Computer Vision

04: Color Spaces

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Color Spaces

Color Space

A color space is a mathematical model that defines a specific range of colors that can be displayed or printed. It's essentially a system for representing colors numerically.

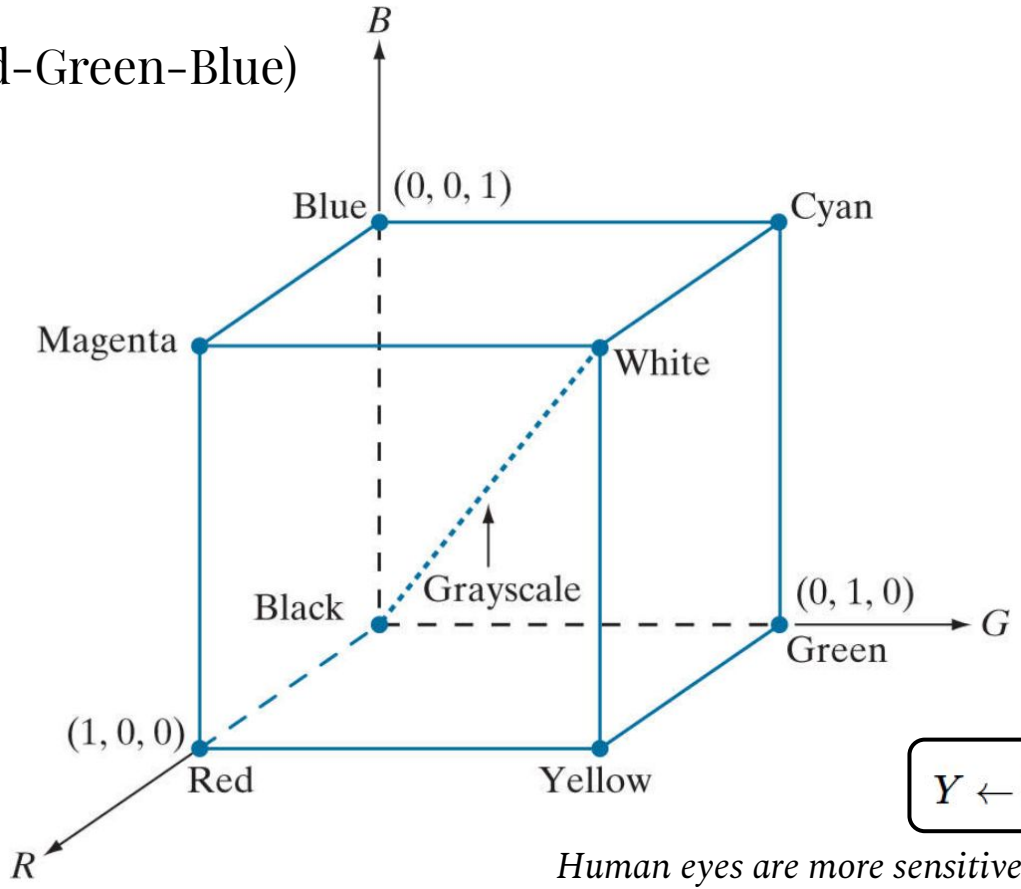
- Each color space offers a different way to represent color information. This can be based on how we perceive colors, how colors are generated, or how they are printed.

- Different color spaces are better suited for different tasks in image processing.
  Some are ideal for display, others for printing, and some are better for image analysis and manipulation.

R G B
Color Space

Color Spaces

R G B (Red-Green-Blue)



Grayscale

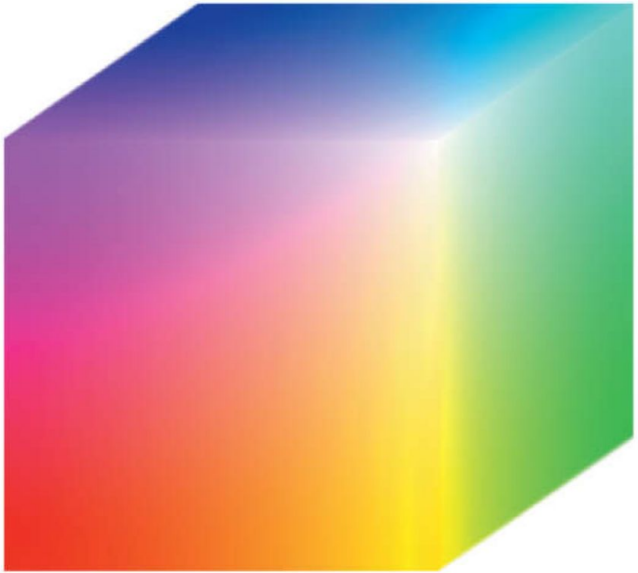
$$Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

Human eyes are more sensitive to Green, then Red and least to Blue.

