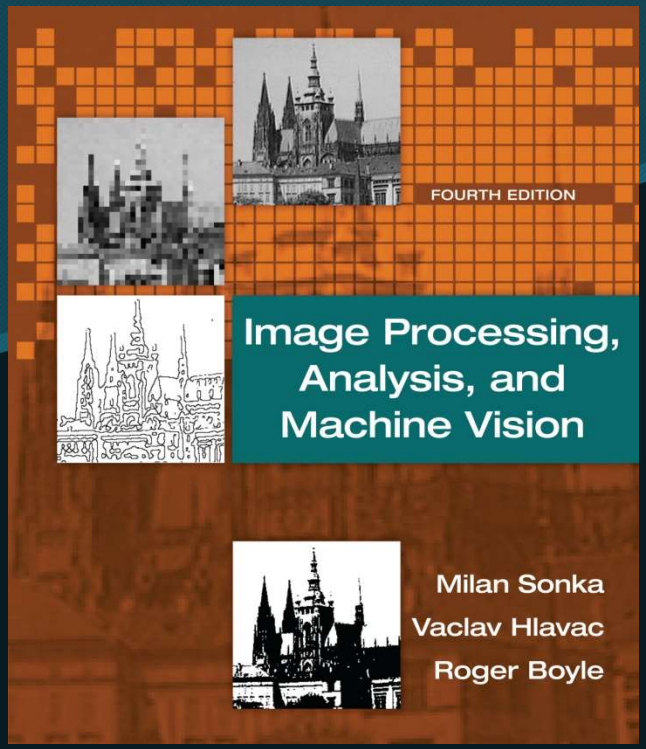
Chapter 2

The image, its representations and properties



Color images

- Physics of color
  - The world is colorless.
  - Human color perception is carried out by the nervous system (神經系統), which interprets differently to distinct electromagnetic wavelengths (電磁波長).
  - Electromagnetic spectrum (電磁頻譜)

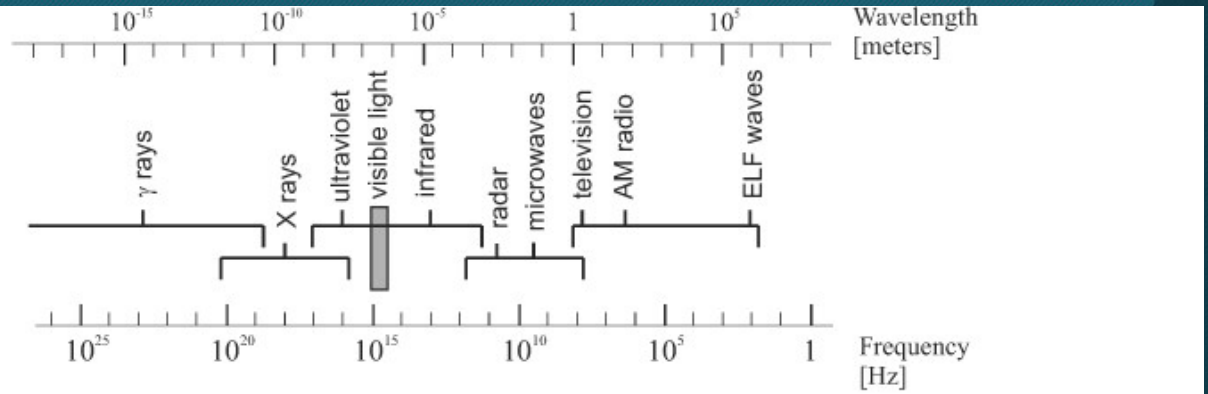


Figure 2.23: Division of the electromagnetic spectrum (ELF is Extremely Low Frequencies).
© Cengage Learning 2015.

