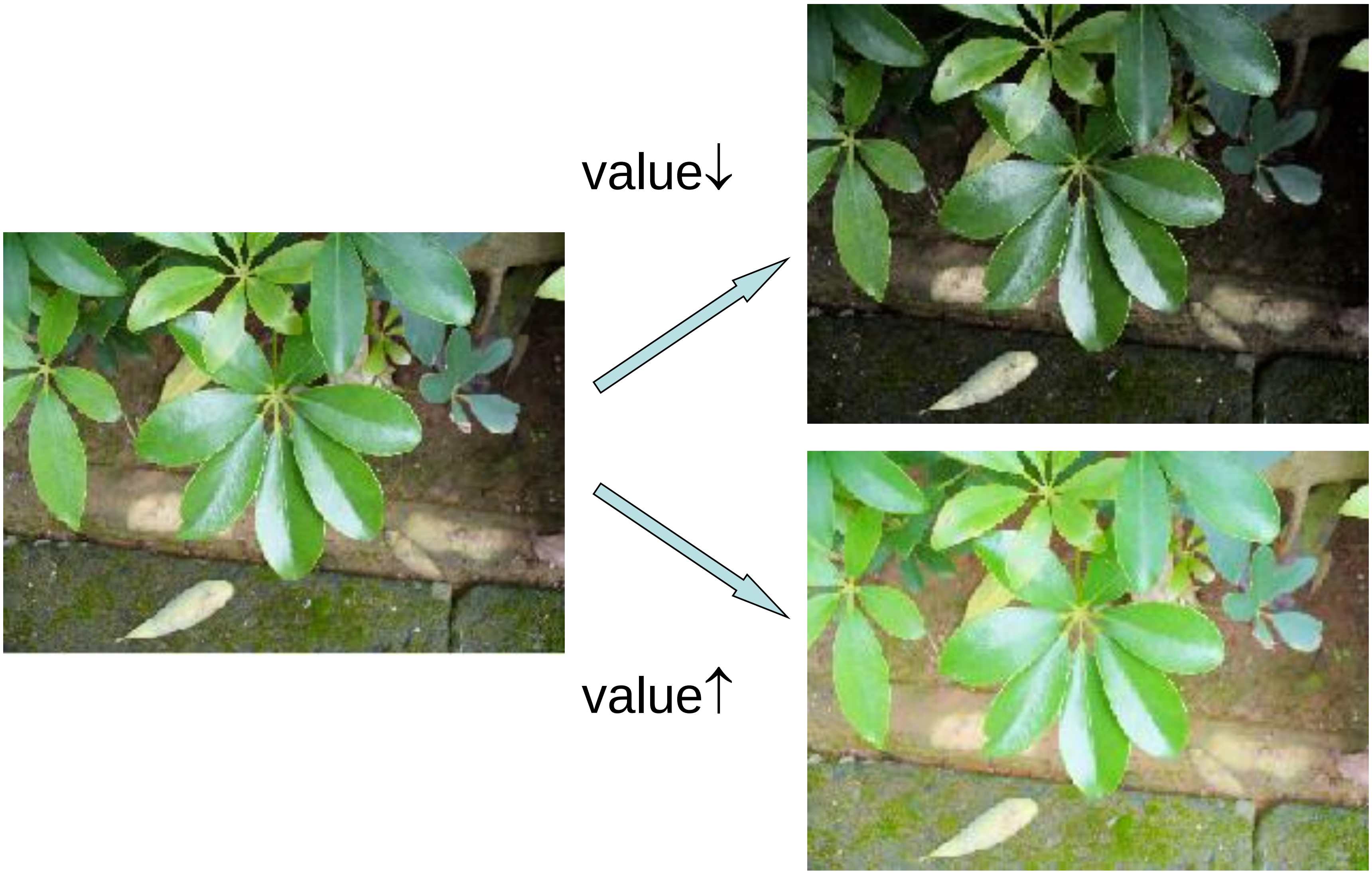
hue
–36º

hue
+36º

Manipulating HSV Components



Manipulating HSV Components



CIE XYZ and CIE LAB Color Models

- Common color models such as RGB are device-dependent. For example, the same RGB values can correspond to different colors on different computer screens.

網頁商品顏色與實品多少有誤差
可接受者再下標喔

- For the most accurate color reproduction, we need to be able to convert colors across devices.

- A device-independent color model can serve as the medium. Each device only needs to know how to transform between its own (displayed, printed) colors and the device-independent model. (Such transformations are the **color profiles** of the devices.)

