Information and Coding

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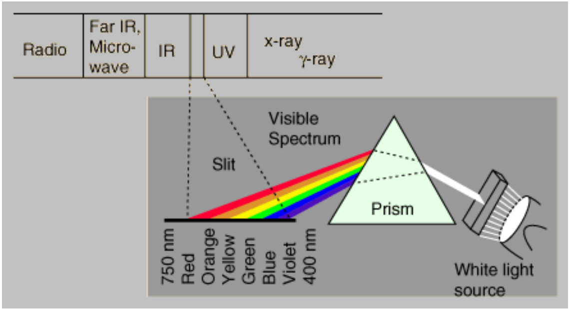
Contents

The visible spectrum

- The typical human eye senses electromagnetic wavelengths between 400 and 700 nm, and has maximum sensitivity around the 555 nm (green zone).



The visible spectrum

Spectral colors (pure colors)

Cor	Wavelength
Violet	$\approx$ 380–440 nm
Blue	$\approx$ 440–485 nm
Cyan	$\approx$ 485–500 nm
Green	$\approx$ 500–565 nm
Yellow	$\approx$ 565–590 nm
Orange	$\approx$ 590–625 nm
Red	$\approx$ 625–740 nm

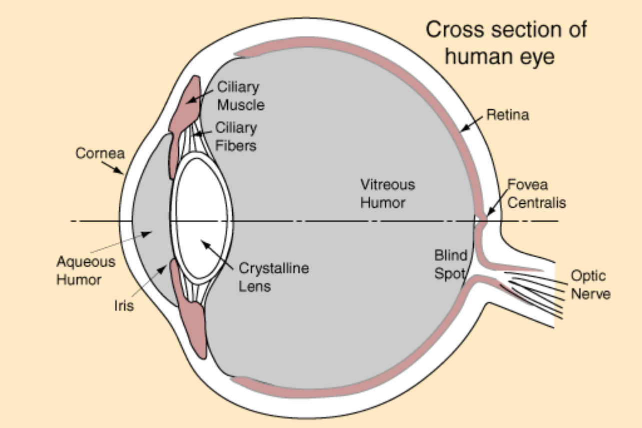
The human perception of color

- Normally, the characteristics that allow colors to be distinguished are:
  - The brightness (how bright is the color).
  - The hue (the dominant color).
  - The saturation (how pure is the color).
- Together, the hue and the saturation define the chromaticity.
- Therefore, a color can be characterized by the brightness and the chromaticity.

The human vision

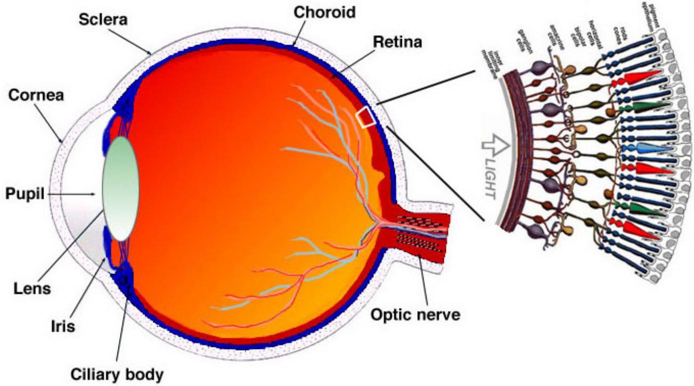
- The human vision is a complex process, still not completely understood, even after hundreds of years of research.
- The visualization of a physical process involves an almost simultaneous interaction of the eyes and the brain.
- This interaction is performed by a network of neurons, receptors and other specialized cells.
- The human eye is equipped with a variety of optical elements, including the cornea, iris, pupil, a variable lens and the retina.

The human eye



The human perception of color

- The human eye has photoreceptors that are sensitive to short wavelengths (S), medium wavelengths (M) and long wavelengths (L), also known as the blue, green and red photoreceptors.