Physics of color

- Visible spectral colors (可見光譜顏色)
  - Colors can be represented as combinations of the primary colors.
    - Primary colors (原色): red, green and blue
    - 1 nm = 10^{-9} m

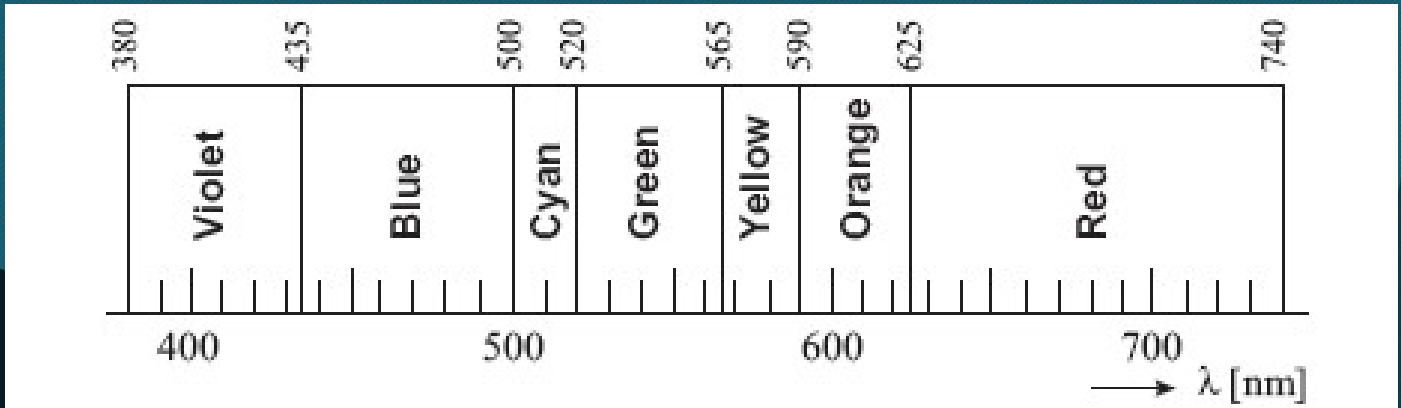
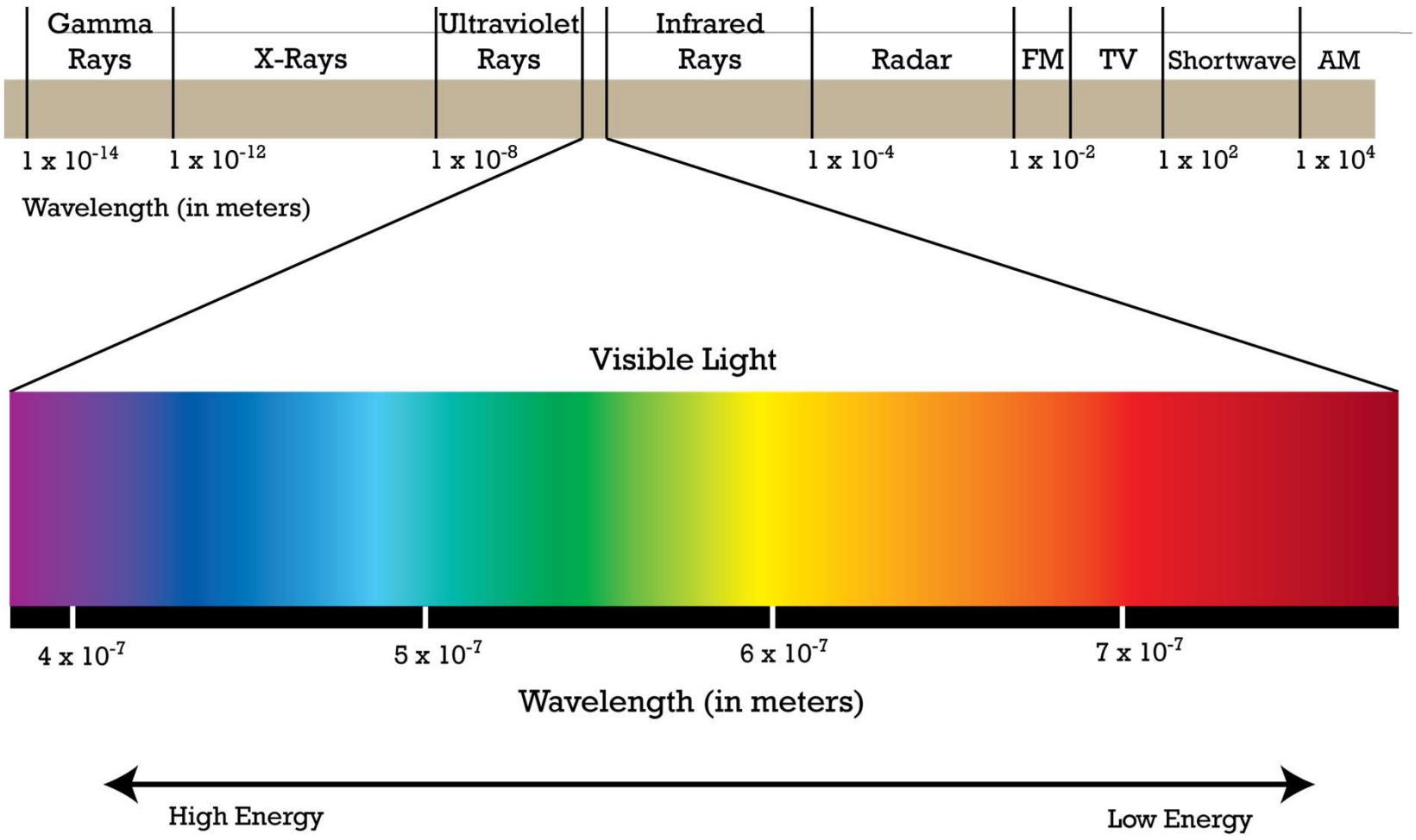