CIE = International Commission on Illumination

CIE XYZ Color Models

- This defines a color space where all visible colors are in the range of $X, Y, Z \in [0,1]$.
- These are called the **tristimulus values** (degrees of stimulus to the three types of cones in the retina).
- The color-only part can be represented using x (red) and y (green) only:

$$x = X/(X+Y+Z)$$

$$y = Y/(X+Y+Z)$$

$$z = Z/(X+Y+Z)$$

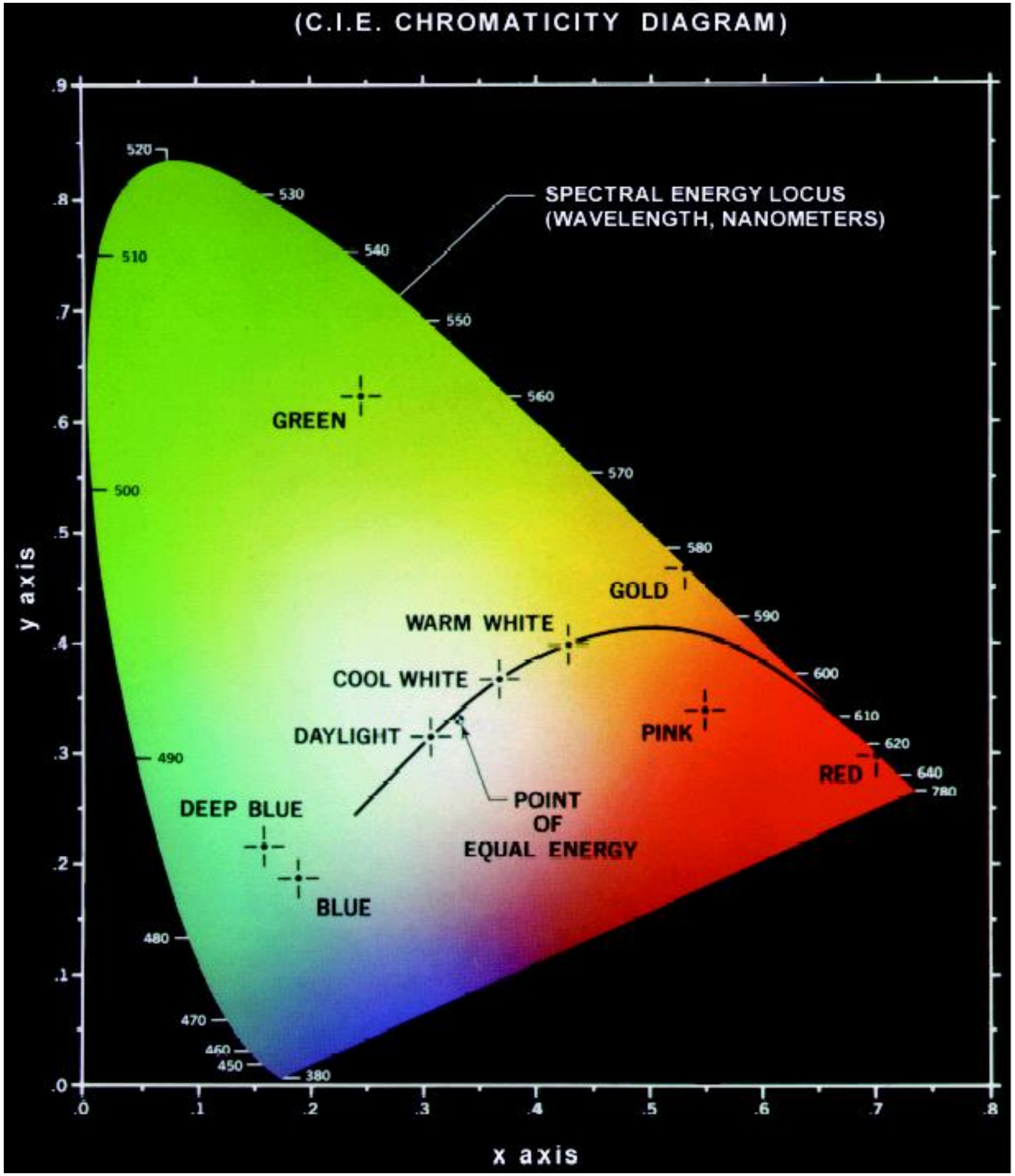
$$x + y + z = 1$$

- Some xyz values, such as (1,0,0), do not actually exist. The simple way to understand this: The responses of the three types of cones are not independent of each other.

CIE XYZ and Chromaticity Diagram

This contains all the colors visible to human.

A straight line segment indicates possible results of additive color mixing.



