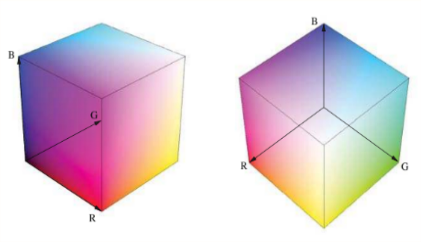
DIGITAL IMAGE PROCESSING

Lecture 14

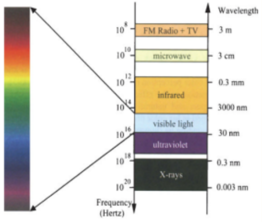
Color Image Processing

October 29, 2018

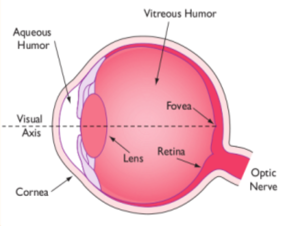
Colour is not just digital, but ...



involves Physics, and ...



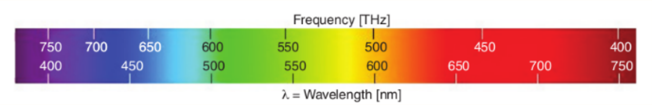
...the Human Vision System



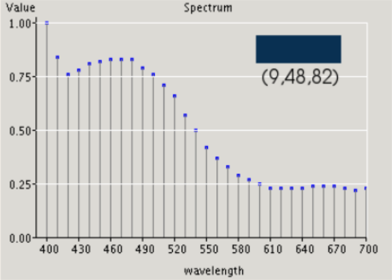
WHAT DO I SEE IN A COLOUR PHOTO?

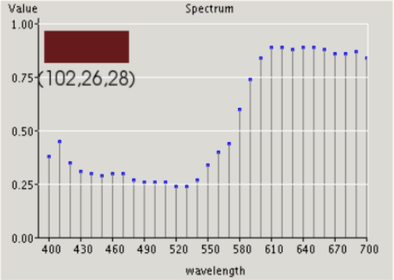
A Spectral Power Distribution (SPD) measurement describes the power per unit area per unit wavelength of an illumination

- Colour is electromagnetic radiation within a specific range of wavelengths ($380\,nm < \lambda < 780\,nm$)



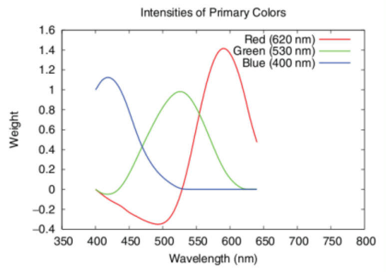
- Colour is a Spectral Power Distribution (SPD)



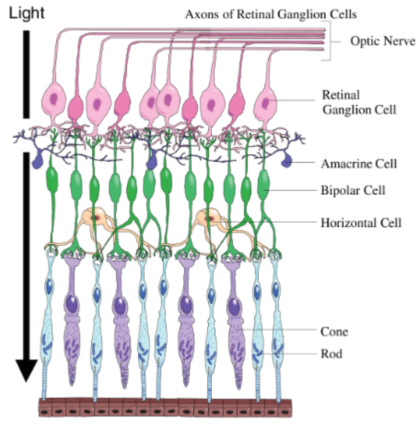


THE PHYSICS OF COLOUR

- Rods and Cones
  - rods: low-light achromatic vision
  - cones: well-lighted colour vision
- Three types of cones: S, M, L



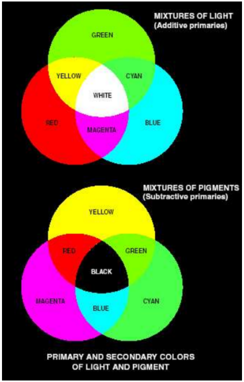
SML Cone Responses



Rods and Cones

HUMAN SIDE OF COLOUR

- Radiance is the total amount of light that flows from a light source (measured in Watts)
- Luminance gives a measure of the amount of energy an observer perceives from a light source (measured in lumens)
- Brightness is a subjective descriptor that is impossible to measure
- Six to seven million cones in the human eye can be divided into three categories: red light sensitive cones (65%), green light sensitive cones (33%) and blue light sensitive cones (2%)



Primary and Secondary Colors

- Red + Green = Yellow
- Red + Blue = Magenta
- Green + Blue = Cyan

- Mixing the three primaries, or a secondary with its opposite primary, in the right intensities produces white light.
- A primary color of pigment is defined as one that subtracts or absorbs a primary color of light and reflects or transmits the other two.
- Therefore, the primary colors of pigments are magenta, cyan, and yellow, and the secondary pigment colors are red, green, and blue.
- Mixing the three pigment primaries, or a secondary with its opposite primary, in the right intensities produces black.
- Color television or a computer monitor is an example of additive nature of the color of light. The inside of the screen is coated with dots of phosphor, each being capable of producing one of the three primary colors. A combination of light of the three primary colors produces all the different colors we see.
- Printing is an example of the subtractive nature of color pigments. For example, a pigment of red color actually absorbs light of all wavelengths, except that corresponding to red color.

