COLOR MODEL

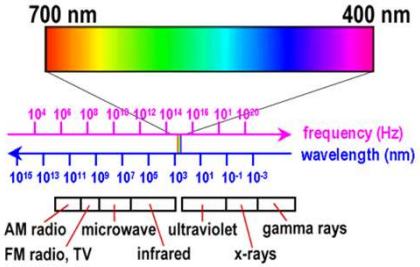
Color Models and Color Applications

LIGHT & COLOR

What is light?
- "light" = narrow frequency band of electromagnetic spectrum

The Electromagnetic Spectrum
- Red: 3.8×10^{14} hertz
- Violet: 7.9×10^{14} hertz

Color is a sensation produced by the human eye and nervous system.



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COLOR MATCHING EXPERIMENTS

Observers had to match a test light by combining three fixed primaries

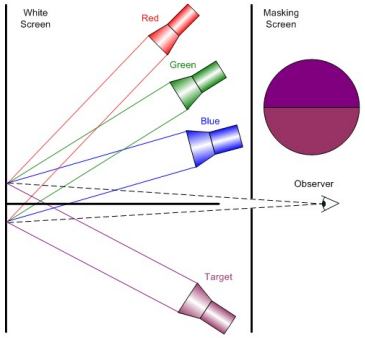
Goal: find the unique RGB coordinates for each stimulus

Tristimulus Values

The values R_Q, G_Q and B_Q for a stimulus Q that fulfill

$$Q = R_Q*R + G_Q*G + B_Q*B$$

are called the tristimulus values of Q
- R = 700.0 nm
- G = 546.1 nm
- B = 435.8 nm



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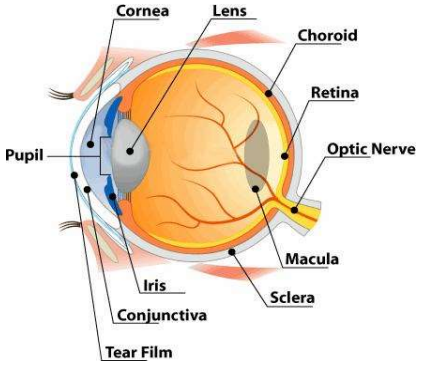
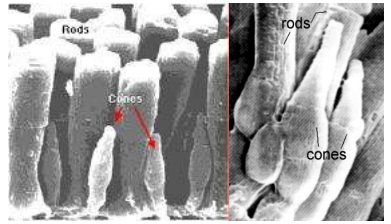
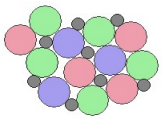
THE HUMAN EYE

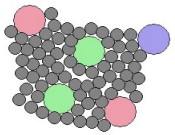






1.35 mm from rentina center

4 μm

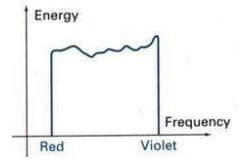


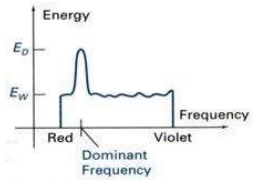
8 mm from rentina center

PSYCHOLOGICAL CHARACTERISTICS OF COLOR

- Dominant frequency (hue, color)
- Brightness (area under the curve), total light energy
- Purity (saturation), how close a light appear to be a pure spectral color, such as red
  - Purity = $E_D - E_W$
  - E_D = dominant energy density
  - E_W = white light energy density

Chromaticity, used to refer collectively to the two properties describing color characteristics: purity and dominant frequency





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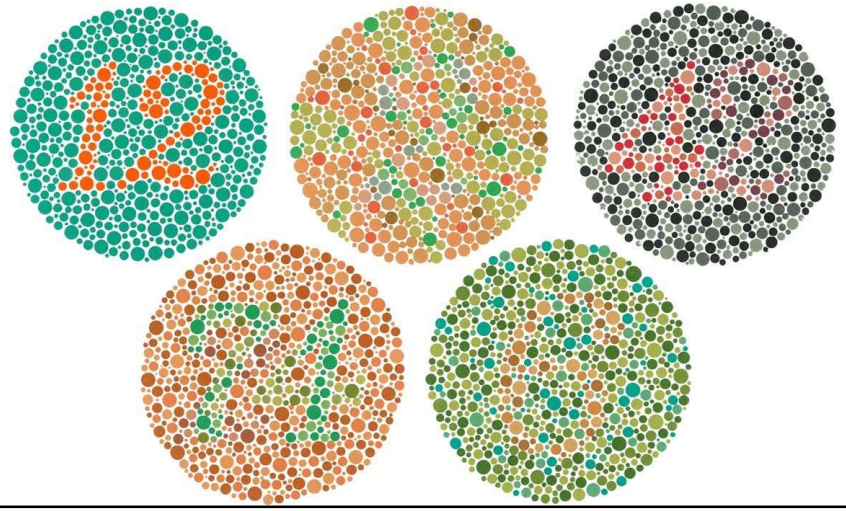