Figure 2.24: Wavelength λ of the spectrum visible to humans.

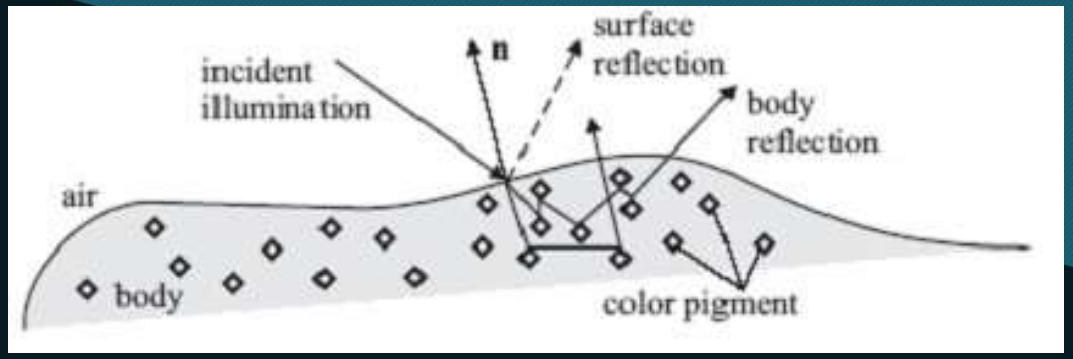
https://zh.wikipedia.org/wiki/%E5%8E%9F%E8%89%B2

Electromagnetic spectrum



Physics of color

- Why do we see the world in color?
  - The surface reflection (表面反射) rebounds (反彈) incoming energy from the surface, whose spectrum remains the same as that of the light source.
    - It is independent of the surface (do not have a color).
  - The energy diffuses (漫射) into the material and reflects randomly from the internal pigment (顏料;色素) in the matter. (body reflection)
    - Observed color of objects is caused by certain wavelength absorptions (吸收) by pigment particles in dielectrics (電介質).



