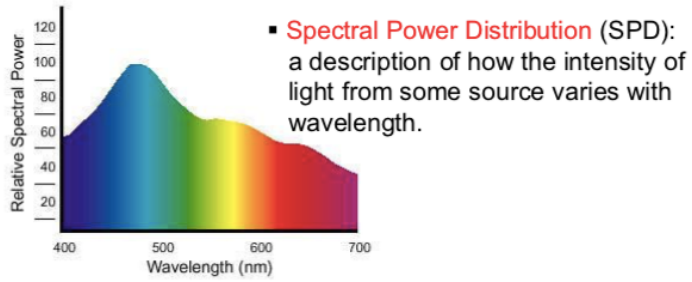
Colours

Agenda

- Colour is a property of light
- Colour vision is a complex phenomenon
- There are different colour models
- RGB is used in computer monitors
- YUV/YCbCr are used for image compression
- CMYK is used for printing
- HSV is an intuitive colour model

Colour is a property of light

Light



The narrower the band, the purer the color (red, orange, …) — color without mixation

Pure spectral color: Colors that correspond to narrower wavelength bands

Properties of Colours

Color is a property of light, not an object in itself

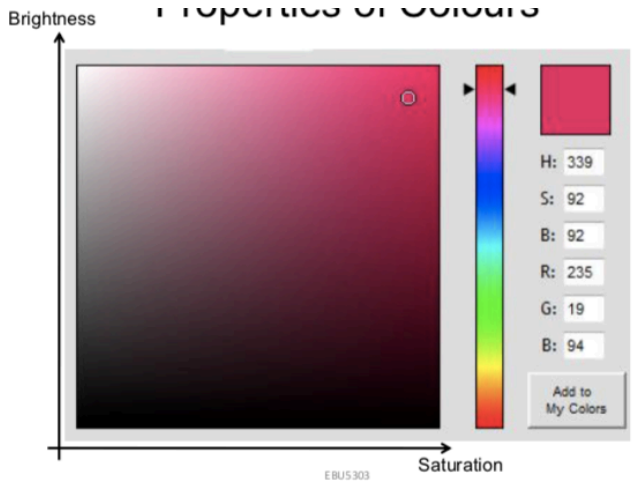
- Objects have no colour of their own, but merely the ability to reflect a certain section of the visible spectrum

Hue + Saturation + Brightness

Hue: the name of the colour (dominant wavelength)

Saturation: a fully saturated colour is one with no mixture of white

Brightness is the extent to which an area appears to emit light



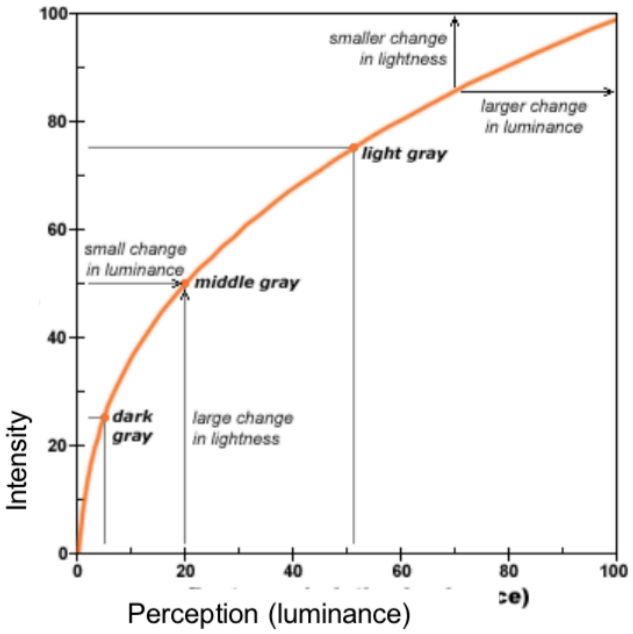
Brightness and Luminance

Brightness: is a matter of subjective perception and has no precise mathematical definition

Luminance: has a mathematical definition that relates a light's wavelength and power to how bright it is perceived to be

note: lights of equal power but different wavelengths do not appear equally bright. The brightest wavelengths are about 550 nm.