INTUITIVE COLOR CONCEPTS

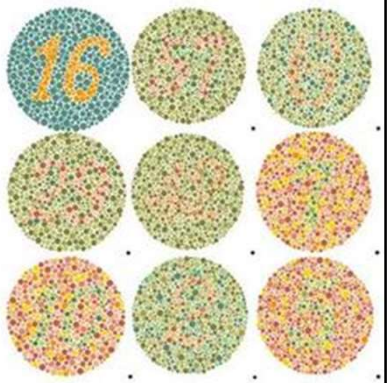
Color mixing created by an artist

Shades, tints and tones in scene can be produced by mixing color pigments (hues) with white and black pigments

Shades
- Add black pigment to pure color
- The more black pigment, the darker the shade

Tints
- Add white pigment to the original color
- Making it lighter as more white is added

Tones
- Produced by adding both black and white pigments



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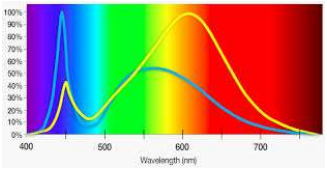
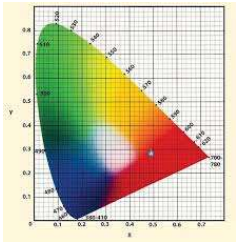
COLORIMETRY (CM)

CM is concerned with numerically specifying the color of a physically defined visual stimulus
- Stimuli with the same specification look alike under the same viewing conditions
- Stimuli that look alike have the same specification
- The numbers used are continuous functions of the physical parameters

Colorimetry n. measuring of the intensity of color





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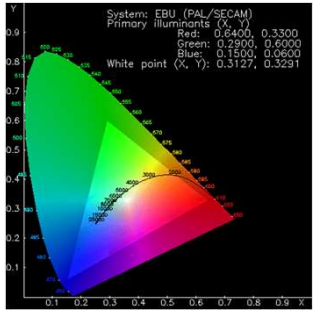
COLOR GAMUTS
CHROMATICITY DIAGRAM

Define *color gamuts*

- Range of colors that can be produced on a device
- CRT monitor's gamut is different from printer's
- Any choice of three primaries can never encompass all visible colors
- RGB are natural choices for primaries as they can cover the largest part of the "horseshoe"



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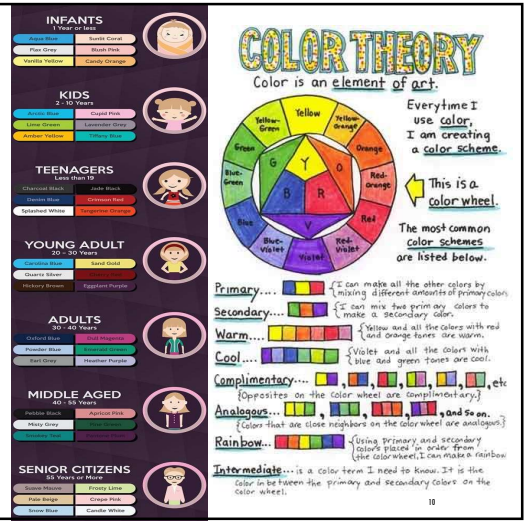
COLOR THEORY

color theory is a body of practical guidance to **color** mixing and the visual effects of a specific **color** combination



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COLOR MODELS

Method for explaining the properties or behavior of color within some particular context

Primary Colors
- 3 primaries are sufficient for most purposes

Hues that we choose for the sources

Color gamut is the set of all colors that we can produce from the primary colors

What is the use?

For display, editing, computation, compression, …?

Several key (very often conflicting) features may be sought after:
- Additive (RGB) or subtractive (CMYK)
- Separation of luminance and chromaticity
- Equal distance between colors are equally perceivable

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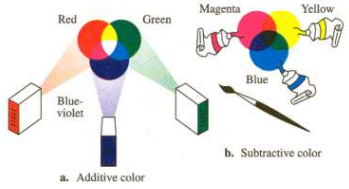
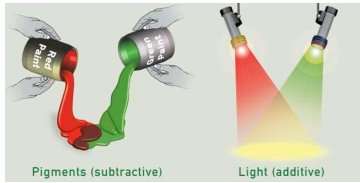
ADDITIVE VS. SUBTRACTIVE COLOR MODELS

- Additive color models display color as a result of light being transmitted (added) the total absence of light would be perceived as **black**.
- Subtractive color models display color as a result of light being absorbed (subtracted) by the printing inks.
  - As more ink is added, less and less light is reflected.
  - Where there is a total absence of ink the resulting light being reflected (from a white surface) would be perceived as **white**.