Color Spaces

R G B (Red-Green-Blue)

Color Cube



R (Red)	G (Green)	B (Blue)	Resulting Color
255	0	0	Bright Red
0	255	0	Bright Green
0	0	255	Bright Blue
255	255	0	Yellow
0	255	255	Cyan
255	0	255	Magenta
0	0	0	Black
255	255	255	White

$$Y \leftarrow 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$

Color Spaces

R G B (Red-Green-Blue)

Why RGB is Important

- RGB is the native color space for most digital devices because electronic displays emit light.
- It's intuitive for hardware since screens light up red, green, and blue subpixels to produce colors.
- Image files like JPEG or PNG commonly store colors in RGB format.

Limitations Compared to Other Color Spaces

- RGB values do not separate color (hue) from brightness/contrast.
- This can make tasks like color detection, enhancement, or segmentation more complex.
- That's why other color spaces such as HSV or Lab* are used where hue, saturation, and brightness are separated for easier manipulation.

H S V
Color Space

Color Spaces

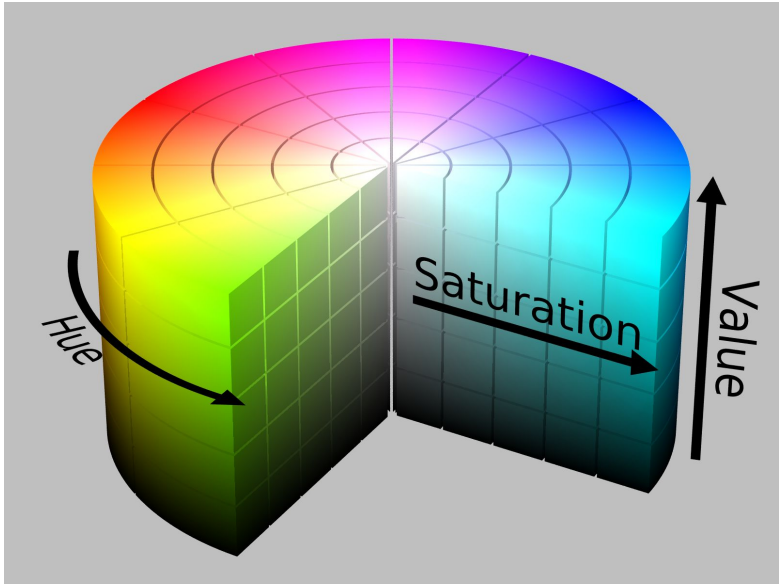
H S V (Hue-Saturation-Value)

Consider a cylinder.

Hue - goes around the circle at the top
Type of color such as Red, Blue or Green which is represented as angle. Range: 0 to 360 is normalized to 0 - 179.

Saturation - distance from the center to the edge
Center means faded gray, edge means vivid color ("purity" or vibrancy of a color). Range: 0 - 255

Value - moving up and down along the height
Top is bright, bottom is dark. Range: 0 - 255

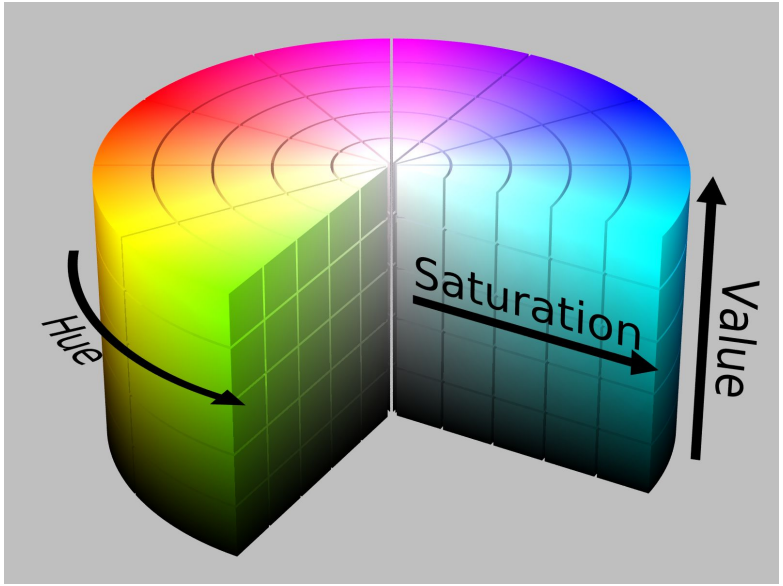


Color Spaces

H S V (Hue-Saturation-Value)

Bright Red vs. Dull Red:

- Both are red hue (H ≈ 0).
- **Bright red**: high saturation and high value (looks vibrant).
- **Dull red**: lower saturation (looks faded) or lower value (looks dark/red-brown).