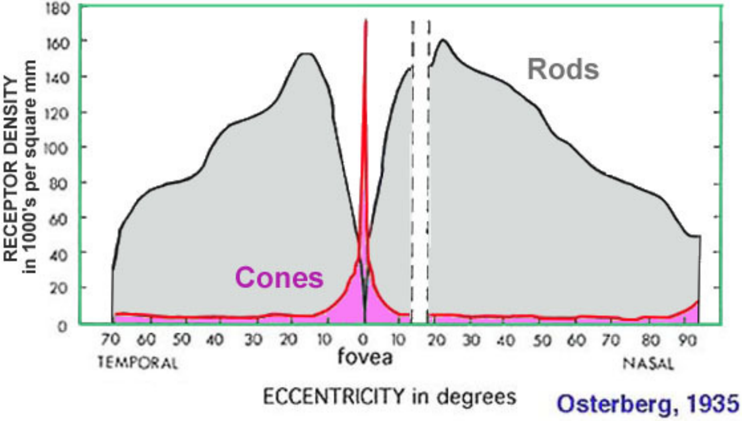
The photoreceptors: cones and rods

- The cones:
  - They provide the photopic vision.
  - They are between 6 and 7 million.
  - They are responsible for the perception of color.
  - There are three types:
    - Sensitive to the blue ($\approx$ 2%)
    - Sensitive to the green ($\approx$ 33%)
    - Sensitive to the red ($\approx$ 65%)
  - They are positioned mainly in the central part of the retina (fovea $\approx$ 0.3 mm diameter).

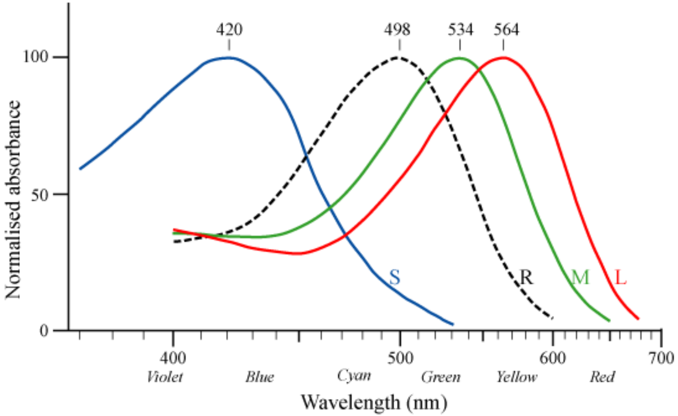
The photoreceptors: cones and rods

- The rods:
  - They provide the scotopic vision (under low light conditions).
  - They are between 75 and 150 million.
  - They are much more sensitive than the cones, but they are unable to distinguish colors.
  - They allow vision at low levels of light.
  - Because several rods are connected to the same nerve, they provide less spatial resolution.

Spatial distribution of the photoreceptors

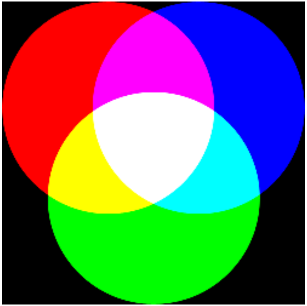


Sensitivity of the photoreceptors



Additive primaries

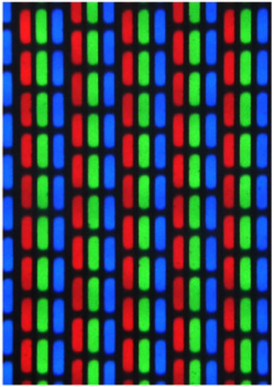
- The red, green and blue are the three additive primary colors.



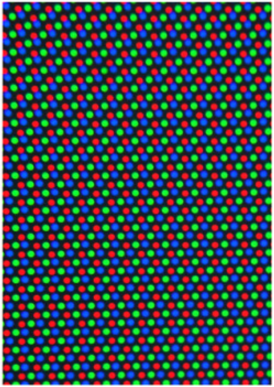
- Adding these three colors produces white.

Additive primaries

- For example, the displays have pigments of these three colors.