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6.COLOR MEASUREMENT SYSTEM

Color order systems:

Munsell Color System

Natural Color System(NCS)

Why do we order colors?

Color Order system

- Trichromatic theory by Hermann von Helmholtz
- The concept of color space

So what are the three parameters?

MUNSELL COLOR SYSTEM

One of the Oldest color order systems with The three main parameters: (H,V, C)

- Munsell Hue (H) : five primary:5R, 5Y, 5G, 5B, 5P
- Munsell Value (V) : the brightness scale from 0(black)~10
- Munsell Chroma (C) : from /0~/14

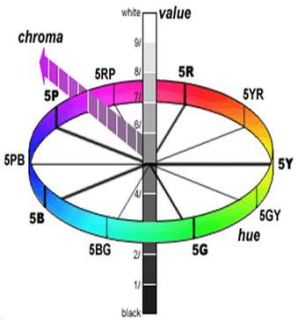
The examples of color expression:

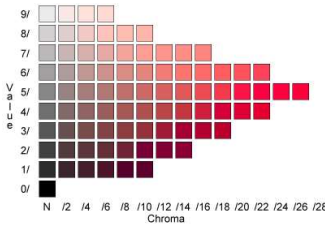
5RP 8/2 :

Hue:5RP

Value:8

Chroma:2





NATURAL COLOR SYSTEM (NCS)

The NCS: six elementary color percepts of human vision — which might coincide with the psychological primaries: white, black, red, yellow, green, and blue

If the color data is: 40% whiteness, 10% blackness, 5% yellowness = 45% redness

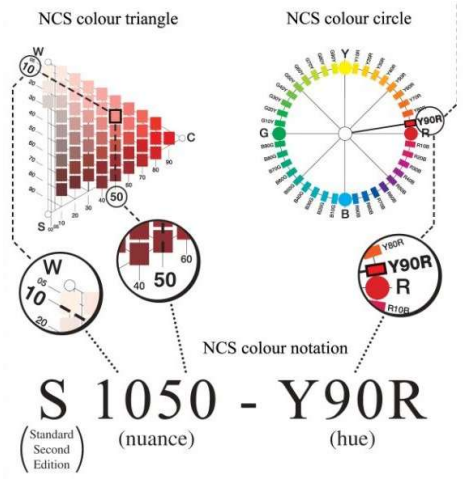
S=10, c=r+y=50

Φ=Y90R

→ 1050-Y90R

Yellow – NCS 0580-Y10R (nuance = 5% blackness, 80% chromaticness, hue = 90% yellow + 10% red.

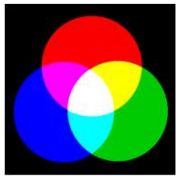
Blue – NCS 4055-R95B (nuance = 40% blackness, 55% chromaticness, hue = 5% red + 95% blue.

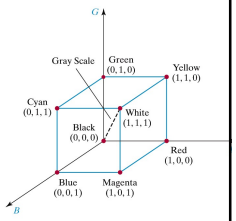


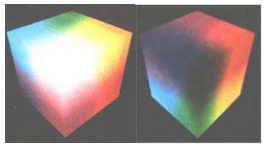
RGB COLOR MODEL

Basic theory of RGB color model

- The tristimulus theory of vision
- It states that human eyes perceive color through the stimulation of three visual pigment of the cones of the retina
  - Red, Green and Blue
- Model can be represented by the unit cube defined on R,G and B axes







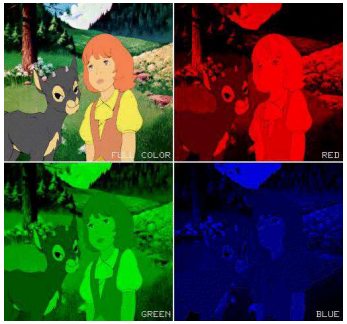
THE RGB COLOR MODEL

An additive model, as with the XYZ color system

Each color point within the unit cube can be represented as a weighted vector sum of the primary colors, using vectors R, G and B

C(λ)=(R, G, B)=RR+GG+BB

Chromaticity coordinates for the National Television System Committee (NTSC) standard RGB primaries