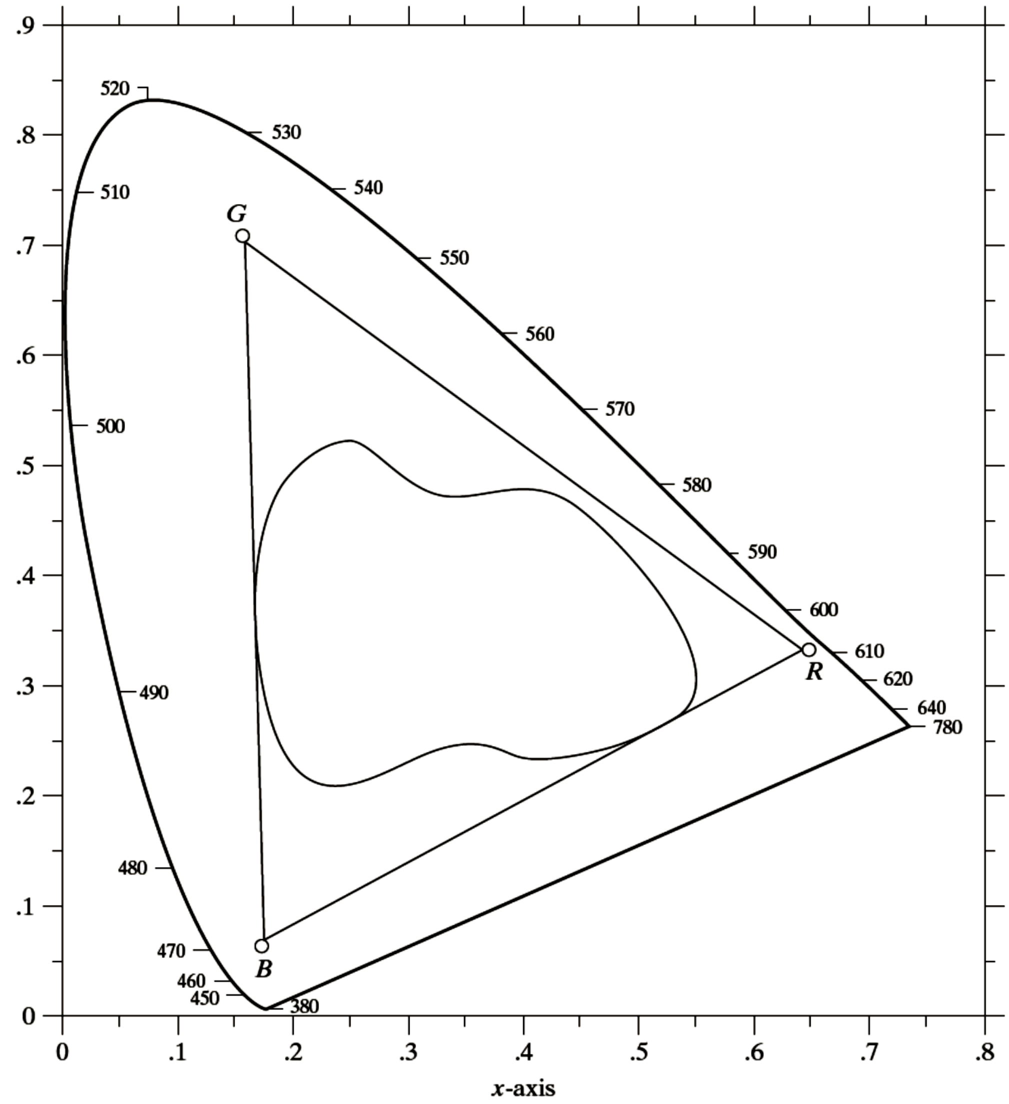
CIE Chromaticity Diagram

Color gamut:
Range of reproducible colors by a device.

Displays have triangular color gamuts.

Printing devices can have more irregular gamuts.

The color model sRGB represents a standard gamut for common CRTs.



CIE LAB Color Model

- CIE LAB is the most commonly used device-independent color model.
- Three components: L*, a*, b*.
- Each visible color can be converted to L*a*b* values through the comparison with an "objective" white color (the perfect diffuse reflection of a particular white light source at a particular viewing angle).
- L*a*b* color model is perceptually uniform. This means that the perceived difference between two colors is proportional to their distances in this color model.