Trichromatic Theory

- Colour is the response to the three stimuli corresponding to the three types of cones: R for L, G for M and B for S

$$C_i = \int_{-\infty}^{+\infty} R_i(\lambda) P(\lambda) d\lambda$$

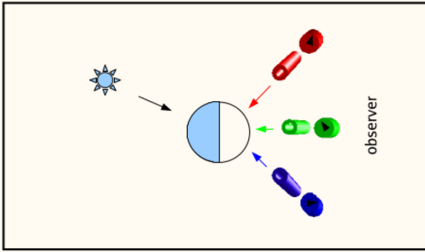
$R_i = S, M$ and L

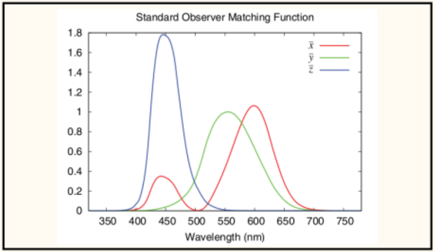
Opponent Colour Theory

- Every colour shade is a linear combination of a colour and its opponent/complementary colour
- Hering (c. 1886) proposed red–green and blue–yellow pairs as primary opponent colours
  - there are no shades like bluish yellow or greenish red

COLOUR THEORIES

- Users asked to match monochromatic colour (reference) by combining light from red, green and blue lamps
  - primaries with known SPDs
  - adjustable knobs to control intensities





- Reference colours varied in intervals of 2 nm and 5 nm from 400 nm to 700 nm
- The knob settings were plotted against wavelength to obtain colour matching functions $\overline{x}, \overline{y}$ and $\overline{z}$

COLOUR MATCHING EXPERIMENT

The amounts of red, green, and blue needed to form any particular color are called the tristimulus values and are denoted by X, Y, and Z, respectively.

- Committee Internationale De L'Eclairage (CIE) proposed the XYZ Tristimulus Space based on the colour matching experiments as a model of human colour perception
- XYZ values are obtained from the colour matching functions $(\overline{x}, \overline{y}, \overline{z})$ as

$$X = \int_{380\mathrm{nm}}^{780\mathrm{nm}} R(\lambda)\overline{x}(\lambda)\,\mathrm{d}\lambda \qquad Y = \int_{380\mathrm{nm}}^{780\mathrm{nm}} R(\lambda)\overline{y}(\lambda)\,\mathrm{d}\lambda$$

$$Z = \int_{380\mathrm{nm}}^{780\mathrm{nm}} R(\lambda)\overline{z}(\lambda)\,\mathrm{d}\lambda$$

where $R(\lambda)$ is the SPD of the object that is imaged

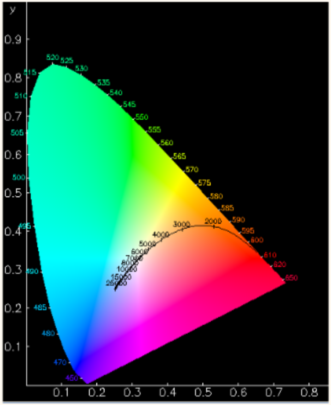
XYZ TRISTIMULUS SPACE

- XYZ Tristimulus values are normalized to give the xyz trichromaticity space

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

- Only two coordinates are necessary for describing colour

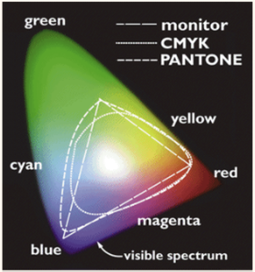
- A plot of x vs. y gives the famous x-y chromaticity diagram (or tongue diagram)

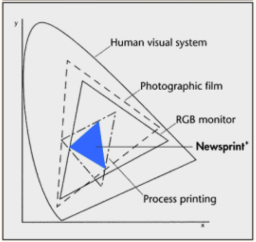


THE (IN)FAMOUS TOUNGUE!

COLOUR GAMUTS

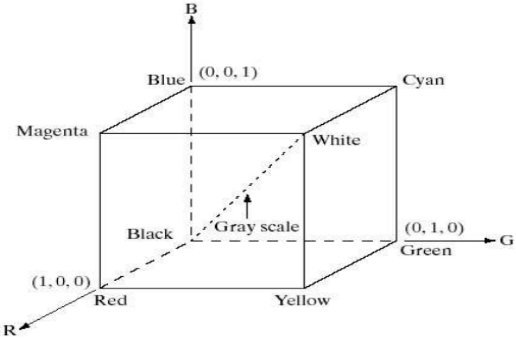
- The entire set of colours that can be perceived or handled by a sensor/device is called its gamut
- The tongue is the gamut of the human vision system
- Although we use a trichromatic system, our human vision system is non-linear and generates a large gamut
- Any linear trichromatic space results in a triangular gamut
- How many colours can we see?