Color perceived by humans

- Retina (視網膜) is composed of photoreceptors (感光器).
- Two types of photoreceptors
  - Rods: sensitive to intensity
  - Cones: sensitive to color

PS 視桿細胞(rod cell) v.s. 視錐細胞(cone cell)

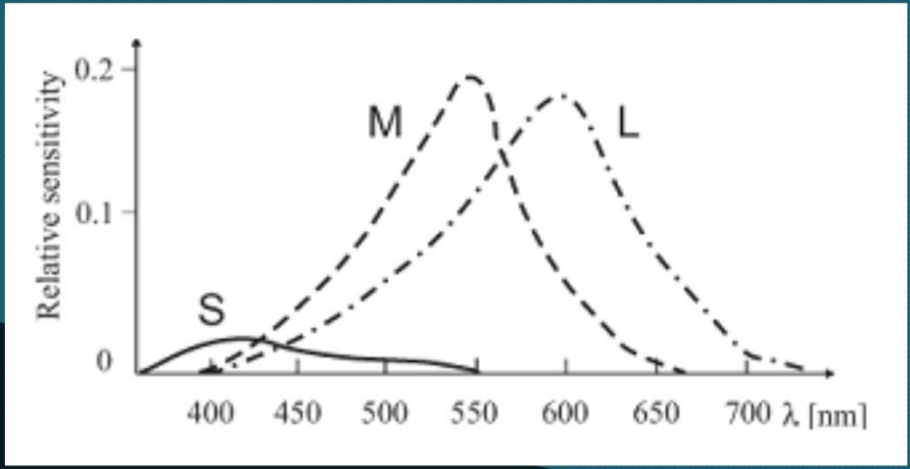
視桿細胞主要與暗視覺有關(對光線的明暗變化、形態與移動特別敏感)，分佈在視網膜周邊部。

視錐細胞則與光視覺有關(用來辨別色彩，並適合偵測各種細節)，分佈在視網膜中心部，中央小凹(foveola)只有視錐細胞。

PS 眼球構造圖 https://mulicia.pixnet.net/blog/post/4213181

Color perceived by humans

- Types of cones: L(red), M(green), S(blue)
  - The figure shows relative sensitivity of S, M, L cones of the human eye to wavelength.



人類每隻眼球視網膜大約600萬~700萬的視錐細胞(cones)，多分布在黃斑處。大多數哺乳動物都具有能感受紅光、藍光以及綠光的三種視錐細胞。
http://cht.a-hospital.com/w/%E8%A7%86%E9%94%A5%E7%BB%86%E8%83%9E

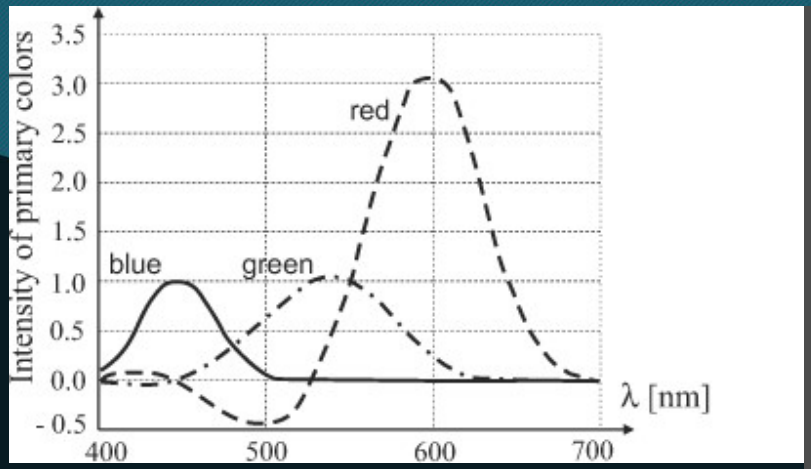
色盲資訊
https://zh.wikipedia.org/wiki/%E8%89%B2%E7%9B%B2
http://blog.fourdesire.com/2014/12/11/wo-he-ni-you-dian-bu-yang-zhen-dui-se-mang-zhe-de-ti-tie-she-ji/