Perception: relative intensity



Colour vision is a complex phenomenon

Colour perception is subjective

- Perception of colour is also determined by the physical context of the object (number, size, proximity and energy characteristics of other objects in the field of view)
- The brain has a major role in interpreting colour: perception of colour may be affected by previous experience and functioning of the brain

Colour perception is difficult because:

– It varies from person to person

– It is affected by adaptation

– It is affected by surrounding colours

Retina — Rodes: night vision | cones: colour vision

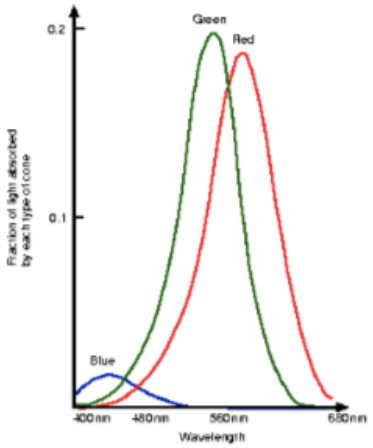
Cones: (3 types) 1. L or R: red light (610 nm)
2. M or G: green light (560 nm)
3. S or B: blue light (430 nm)

Colour blindness results from missing cone type(s)

The Tristimulus Theory of Colour Vision

Human perception of colour derives from the eye's response to 3 different groups of wavelengths, i.e. those corresponding to red, green and blue (RGB)

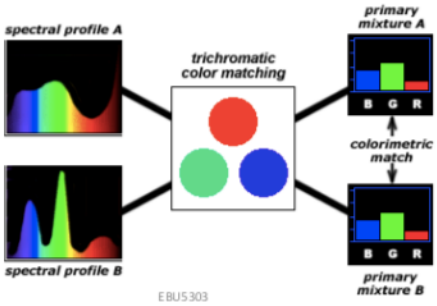
Therefore any sensation of colour can be produced by mixing together suitable amounts of these colours



Metamers

Metamers: two colors that produce the same tristimulus values are visually intinguishable

- Identical perceptions of colour can thus be caused by very different spectra



Colour models

Color model: A colour model is an abstract mathematical model describing the way colours can be represented as sets of numbers

Different color models

RGB: used in computer monitors
YUV/YCbCr: used for image compression
CMYK: used for printing
HSV: an intuitive colour model

RGB

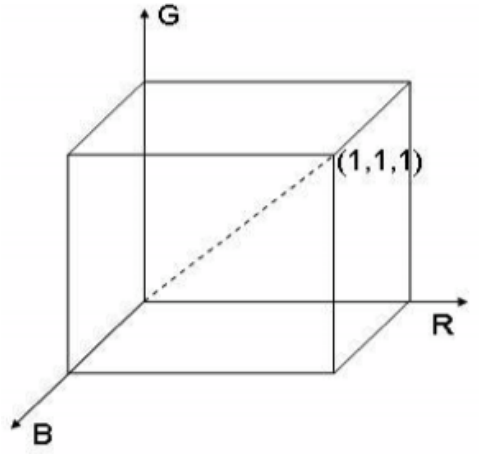
- In the RGB model, we can define any colour value in terms of the proportions of R, G and B it contains
- (r, g, b)
- colour depth: The number of bits used to hold a colour value

black: (0,0,0)
red: (255,0,0)
white: (255,255,255)
gray: (100,100,100)

From R,G,B to Grayscale

Let an RGB color pixel be given by (R, G, B), where R, G, and B are the red, green, and blue color components, respectively. Then the corresponding grayscale value is given by (L, L, L), where: L = 0.30R + 0.59G + 0.11B

Exercise 1: What colours correspond to the eight corners of this cube?



(0,0,0): black
(255,0,0): red
(0,0,255): blue
(255,0,255): magenta
(0,255,0): green
(255,255,0): yellow
(0,255,255): magenta
(255,255,255): white

Exercise 2: What does a straight line running from the origin (0,0,0) to (255,255,255) represent?

Grayscale

YUV

The YUV model is a simple translation of the RGB model, separating all the luminance information (Y) from the colour (or chrominance) information (U, V)

RGB to YUV

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

RGB to YCbCr

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 0 \\ 128 \\ 128 \end{bmatrix} \quad \begin{matrix} Y \in [0, 255] \\ C_b \in [0, 255] \\ C_r \in [0, 255] \end{matrix}$$

YCbCr to RGB

$$\begin{aligned} R &= Y + 1.402 \cdot (C_R - 128) \\ G &= Y - 0.34414 \cdot (C_B - 128) - 0.71414 \cdot (C_R - 128) \\ B &= Y + 1.772 \cdot (C_B - 128) \end{aligned}$$

CMY(K)

The CMYK model is a subtractive model that is used in printing: C = W-R ; M = W-G ; Y = W-B

Whereas the RGB model depends on a light source to create colour, the CMYK model is based on the light-absorbing quality of ink printed on paper. It uses the subtractive primaries Cyan, Magenta and Yellow

颜色的本质是某物质吸收了特定波长光后剩余的光反射到眼睛里所产生的视觉，比如红色就是那种物质专吸收了绿色、蓝色和其他波长的光，反射了红色光，而黑色则是吸收了所有光色。

CMYK：白光照射下，Cyan ink吸收红色，反射Cyan。

Question:

Colour ink jet printers use the CMY model. When the cyan ink colour is sprayed onto a sheet of white paper, what colour would it appear under a green light? Why?

在绿光照射下，Cyan ink吸收红光，反射绿光

When the cyan paper under a green light, what colour would it appear? Why?