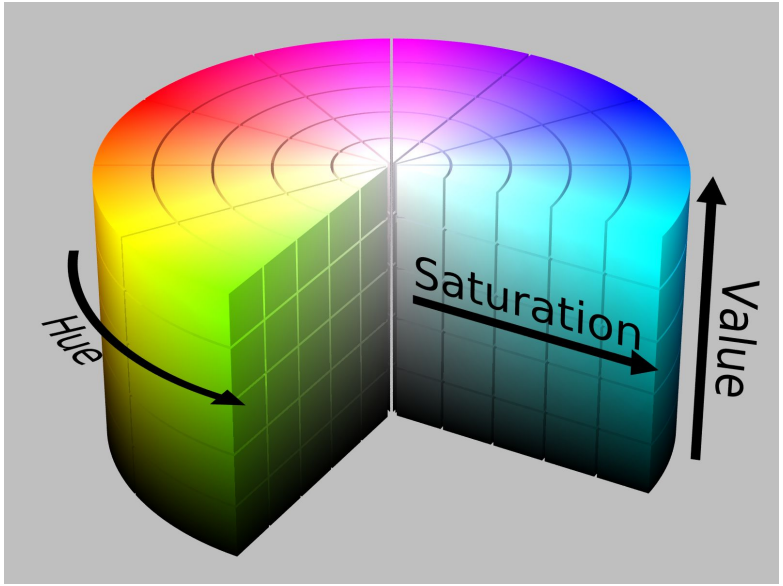
Color Spaces

H S V (Hue-Saturation-Value)

$$V \leftarrow max(R, G, B)$$

$$S \leftarrow \begin{cases} \frac{V - min(R,G,B)}{V} & \text{if } V \neq 0 \\ 0 & \text{otherwise} \end{cases}$$

$$H \leftarrow \begin{cases} 60(G-B)/(V - min(R,G,B)) & \text{if } V = R \\ 120 + 60(B-R)/(V - min(R,G,B)) & \text{if } V = G \\ 240 + 60(R-G)/(V - min(R,G,B)) & \text{if } V = B \end{cases}$$



L a b*
Color Space

Color Spaces

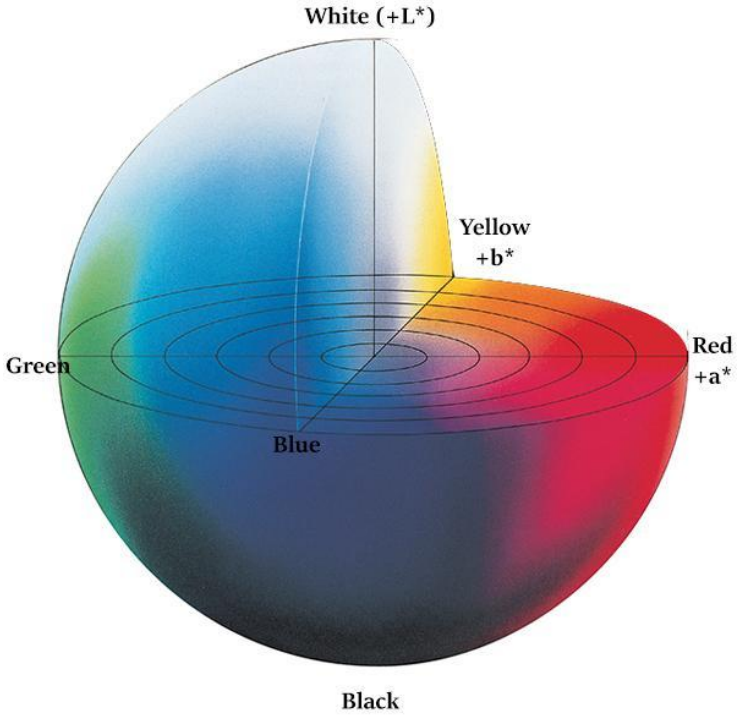
L*a*b* (Lightness; green-red; blue-yellow)

Lab* (or L*a*b*) separates images into lightness component and color differences. The symbol * represents the perceptual uniformity. *Closest to human perception.*

Lightness: This axis is independent of color and represents the lightness of the color.
Range: 0 to 100, pure black (L = 0) to diffuse white (L* = 100).*

a*: represents the position of a color between green and red.
Range: -127 to +128, negative in green and positive in red direction.

b*: represents the position of a color between blue and yellow.
Range: -127 to +128, negative in blue and positive in yellow direction.