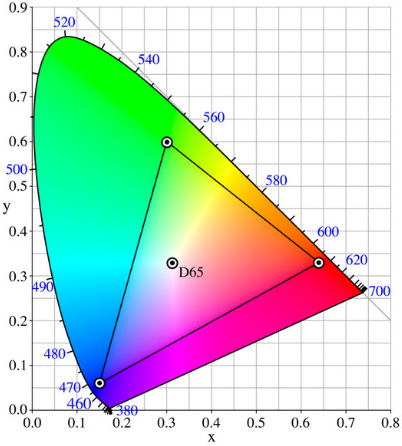
21" TV CRT Display



17" PC CRT Display

The standard *RGB* (*sRGB*) color space

- Chromaticity diagram and corresponding color gamut of *sRGB* (proposed by HP and Microsoft):



The *sRGB* color space

R component

G component

B component

The *CMY* color space

- *CMY* is based on the subtractive properties of inks.
- The cyan, magenta and yellow are the subtractive primaries. They are the complements, respectively, of the red, green and blue. For example, the cyan subtracts the red from the white.

- Conversion from *RGB* to *CMY*: $C = 1 - R$, $M = 1 - G$, $Y = 1 - B$.

The *CMY* color space

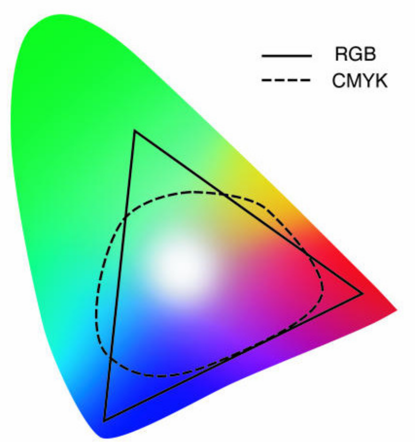
C component

M component

Y component

The *CMYK* color space

- Due to technological difficulties regarding the reproduction of black, it is generally used the *CMYK* color space for printing.



The *CMYK* color space

C component

M component

Y component

K component

The *YUV* color space

- The *YUV* color space is used by the PAL television standard.
- Y is the luminance component:

$$Y = 0.299R + 0.587G + 0.114B$$

- Components U and V represent the chrominance:

$$\begin{aligned} U &= -0.147R - 0.289G + 0.436B = 0.492(B - Y) \\ V &= 0.615R - 0.515G - 0.100B = 0.877(R - Y) \end{aligned}$$

- For $R, G, B \in [0, 1]$, we have $Y \in [0, 1]$, $U \in [-0.436, 0.436]$ and $V \in [-0.615, 0.615]$.

Some advantages of the *YUV* color space

- The *YUV* color space allowed to maintain the compatibility with the old “black and white” television receivers.
- The human eye is more sensitive in the green zone, which is represented mainly by the *Y* component (the *U* and *V* components are related to the blue and red.
- Because the human eye is less sensitive to the blue and red, it is possible to reduce the bandwidth used to represent the *U* and *V* components, without introducing significant perceptual degradation.

The YC_bC_r color space

- YC_bC_r is a family of color spaces used mainly in digital video systems. Before being converted to digital format, they are referred to as YP_bP_r.
- The YP_bP_r signals are obtained from the RGB signals:

$$
\begin{aligned}
Y &= K_r R + (1 - K_r - K_b)G + K_b B \\
P_b &= 0.5(B - Y)/(1 - K_b) \\
P_r &= 0.5(R - Y)/(1 - K_r)
\end{aligned}
$$

- Constants K_b and K_r depend on the RGB color space that is used.
- With $R, G, B \in [0, 1]$, we have $Y \in [0, 1]$, $P_b \in [-0.5, 0.5]$ and $P_r \in [-0.5, 0.5]$.