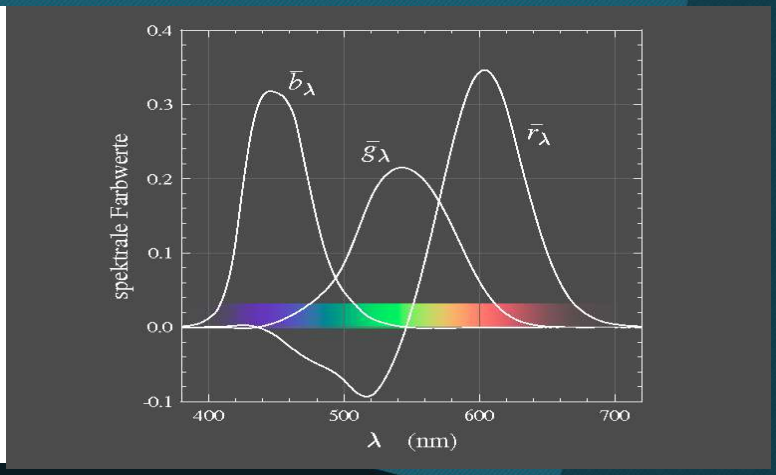
Color perceived by humans

- RGB color space
  - Given primary colors R, G, B, then color matching functions can be obtained by

$$C(\lambda) = w_1(\lambda)R + w_2(\lambda)G + w_3(\lambda)B;$$

where $w_1(\lambda), w_2(\lambda), w_3(\lambda)$ may be negative.





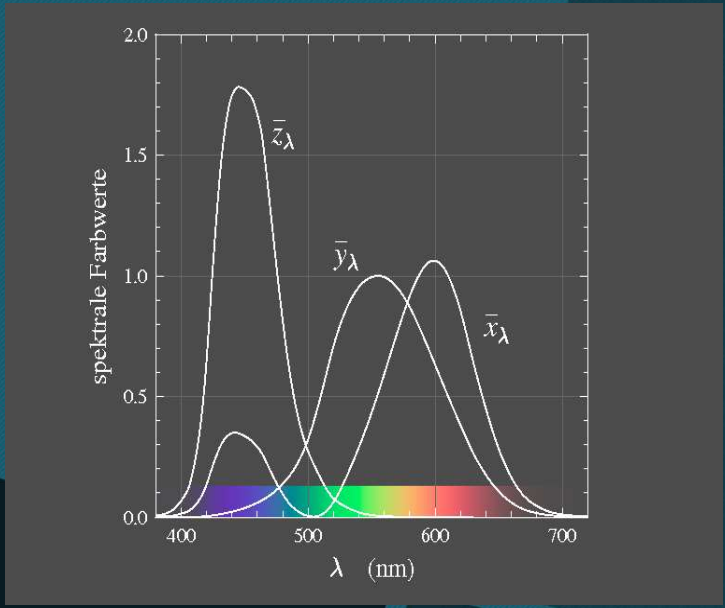
https://www.itp.uni-hannover.de/~zawischa/ITP/colmetr.html

Color perceived by humans

- CIE XYZ color space
  - CIE: an organization responsible for color standard
    - Commission internationale de l'éclairage (French)
    - International Commission on Illumination
    - 國際照明委員會
  - XYZ
    - Y: brightness (luminance)
    - The actual color is a mixture of

      $c_X X + c_Y Y + c_Z Z$

      where $0 \leq c_X, c_Y, c_Z \leq 1$ are weights in the mixture



CIE XYZ color space
https://zh.wikipedia.org/wiki/CIE1931%E8%89%B2%E5%BD%A9%E7%A9%BA%E9%97%B4

Color perceived by humans

- Color gamut (色域)
  - The subspace of colors perceivable by humans is called the color gamut.