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CMY COLOR MODELS

- Color models for hard-copy devices, such as printers

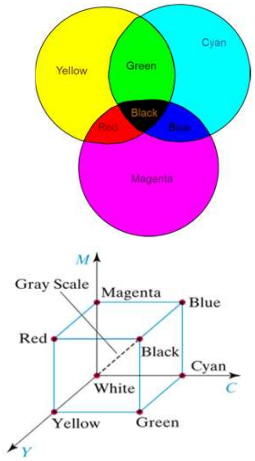
Produce a color picture by coating a paper with color pigments

Obtain color patterns on the paper by reflected light, which is a subtractive process

- The CMY parameters

A subtractive color model can be formed with the primary colors cyan, magenta and yellow

Unit cube representation for the CMY model with white at origin



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THE CMY COLOR MODELS

Transformation between RGB and CMY color spaces

- Transformation matrix of conversion from RGB to CMY

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

- Transformation matrix of conversion from CMY to RGB

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

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CMYK MODEL

Assumption: ink printed on pure white paper

CMY = White – RGB:

C = 1 – R, M = 1 – G, Y = 1 – B

CMYK from CMY (K is black ink):

K = min(C, M, Y)

C = C – K, M = M – K, Y = Y - K

INTUITIVE COLOR CONCEPTS

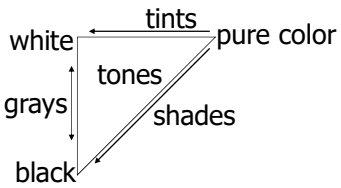
Terminology

Perceptual Term	Colorimetry	Comments
hue	dominated wavelength	to distinguish colors
saturation	excitation purity	e.g., red and pink
Lightness (reflecting objects)	luminance	
Brightness (self-luminous objects)	luminance	e.g., Sun, CRT

INTUITIVE COLOR CONCEPTS

- Tint: white pigment added to pure pigment
  - ➔ saturation reduced
- Shade: black pigment added to pure pigment
  - ➔ lightness reduced
- Tone: consequence of adding both white and black pigments to pure pigments

Tints, shades, and tones ➔ different colors of same hue are produced



Grays

= black pigments + white pigments

Graphics packages that provide color palettes to users often employ two or more color models

THE HSV COLOR MODEL

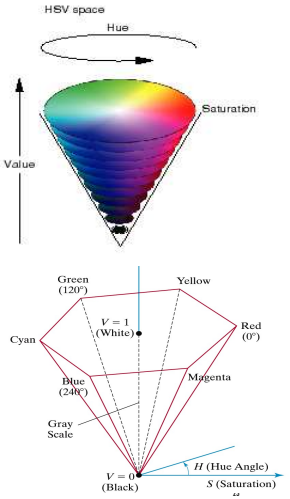
The HSV colors often use a color model based on intuitive concepts

Color parameters are hue (H), saturation (S) and value (V)

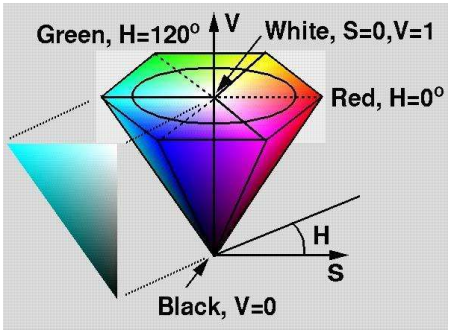
- Derived by relating the HSV parameters to the direction in the RGB cube
- Obtain a color hexagon by viewing the RGB cube along the diagonal from the white vertex to the origin

The HSV hexcone

- Hue is represented as an angle about the vertical axis ranging from 0 degree at red to 360 degree
- Saturation parameter is used to designate the purity of a color
- Value is measured along a vertical axis through center of hexcone



HSV COLOR MODEL HEXCONE



Color components:

- Hue (H) ∈ [0°, 360°]
- Saturation (S) ∈ [0, 1]
- Value (V) ∈ [0, 1]

Color definition

- Select hue, S=1, V=1
- Add black pigments, i.e., decrease V
- Add white pigments, i.e., decrease S

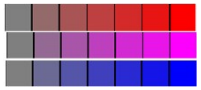
Cross section of the HSV hexcone showing regions for shades, tints, and tones

HSV

Hue is the most obvious characteristic of a color

Chroma is the purity of a color
- High chroma colors look rich and full
- Low chroma colors look dull and grayish
- Sometimes chroma is called saturation

Value is the lightness or darkness of a color
- Sometimes light colors are called tints, and
- Dark colors are called shades