The YC_bC_r color space

- In the case of standard definition television, these constants are $K_b = 0.114$ and $K_r = 0.299$, which result in the conversion equations (ITU-R BT.601):

$$
\begin{aligned}
Y &= 0.299R + 0.587G + 0.114B \\
P_b &= -0.169R - 0.331G + 0.500B \\
P_r &= 0.500R - 0.419G - 0.081B
\end{aligned}
$$

- The conversion to the digital format is given by:

$$
\begin{aligned}
Y &= 16 + 65.481R + 128.553G + 24.966B \\
C_b &= 128 - 37.797R - 74.203G + 112.0B \\
C_r &= 128 + 112.0R - 93.786G - 18.214B
\end{aligned}
$$

- In this case, with $R, G, B \in [0, 1]$, we have $Y \in \{16, \ldots, 235\}$, $C_b, C_r \in \{16, \ldots, 240\}$.

The YC_bC_r color space

- The JPEG standard allows all 256 values in a 8 bits per component representation.
- In this case, considering $R, G, B \in \{0, \ldots, 255\}$, we have:

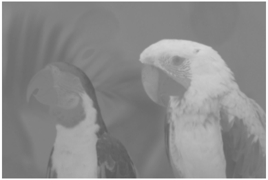
$$
\begin{aligned}
Y &= 0.299R + 0.587G + 0.114B \\
C_b &= 128 - 0.168736R - 0.331264G + 0.5B \\
C_r &= 128 + 0.5R - 0.418688G - 0.081312B
\end{aligned}
$$

- After the conversion, $Y, C_b, C_r \in \{0, \ldots, 255\}$.

The YC_bC_r color space

Y component

C_b component



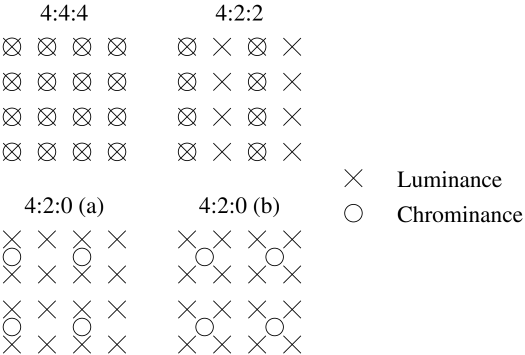
C_r component

Chrominance sub-sampling

- The *YUV* or YC_bC_r color spaces separate the chrominance component (*UV* / C_bC_r) from the luminance component (Y).
- The human eye is more sensitive to the greens, which are represented mainly by the Y component.
- For this reason, it is common to sub-sample the chrominance components *UV* / C_bC_r, producing a reduction in the data rate.
- This reduction is used by both the video coding standards (H.261, MPEG-1, MPEG-2, . . .) and the image coding standards (JPEG).

Chrominance sub-sampling

- The most common types of chrominance sub-sampling:



- The 4:2:0 mode has two variants: (a) used by MPEG-2; (b) used by JPEG, MPEG-1, H.261,...

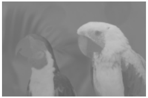
Example YUV 4:2:0

RGB

YC_bC_r 4:2:0

Y component

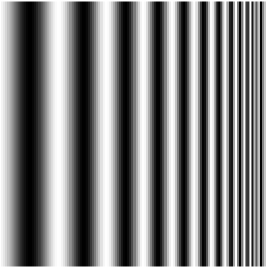
C_b component

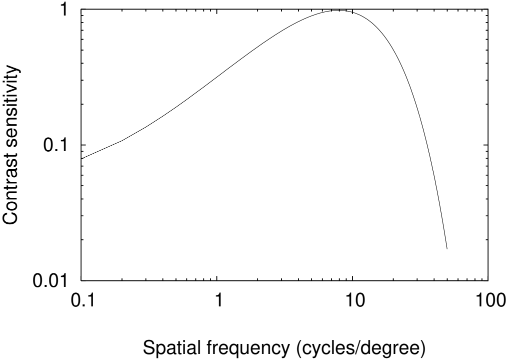


C_r component

Spatial frequency

- The human visual system is characterized by a bandpass behavior in the spatial frequency domain:



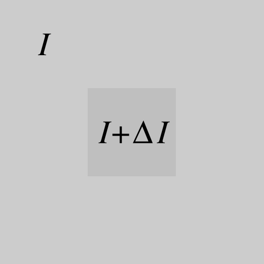


Weber's law

- Non-linear response to the light intensity (Weber's law):

$$\frac{\Delta I}{I} \approx d(\log I) \approx \text{const.}$$

where ΔI represents the minimum intensity variation that can be perceived on a background of intensity I.