在绿光下，Cyan paper吸收绿光（除Cyan外其他颜色），反射黑色

$$C = 1 - R \qquad K = \min(C, M, Y)$$
$$M = 1 - G \qquad C_{new} = C - K$$
$$Y = 1 - B \qquad M_{new} = M - K$$
$$Y_{new} = Y - K$$

HSV

H: hue

S: saturation

V: value/brightness

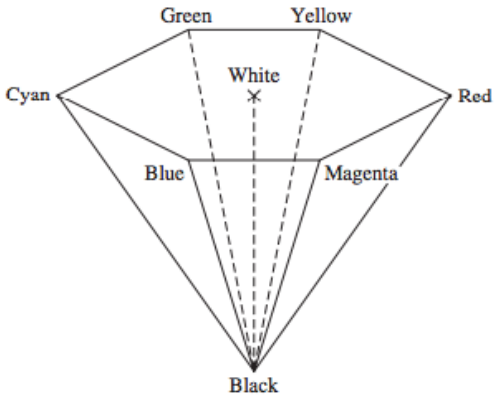


Figure 2.47 HSV color space, a hexacone

H	S	V	Color
0	1.0	1.0	Red
120	1.0	1.0	Green
240	1.0	1.0	Blue
*	0.0	1.0	White
*	0.0	0.5	Gray
*	*	0.0	Black
60	1.0	1.0	?
270	0.5	1.0	?
270	0.0	0.7	?

Exercise 1:

What RGB values and what HSV values could represent the following colours?

- Light grey

- Bright magenta
- Bright non-saturated red

Solution:
Light grey: RGB (200,200,200), HSV(*,0.0,0.8)
Bright magenta: RGB (200,0,200), HSV(300,1,1)
Bright no-saturate red: RGB (200,0,0), HSV(0,0.8,1)

Exercise 2:
Consider the following three colours expressed using 24 bits, in the RGB colour model: Colour A = (220, 30, 20); Colour B= (100, 100, 100); Colour C = (50, 0, 50).

- Estimatethe H, S, and Vvalues for each of these colours in the HSV colour model (H can also be specified using a colour name rather than a value)
- Estimatethe C, M, Y and K values for eachof these colours in the CMYK colour model.

Exercise from test

b) This question is about colour encoding.

[12 marks]

i) In a true colour image, what is the number of different colours that can be represented? Justify your answer.

(2 marks)

ii) Describe the properties of a fully saturated colour.

(2 marks)

iii) In the HSV colour model, how is the grayscale represented?

(2 marks)

iv) What (R, G, B) values would you use to encode an unsaturated dark blue colour?

(2 marks)

v) What (C, M, Y) values would you use to encode a fully saturated bright green colour?

(2 marks)

vi) Yellow ink is spread onto a white sheet of paper. What colour will you see if the paper is illuminated with a blue light? Justify your answer.

(2 marks)

1) True color image: 2^{24} = 16777216 = 16.7 million colours
2) A fully saturated colours is a color without any mixture of white
3) In HSV, the grayscale is represented as (*,0,a) (a is a value from 0 ~ 1), which is the vertical axis of HSV
4) Unsaturated dark blue color: (0,0,100)
5) Fully saturate bright green color: (255,0,255,0)
6) Black

What (R, G, B) values would you use to encode an unsaturated bright green colour?
(100,255,100) (R=B, G=255)
What (H, S, V) values would you use to encode a fully saturated dark red colour?
(0,100,20) (The maximum value of S and V is 100)

Describe the colour which is encoded with the following RGB values: (200, 200, 50), in terms of its hue, saturation and brightness. Explain your answer.

Solution: Since it has same R value with G value, its hue is close to yellow. Because its R value and G value are not reached 255 and it has a B value 50, it is not saturated. Since the R value and G value are above 127, the brightness is high.

Describe the best you can a dark pink colour using the following three properties: hue, saturation and brightness

Solution: the hue is red; the colour is unsaturated, the brightness is low.

Give values in the RGB colour model that correspond to dark pink

Solution: (100,20,20)

Explain why K has been added to the CMY model used in printing

Solution: to obtain black in CMY, the three inks must be put on paper in large quantity which is a waste of ink and does not allow a perfect black in practice

Explain how the three following colour properties: hue, saturation and brightness, are represented in the HSV model. Make a drawing to support your explanations. (5 marks)

Solution: The Hue (H) is represented along the edge of the hexagone. The Saturation (S) is represented on the horizontal axis from the center of the hexagone to its edge. The brightness (V for Value) is represented on the vertical axis from the bottom to the top of the hexagone.

Which of the following sets (R, G, B) values correspond to a non-saturated dark green colour?

A. (0, 255, 0)
B. (100, 255, 100)
C. (50, 100, 70)
D. (50, 100, 50)