TRANSFORMATION HSV-RGB

min = the minimum R, G, or B value

max = the maximum R, G, or B value

$$h = \begin{cases} 0 & \text{if max} = \text{min} \\ 60^\circ \frac{g-b}{\text{max}-\text{min}} + 0^\circ & \text{if max} = \text{r and } g \geq b \\ 60^\circ \frac{g-b}{\text{max}-\text{min}} + 360^\circ & \text{if max} = \text{r and } g < b \\ 60^\circ \frac{b-r}{\text{max}-\text{min}} + 120^\circ & \text{if max} = g \\ 60^\circ \frac{r-g}{\text{max}-\text{min}} + 240^\circ & \text{if max} = b \end{cases}$$

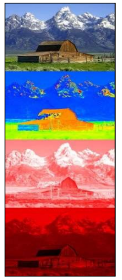
$$s = \begin{cases} 0 & \text{if max} = 0 \\ \frac{\text{max}-\text{min}}{\text{max}} & \text{otherwise} \end{cases}$$

$v = \text{max}$

To move from RGB space to HSV space:
- Can we use a matrix? No, it's non-linear.

RGB

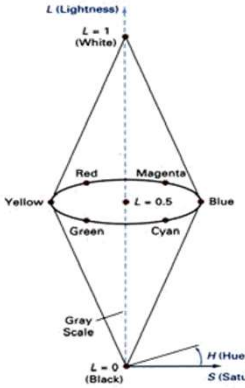
CMY

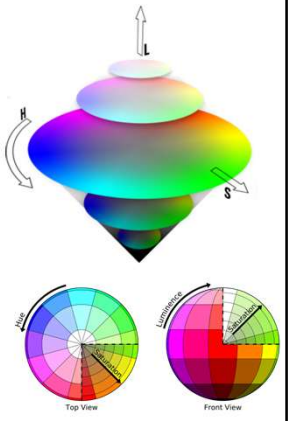


HSV

THE HLS COLOR MODEL

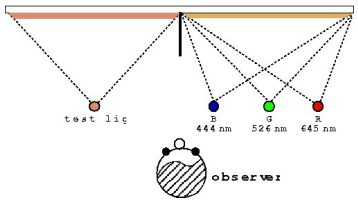
HLS color model
- Another model based on intuitive color parameter
- Used by the Tektronix Corporation
- The color space has the double-cone representation
  - Used hue (H), lightness (L) and saturation (S) as parameters





CIE 1931 COLOR MODEL

Color Matching Experiment



Problem solution: XYZ color system

Tristimulus system derived from RGB

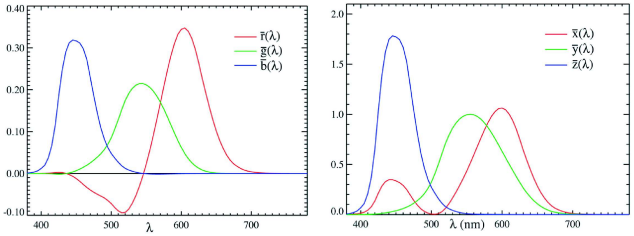
Based on 3 imaginary primaries

All 3 primaries are outside the human visual gamut

Only positive XYZ values can occur

1931 by CIE (Commission Internationale de l'Eclairage)

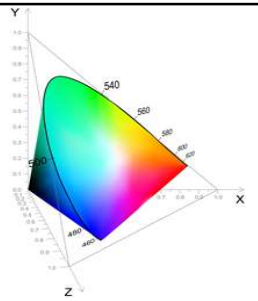
CIE COLOR MATCHING FUNCTIONS



CIE *RGB* Matching Functions CIE *XYZ* Matching Functions

XYZ is not RGB. X, Y and Z are extrapolations of RGB created mathematically to avoid negative numbers

CIE RGB->XYZ



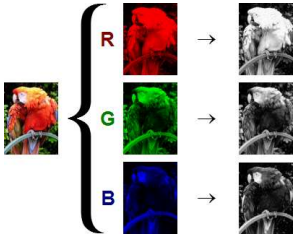
Projective transformation specifically designed so that Y = V (luminous efficiency function)

XYZ → CIE RGB uses inverse matrix

XYZ → any RGB matrix is device dependent

$$X = 0.723R + 0.273G + 0.166B$$
$$Y = 0.265R + 0.717G + 0.008B$$
$$Z = 0.000R + 0.008G + 0.824B$$

CIE *xyY* FROM CIE *XYZ*

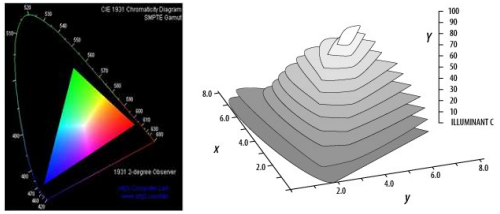


CIE xyY color model is used to catalog colors:

x = X / (X + Y + Z)

y = Y / (X + Y + Z)