Visual masking

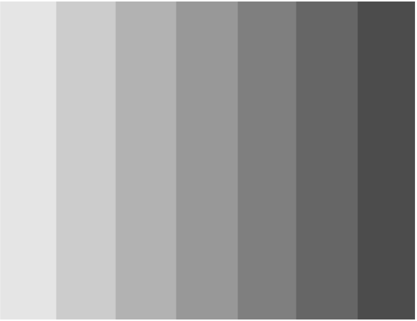
- In zones where large intensity variations occur, small imperfections are masked (i.e., cannot be seen):

Original

Uniform noise: $[-20, 20]$

Intensity vs. perception

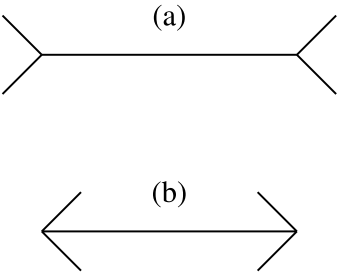
- Mach bands:



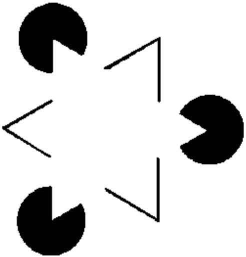
Intensity vs. perception

- Simultaneous contrast:

Other illusions. . .

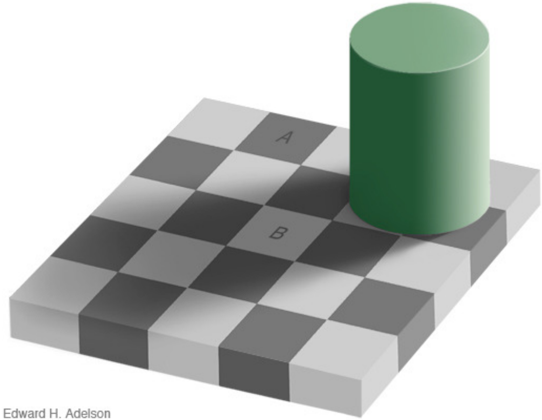


Which is the longer one?



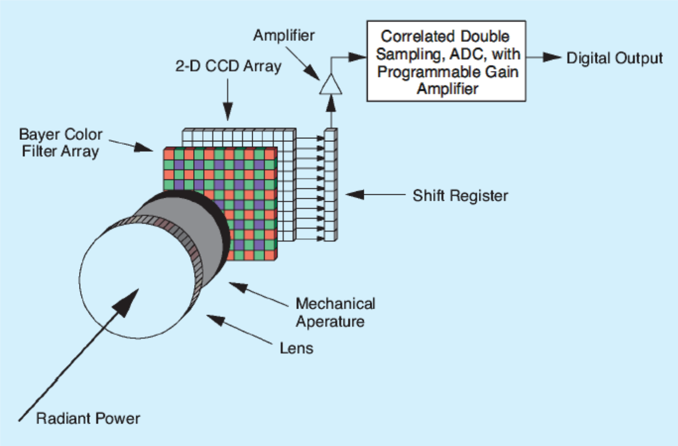
A triangle?

Other illusions. . .