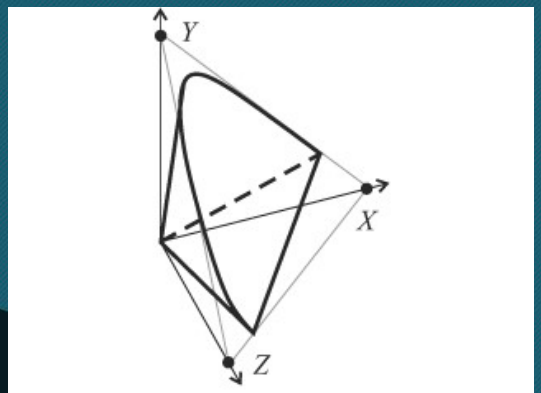
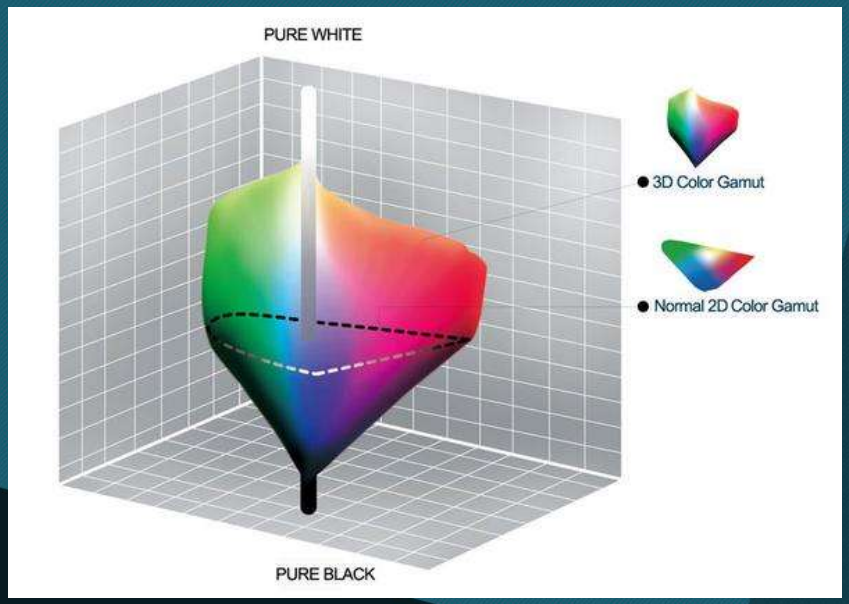


Figure 2.29: Color gamut - a subspace of the X, Y, Z color space showing all colors perceivable by humans. © *Cengage Learning 2015.*



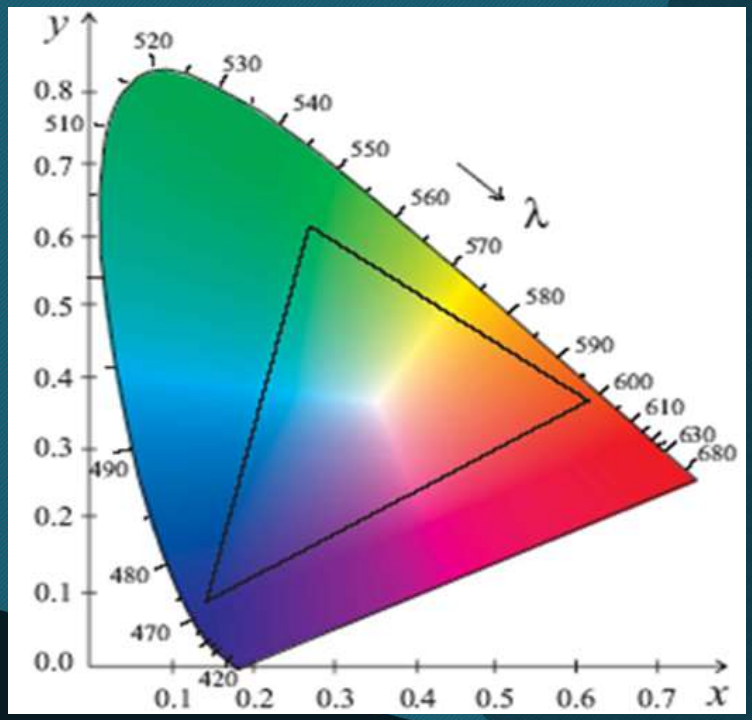
http://www.avsforum.com/forum/465-high-dynamic-range-hdr-wide-color-gamut-wcg/2442082-hdr-misconceptions-still-prevail-3.html