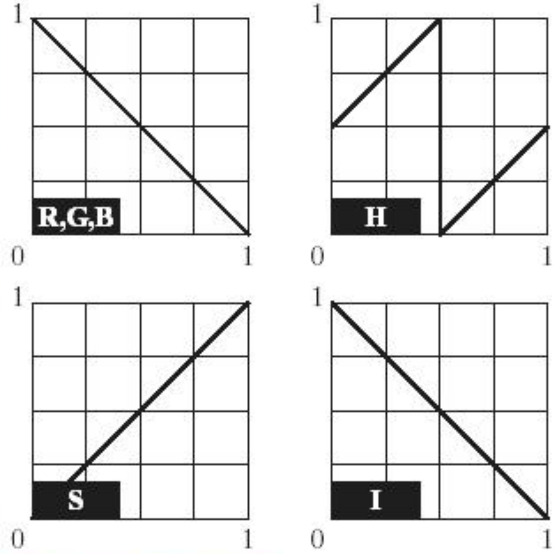
Color Image Transformations

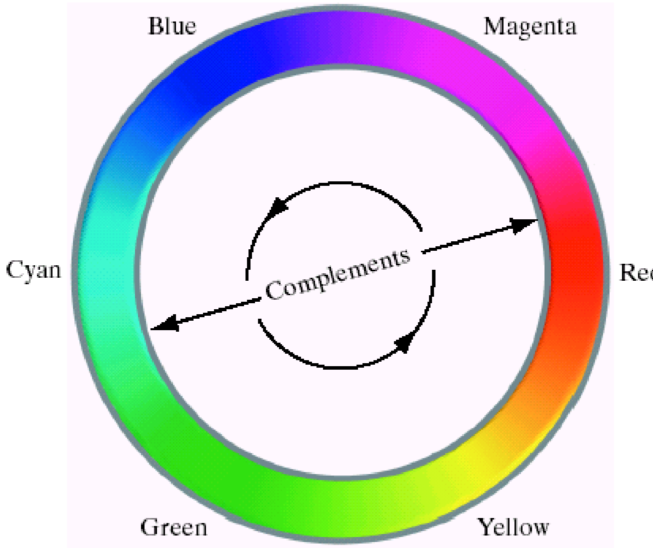
The next question is: For the processing techniques we have learned for grey-level images, how do we apply them to color images?

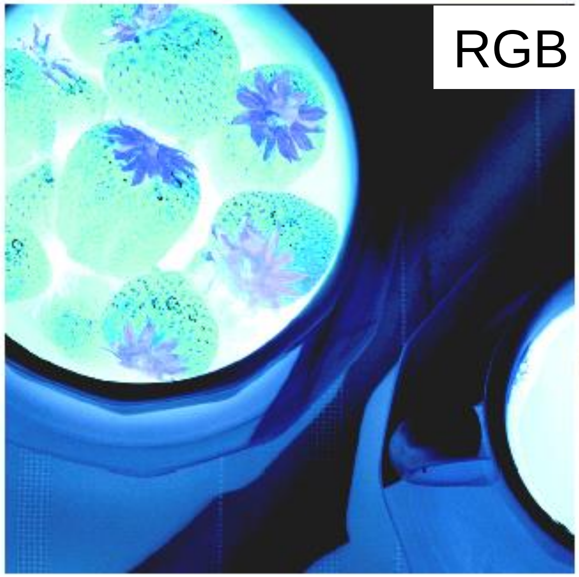
Some points to note:

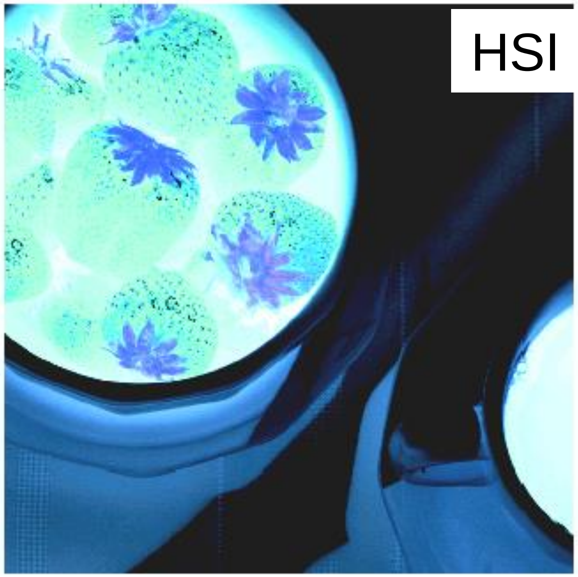
- RGB images: vector-based or per-channel?
  - They are equivalent if the transformations are linear, including linear spatial filtering.
  - They are different if the transformations are nonlinear, including order-statistics filters.
- Selecting the color space to do the transformation in.

Color Complements









Note:
In HSI color space, complement by changing only hue and intensity is sometimes invalid. Example: consider the complement of (0, 0.6, 0.6).