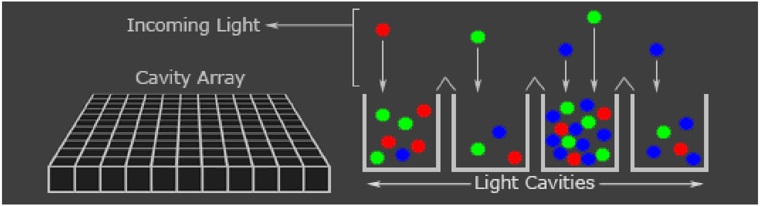


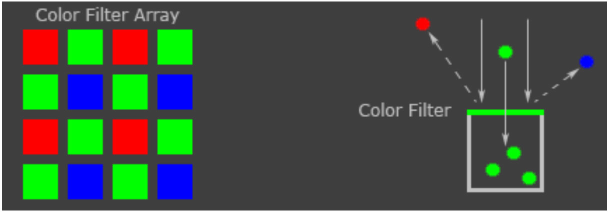
Digital camera

- Image acquisition using a digital camera:
  (IEEE SP Magazine, Jan 2005)

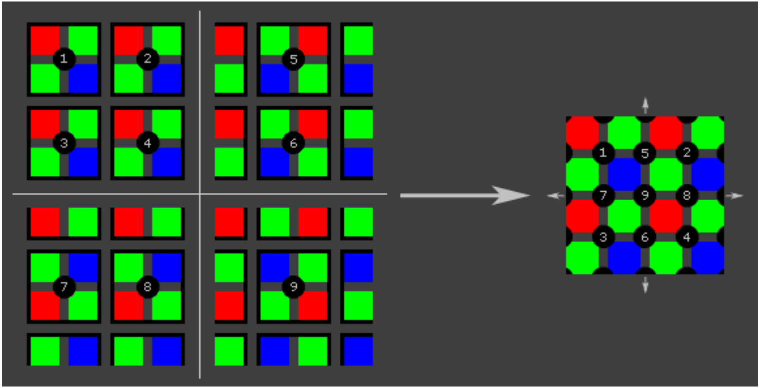


The Bayer matrix

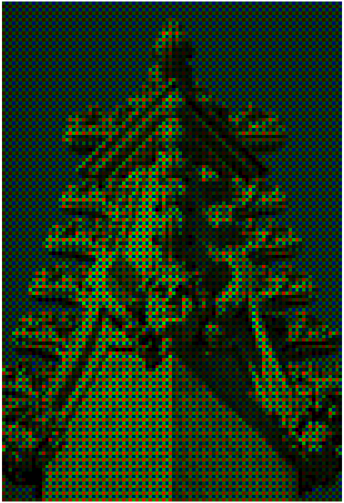




The Bayer matrix



The Bayer matrix



Quality assessment of images

- How to measure the quality of images? This is an important and still open problem. . .
- The techniques for assessing the quality of the images can be classified as subjective or objective.
- A subjective evaluation involves a number of human observers, which can perform absolute or relative assessments.
- In relative assessments, the images are ranked according to the perceived quality.

Quality assessment of images

- In absolute assessments, the observers have to assign a classification, according to some predefined scale, such as,

5.	Excellent
4.	Good
3.	Fair
2.	Poor
1.	Very poor

- Subjective evaluation is the most reliable criterion when the images are intended to be seen by persons. However, these methods are not very practical…

Quality assessment of images

- The use of objective criteria (mathematical models) is frequently unavoidable.
- Typically, the objective criteria are based on the mean squared error or on some other similar measures.
- One of the most popular is the peak signal to noise ratio,

$$\mathrm{PSNR} = 10 \log \frac{A^2}{e^2},$$

where A is the maximum value of the signal, e^2 is the mean squared error between the reconstructed image, $\tilde{f}$, and the original image, f,

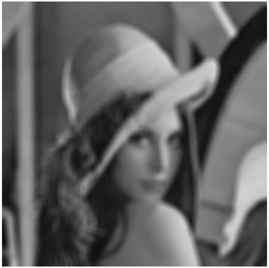
$$e^2 = \frac{1}{N_R N_C} \sum_{i=1}^{N_R} \sum_{j=1}^{N_C} [f(i,j) - \tilde{f}(i,j)]^2.$$

Quality assessment of images

- This type of similarity measures is used often, due to its simplicity.
- However, it is known that, in some cases, they may fail to provide a good indication of the distortion that really affects the image.

Emax: 32; PSNR: 18.5 dB

Original



Emax: 123; PSNR: 23.9 dB