Color perceived by humans

- The CIE 1931 color space chromaticity diagram (色度圖)
  - CIE chromaticity diagram is a projection of XYZ color space into a plane.
  - The triangle depicts a subset of colors spanned by red, green, and blue. These are TV colors, i.e., all possible colors, which can be seen on a CRT display.
  - Given X, Y, Z, then x, y, z can be obtained by

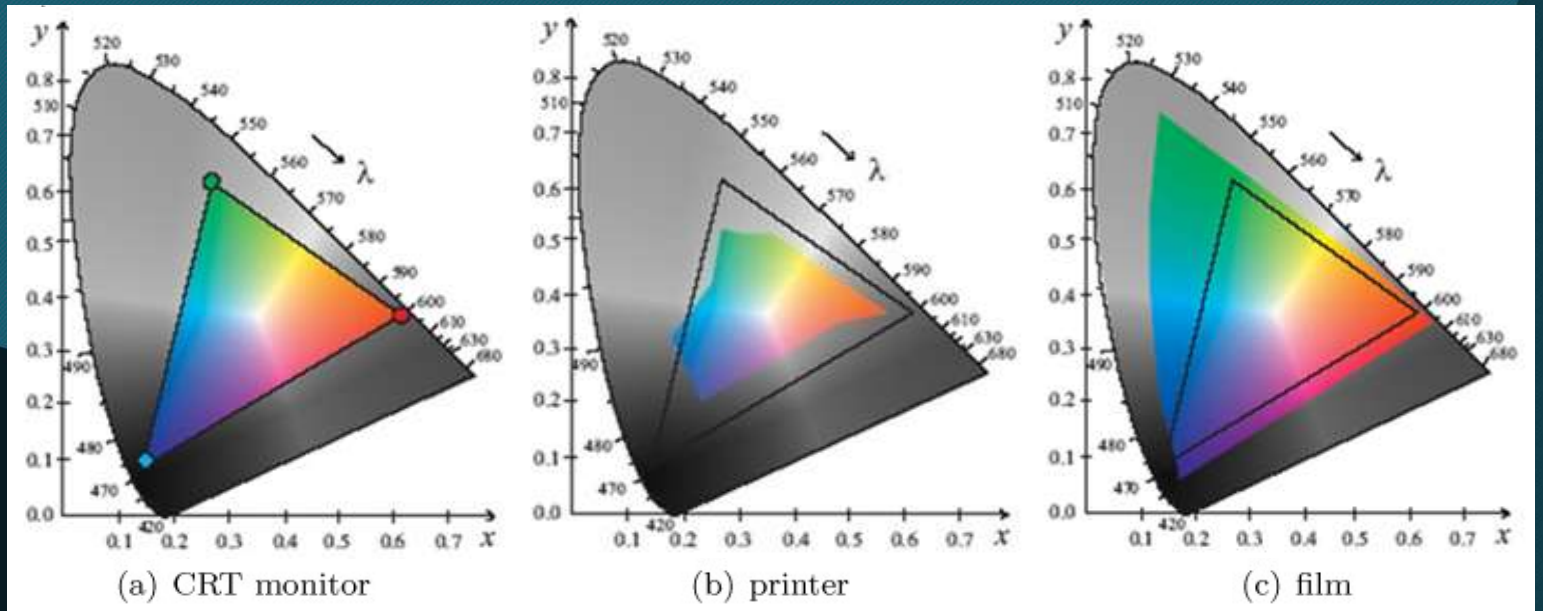
$$x = \frac{X}{X+Y+Z}; y = \frac{Y}{X+Y+Z}$$

$$z = 1 - x - y$$



Color perceived by humans

- Display and printing devices use three selected real primary colors.