Tonal and Color Corrections

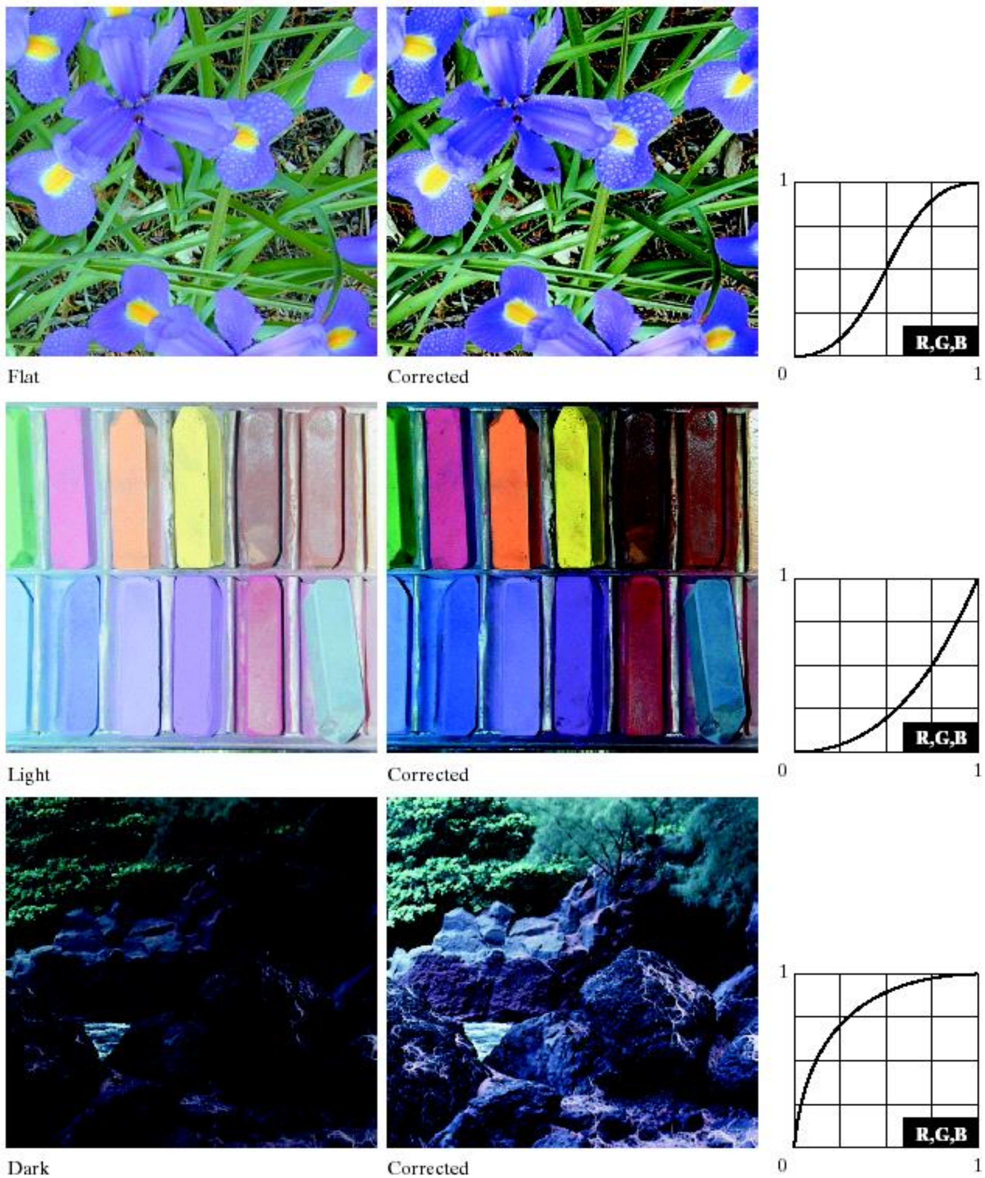
- Tonal corrections: Modifying the intensity component of an image.
- Color corrections: Modifying the chromatic components of an image.
- Best reference colors (areas of known colors in the image) for color corrections of photos: **white** and **skin color**. High-saturation colors are not very useful.