- The positions of various spectrum colors (completely saturated or pure colors) are indicated along the boundary of the tongue-shaped chromaticity diagram.
- Points inside this region represent some mixture of the pure colors.
- Point of equal energy corresponds to equal fractions of the three primary colors. It represents the Commission Internationale de lEclairge — The International Commission on Illumination (CIE) standard for white light.
- As a point leaves the boundary and moves towards the center, more white light is added to the color and it becomes less saturated.
- The point of equal energy corresponds to zero saturation.

- The chromaticity diagram can be used for color mixing, since a line joining two points in the diagram represents all the colors that can be obtained by mixing the two colors additively.
- A line joining the point of equal energy to any point on the boundary represents different shades of that color.
- Similarly, the triangular region enclosed by the line segments joining three points in the chromaticity diagram represents all the colors that can be obtained by combining the three colors.
- This is consistent with the remark made earlier that the three pure primary colors by themselves cannot produce all the colors (unless we change the wavelengths as well).
- The triangular region shown in the figure below represents the typical range of colors (gamut of colors) produced by RGB monitors. The irregular region inside the triangular region represents the color gamut of modern high-quality color printers.
- Color printing is a complicated process and it is more difficult to control the color of printed object than it is to control the color displayed on a monito


B
Blue
(0, 0, 1)
Cyan
Magenta
White
Gray scale
Black
(0, 1, 0)
G
Green
(1, 0, 0)
Red
Yellow
R

- The purpose of a color model (or color space or color system) is to facilitate the specification of color in some standard fashion.
- A color model is a specification of a 3-D coordinate system and a subspace within that system where each color is represented by a single point.
- Most color models in use today are either based on hardware (color camera, printer) or on applications involving color manipulation (computer graphics, animation).
- In image processing, the hardware based color models mainly used are: RGB, CMYK, and HSI.
- The RGB (red, green, blue) color system is used mainly in color monitors and video cameras.
- The CMYK (cyan, magenta, yellow, black) color system is used in printing devices.
- The HSI (hue, saturation, intensity) is based on the way humans describe and interpret color. It also helps in separating the color and grayscale information in an image.

- Different points on or inside the cube correspond to different colors and can be represents as a vector or three values or coordinates. Each coordinate represents the amount of that primary color present in the given color.
- Images in the RGB model consist of three independent component images, one for each primary color.
- When fed to into an RGB monitor, these three images combine on the phosphor screen to produce a composite color image.
- The number of bits used to represent each pixel in RGB space is called pixel depth.
- For example, if eight bits are used to represent each of the primary components, each RGB color pixel would have a depth of 24 bits. This is usually referred to as a full color image.

- Although high-end monitors can display true 24-bit colors, more modest display devices are limited to smaller (typically 256) set of colors.
- Moreover, in many applications, it not useful to use more than a few (say 10-20) colors.
- Given the variety of display devices, it is useful to have a small subset of colors that are reproduced reliably and faithfully, independently of the display hardware specifics. This subset of colors is referred to as safe RGB colors or the set of all-systems-safe colors. They are also referred to as safe web colors or safe browser colors in internet applications.
- Assuming 256 distinct colors as the minimum capability of any color display device, a standard notation to refer to these safe colors is necessary.
- Forty of these 256 colors are known to be processed differently by various operating systems, leaving 216 colors that are common to most systems.
- These 216 colors are formed by a combination of RGB values, where each component is restricted to be one of possible six

FIGURE 6.8 RGB 24-bit color cube.

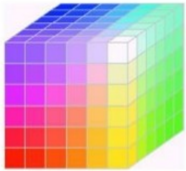
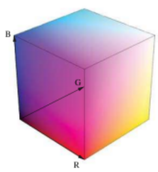


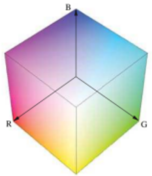
FIGURE 6.11 The RGB safe-color cube.

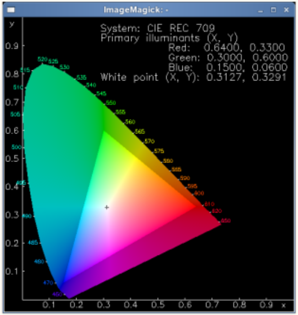
- The total number of colors in a 24 Bit image is

  $(2^8)^3 = 16{,}777{,}216$ (> 16 million)

- Define three standard primaries — R, G and B
- Cartesian Coordinate system: Dark Biscuit is (192,128,0)
- Most popular because of hardware support
- Not a very good candidate for colour image processing
  - perceptually non-uniform
  - non-descriptive
  - does not decouple achromatic and chromatic aspects







RGB COLOUR SPACE (at last!)

- Major tasks associated with colour are specification, description and measurement
- Colour specification models require completeness, uniqueness and resolution
    - XYZ and RGB allow specification but do not satisfy completeness
- Colour description models need to be human-oriented and should separate chromatic and achromatic aspects
    - HSV and variants
- Colour measurement requires linearity and existence of a simple distance measure
    - CIELAB is the best example

Let's turn to colour image processing now ...