Y = luminance



COLOR MODEL YIQ

YIQ contoh

Used for: video encoding for some standard such as NTSC

Axes:

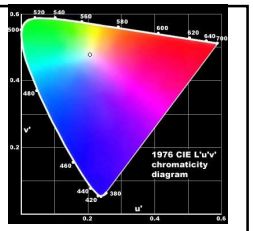
- Y: luma , same as the Y complement in CIE XYZ color space,
- I: blue chroma I = R – Y
- Q: red chroma Q = B – Y

Separate luminance or brightness from color, because we perceive brightness ranges better than color

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.701 & -0.587 & -0.114 \\ -0.299 & -0.587 & 0.886 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & -0.509 & -0.194 \\ 1 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

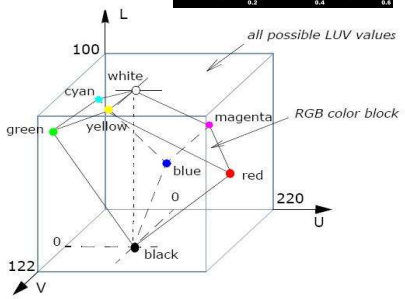
CIE *LU*V** PERCEPTUALLY UNIFORM SPACES



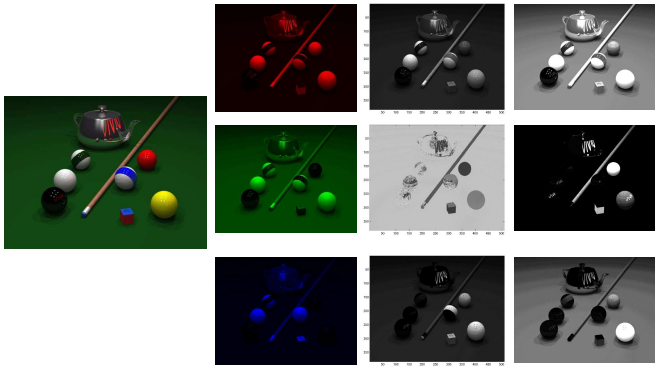
'Luv' was designed to be 'perceptually linear'.

That change in color in one part of the colorspace looks similar change in another part of the colorspace.

LUV colorspace much better suited for image difference comparisions.



EXAMPLES (RGB, HSV, LUV)



LAB MODEL

The CIE L*a*b* **color model** (**Lab**) is based on the human perception of **color.**

It aspires to perceptual uniformity, and its *L* component closely matches human perception of lightness

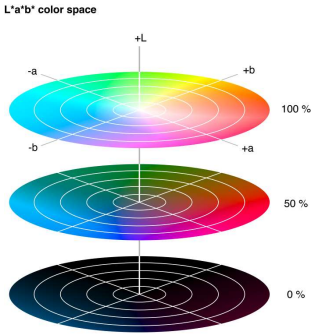
Chrominance:

a – ranges from green to red and

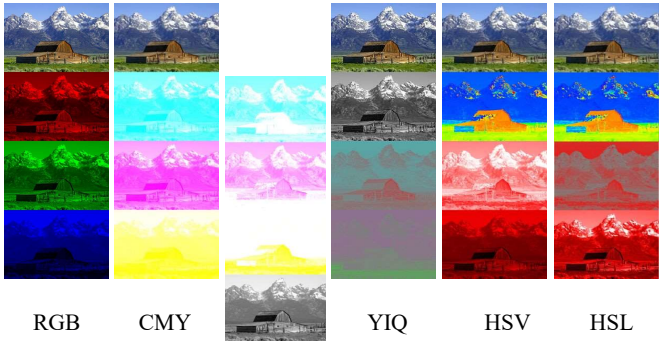
b - ranges from blue to yellow

Photoshop uses this model to get more control over color

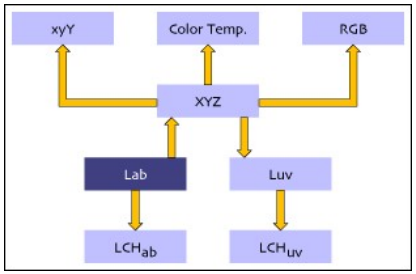
- *Adobe Photoshop, image editing using "Lab mode" is CIELAB*
- *Affinity Photo, Lab editing is achieved by changing the document's Colour Format to "Lab (16 bit)"*
- *TIFF files, the CIELAB color space*
- *PDF documents, the "Lab color space" is CIELAB*
- *Digital Color Meter on OS X, it is described as "L*a*b*"*