Color Spaces

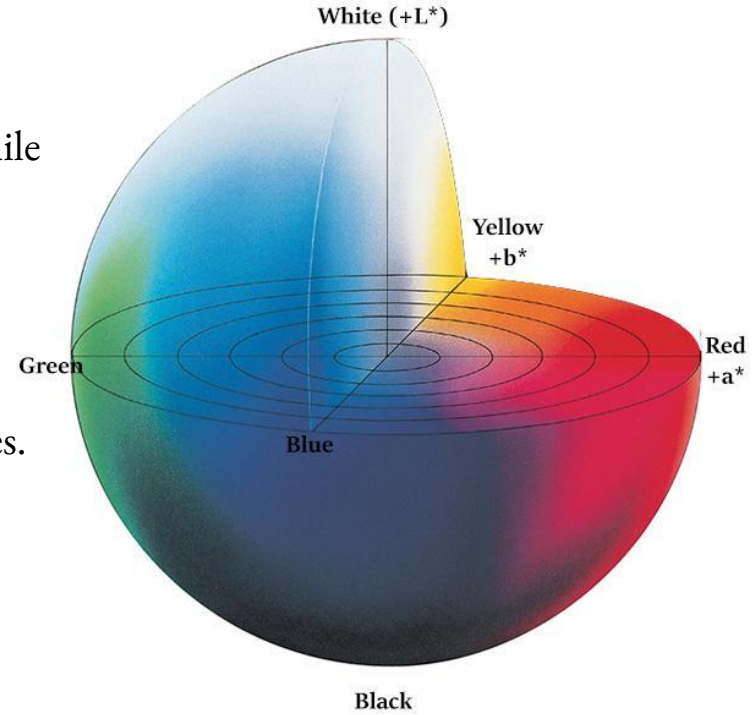
L*a*b* (Lightness; green-red; blue-yellow)

Example usage:

- Brighten the image by adjusting L* without changing the natural looking green/red (a*) or blue/yellow (b*) colors.
- Enhance just the color saturation by tweaking a* and b* while keeping brightness unchanged.

Usefulness:

- Enhance contrast by working only on the L* channel.
- Perform color-based segmentation based on a* and b* values.
- It often results in better color manipulations when compared to RGB or HSV.



Color Spaces

L*a*b* (Lightness; green-red; blue-yellow)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

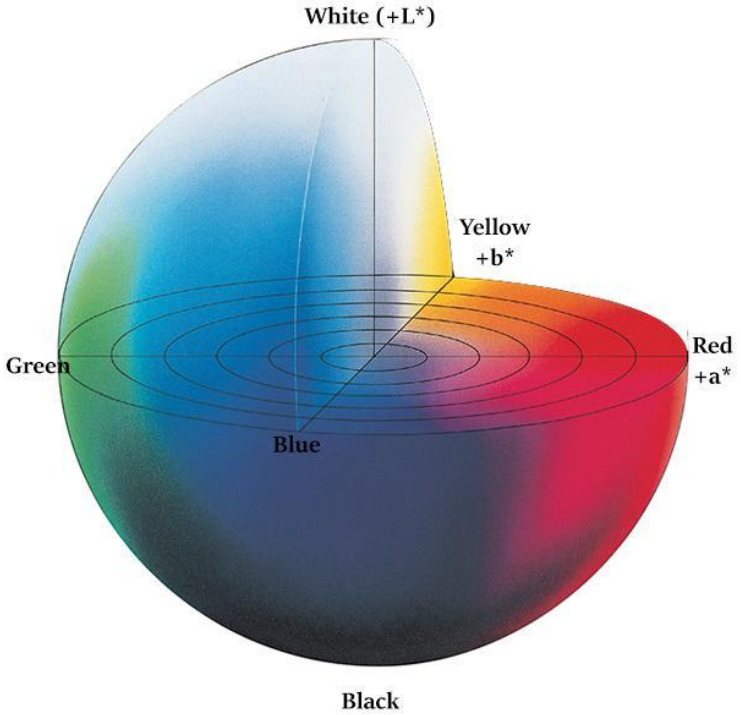
$$X \leftarrow X/X_n, \text{where} X_n = 0.950456$$

$$Z \leftarrow Z/Z_n, \text{where} Z_n = 1.088754$$

$$L \leftarrow \begin{cases} 116 * Y^{1/3} - 16 & \text{for } Y > 0.008856 \\ 903.3 * Y & \text{for } Y \leq 0.008856 \end{cases}$$

$$a \leftarrow 500(f(X) - f(Y)) + delta$$

$$b \leftarrow 200(f(Y) - f(Z)) + delta$$



Color Spaces

Colourization

Color Spaces

Summary Table

Color Space	Channels	Typical Range	Key Usage
Grayscale	Intensity	0–255	Fast analysis, preprocessing
RGB/BGR	R, G, B	0–255 each	Display, storage, basic analysis
HSV	H, S, V	H: 0–179, S: 0–255, V: 0–255	Segmentation, color detection
Lab*	L*, a*, b*	L*: 0–100 or 0–255, a*,b*: -128–127	Histogram equalization, color correction