Tonal Correction

Flat

Light

Dark

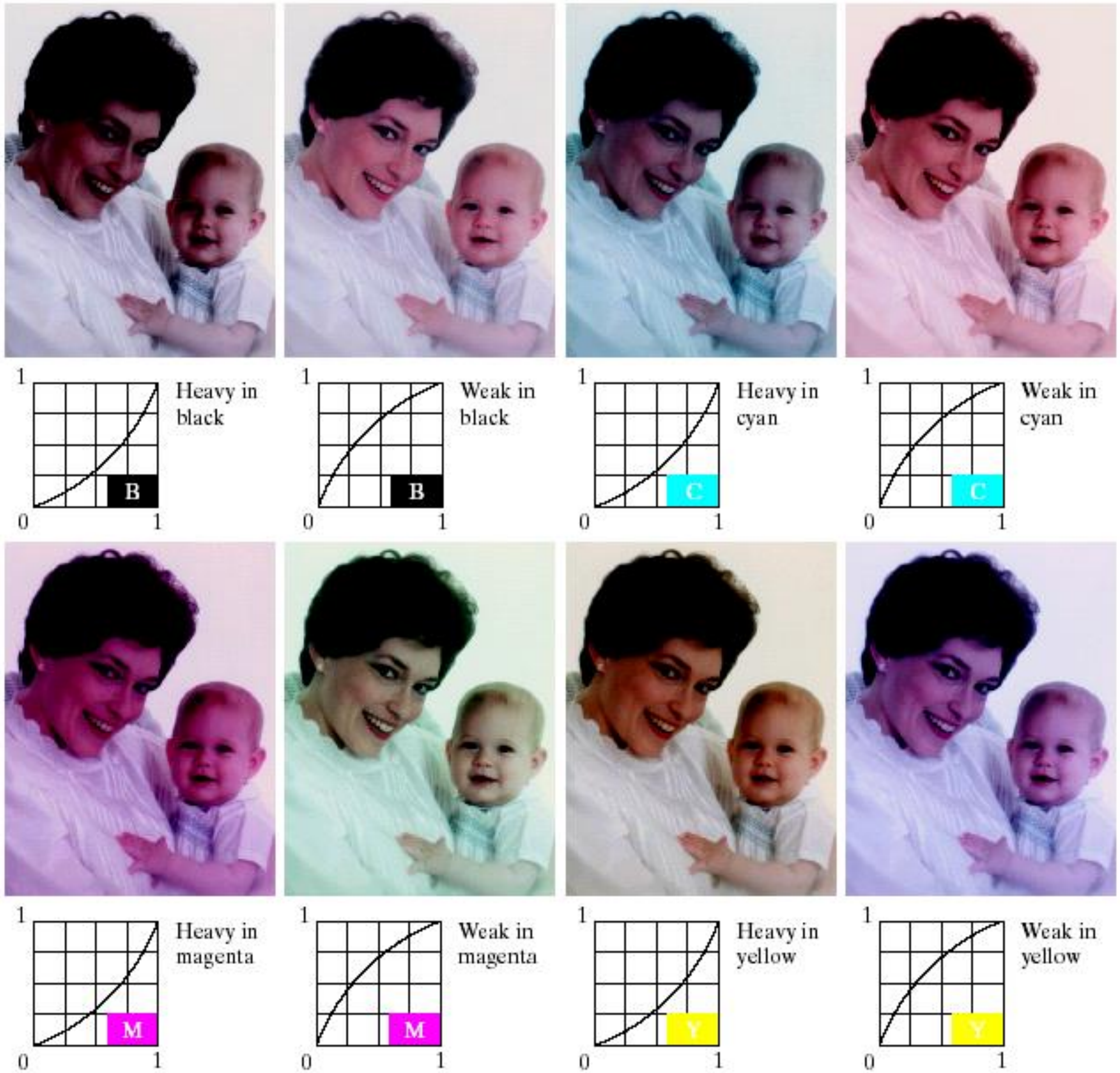


Note: Hue actually can change by such nonlinear transforms applied to individual color components.

Color Correction

Example in CMYK

images to be corrected
+ color transformation to be used for correction



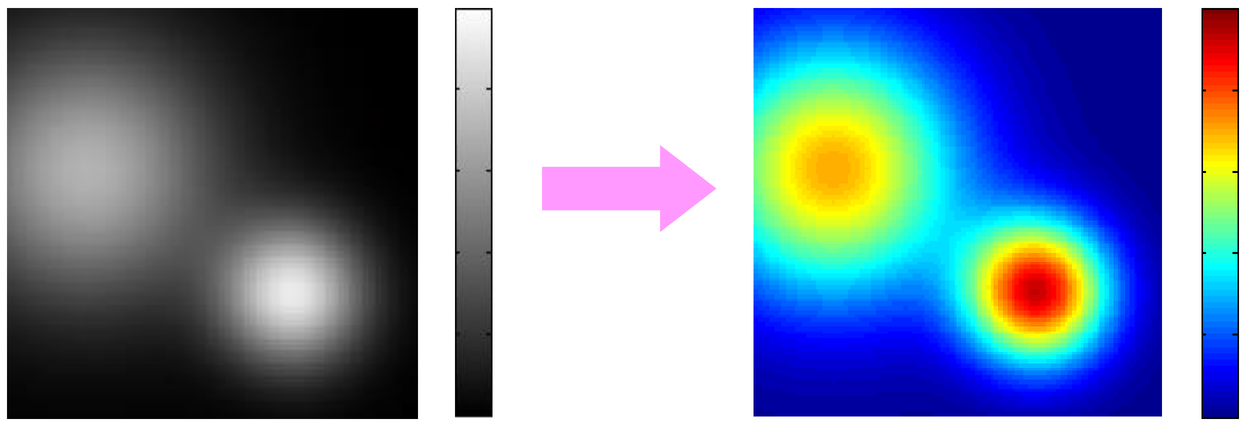
Other Processing Methods

Now, how are the other gray-level processing techniques applied to color images?

- Histogram processing: Applied only to the intensity component.
- Linear spatial filtering (smoothing, sharpening, etc.): Usually applied to individual RGB components. Vector-based and per-color-component processing are equivalent here.
- Median and other order-statistics filters: Vector-based and per-color-component processing are both applicable but are not equivalent.
    - Spatial filtering of only the intensity/luminance component is also applicable.