COMPARISON



COLOR MODEL SUMMARY



Colorimetry:
- CIE XYZ: contains all visible colors

Device Color Systems:
- RGB: additive device color space (monitors)
- CMYK: subtractive device color space (printers)
- YIQ: NTSC television (Y=luminance, I=R-Y, Q=B-Y)

Color Ordering Systems:
- HSV, HLS: for user interfaces

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APPLICATION

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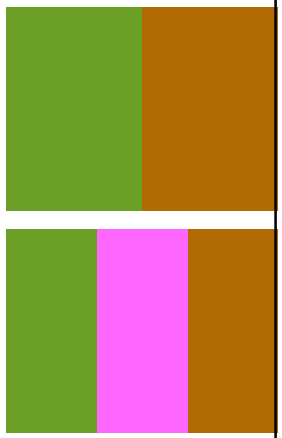
COLOR SELECTION AND APPLICATIONS

Graphical package provide color capabilities in a way that aid users in making color selections

Guidelines
- Displaying blue pattern next to a red pattern can cause eye fatigue
- Smaller number of colors produces a better looking display
- Tints and shades tend to blend better than pure hues
- Gray or complement of one of the foreground color is usually best for background



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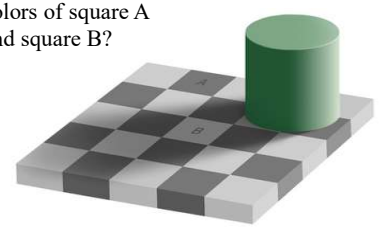
COLOR CONSTANCY

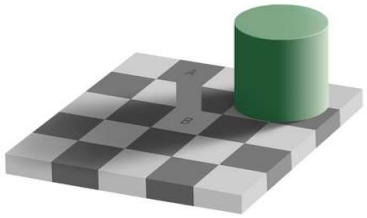
How different are the colors of square A and square B?



Perceived color is highly context dependent

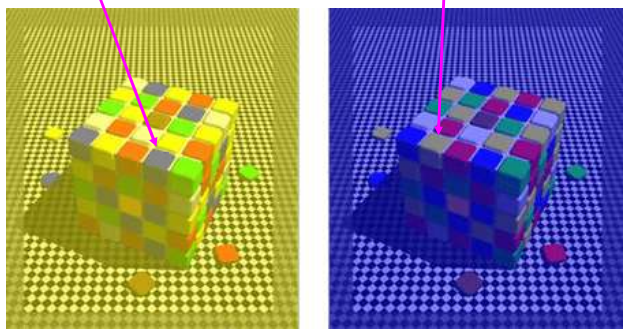
Allowing color recognition with variable lighting conditions

COLOR CONSTANCY



Perceived color is highly context dependent

Allowing color recognition with variable lighting conditions



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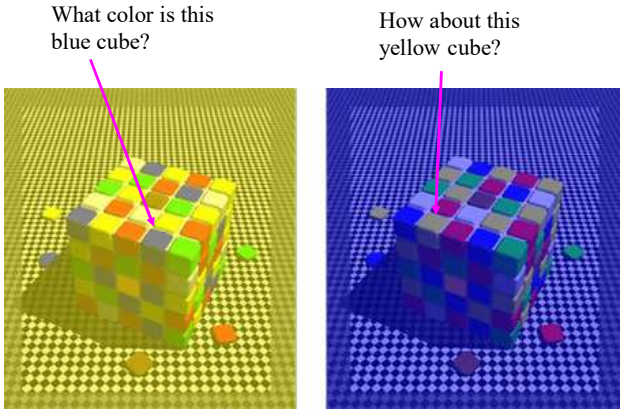
WANT TO SEE IT SLOWER?



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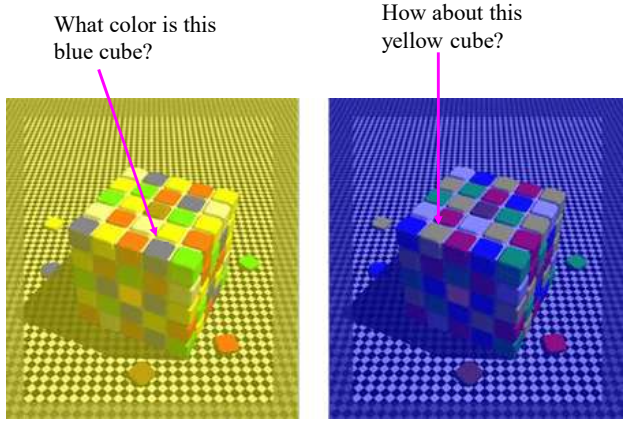
Even slower?