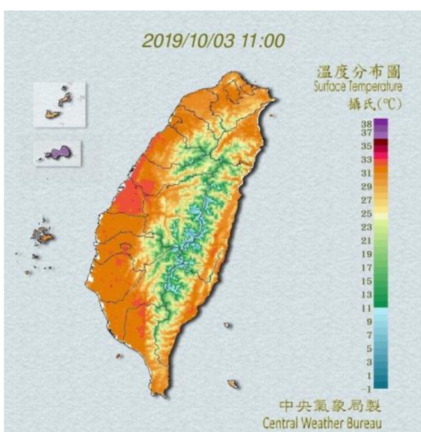
Pseudocolor Processing

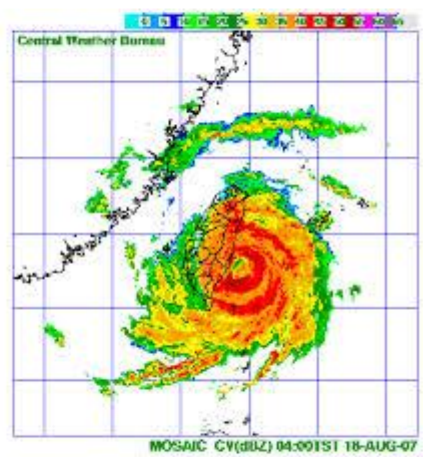
Pseudocolor processing is not related to colors in the real world. Instead, colors are used to provide better data visualization. A most familiar example is the color-coded elevation information in maps.

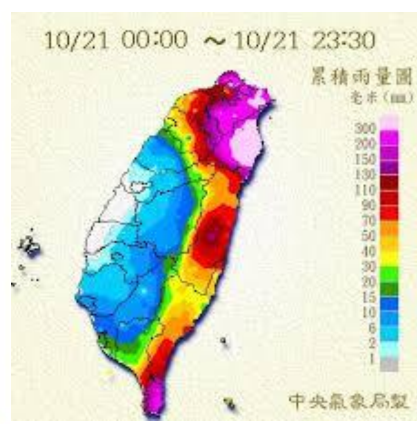


More examples:

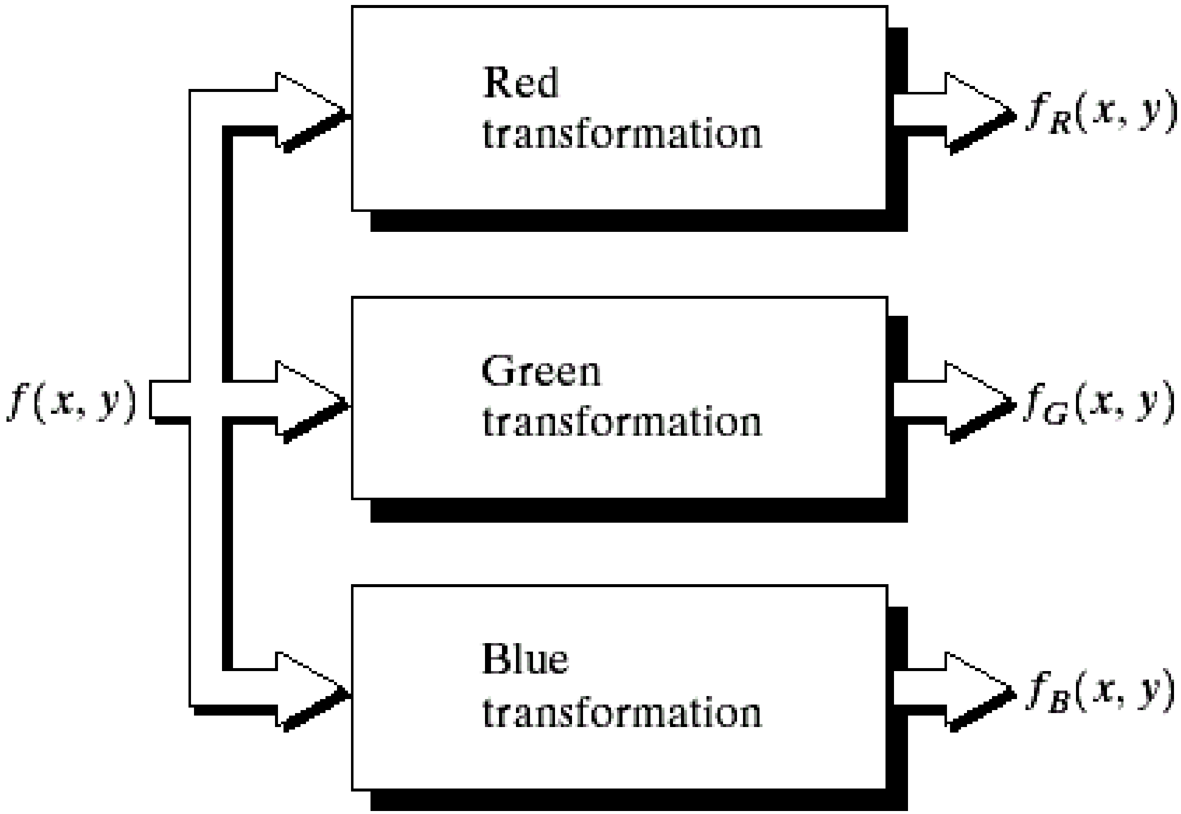
cwb.gov.tw



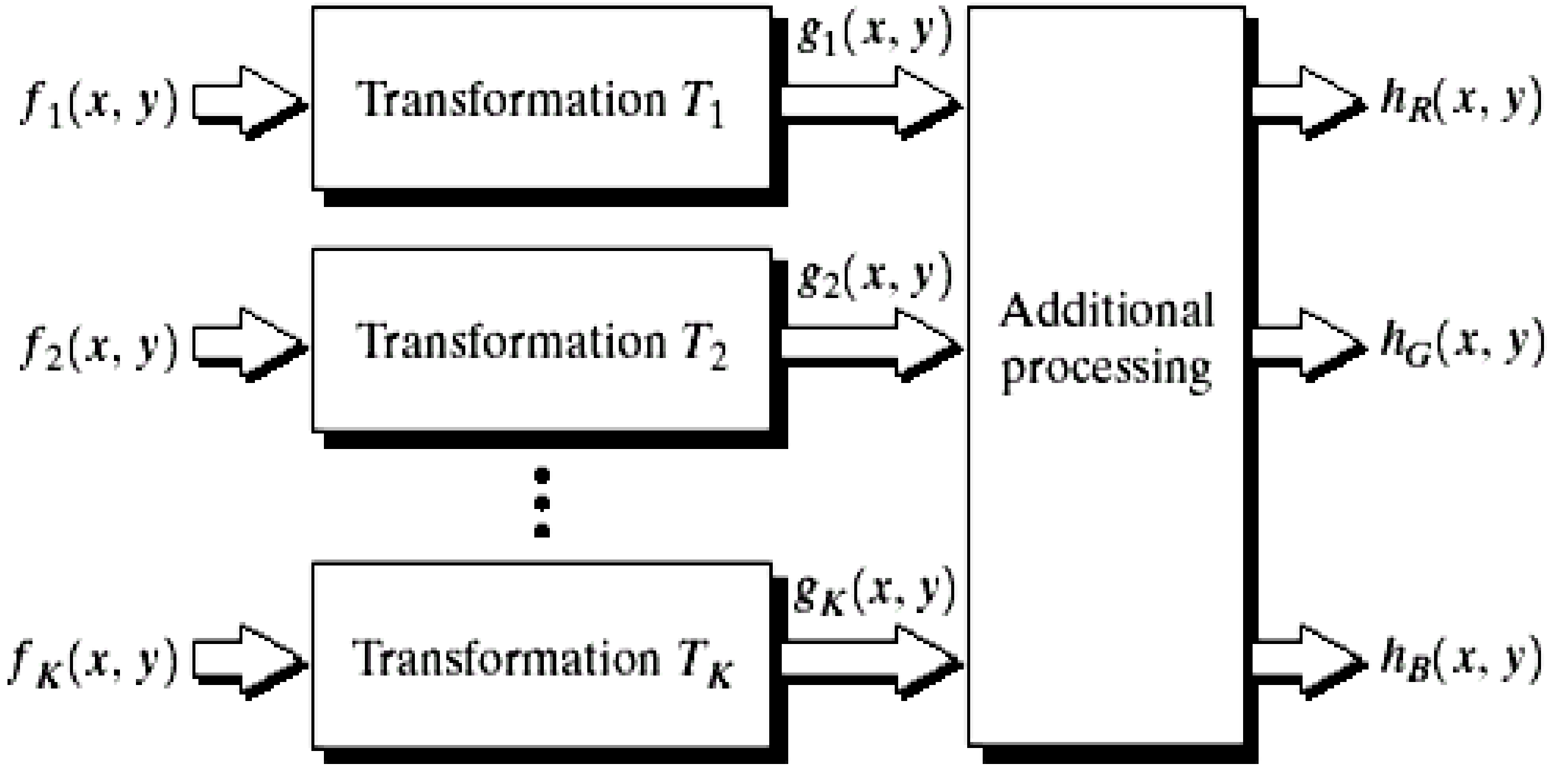




Gray-Level to Color Transformations



Multispectral Images



Multispectral Images