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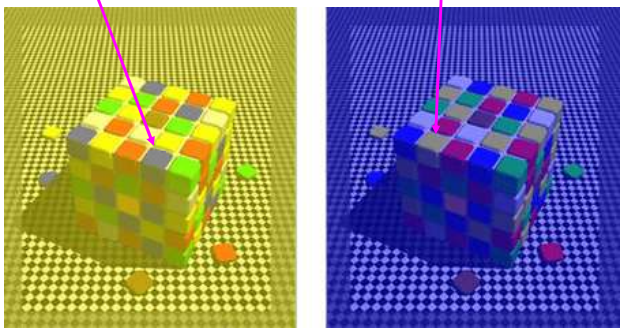
So what color is it?

What color is this blue cube?

It's gray!

How about this yellow cube?



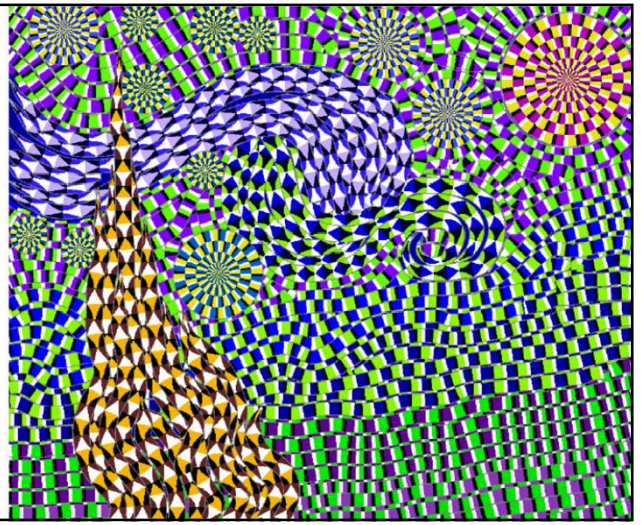
HUMANS ONLY PERCEIVE RELATIVE BRIGHTNESS

CORNSWEET ILLUSION

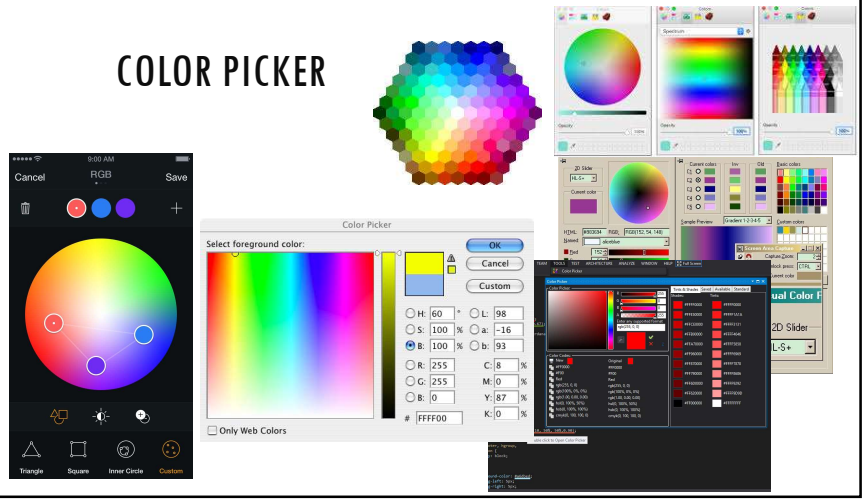
Cornsweet illusion. Left part of the picture seems to be darker than the right one. In fact they have the same brightness.

The same image, but the edge in the middle is hidden. Left and right part of the image appear as the same color now.

SELF-ANIMATED IMAGES



COLOR PICKER



WHAT HAPPENS WHEN CHICKENS SEE RED?

A company * that markets red contact lenses for chickens (at **20** cents a pair), points to medical studies showing that chickens wearing red-tinted contact lenses behave differently from birds that don't.

They eat less, produce more and don't fight as much. This decreases aggressive tendencies and birds are less likely to peck at each other causing injury.

A spokesman said the lenses will improve world egg-laying productivity by $600 million a year. (Perhaps everything looks red and they cannot distinguish combs, wattles, or blood.

Or ...perhaps the chickens are happier because they're viewing the world through rose colored glasses.)

Animalens Inc. of Wellesley, Mass

If you don't believe this, read the facts!
http://www.inc.com/magazine/19890501/5636.html