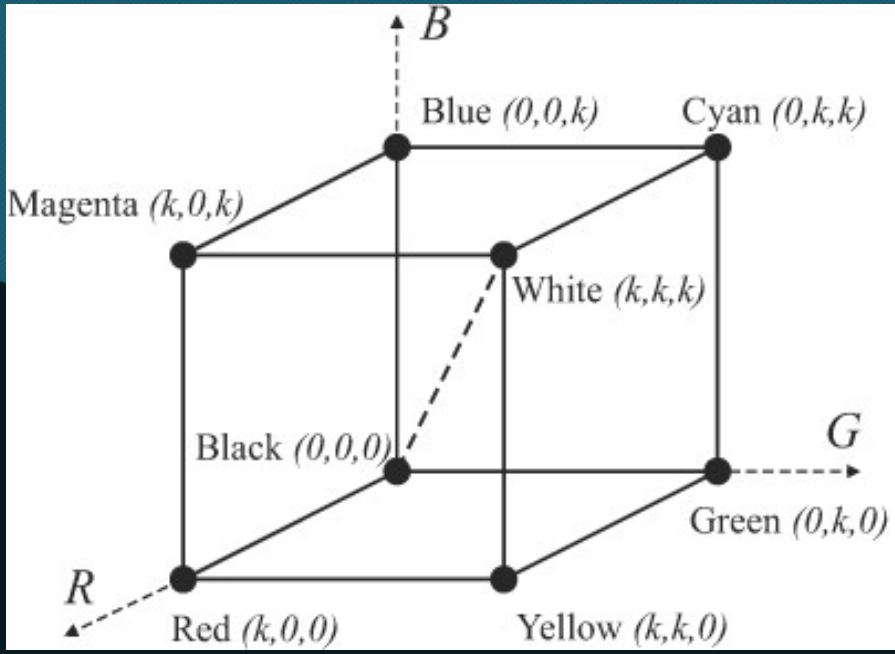


(a) CRT monitor (b) printer (c) film

Figure 2.31: Gamuts which can be displayed using three typical display devices. © *Cengage Learning 2015. A color version of this figure may be seen in the color inset—Plate 2.*

Color spaces

- RGB color space



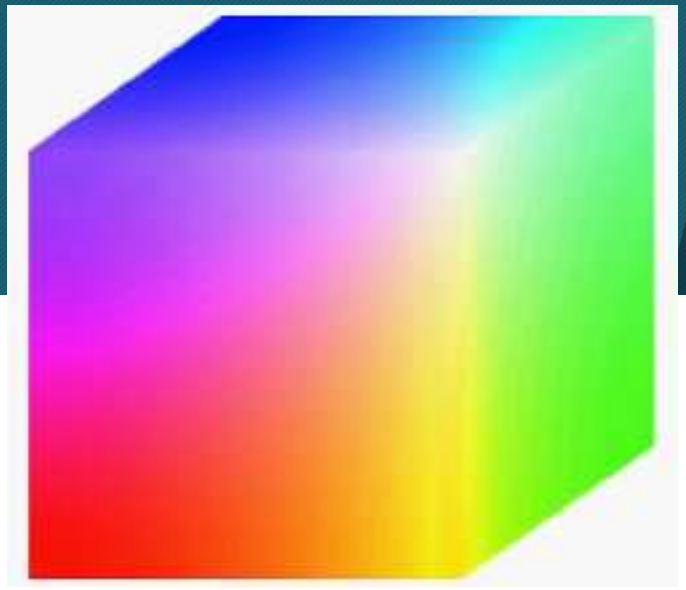
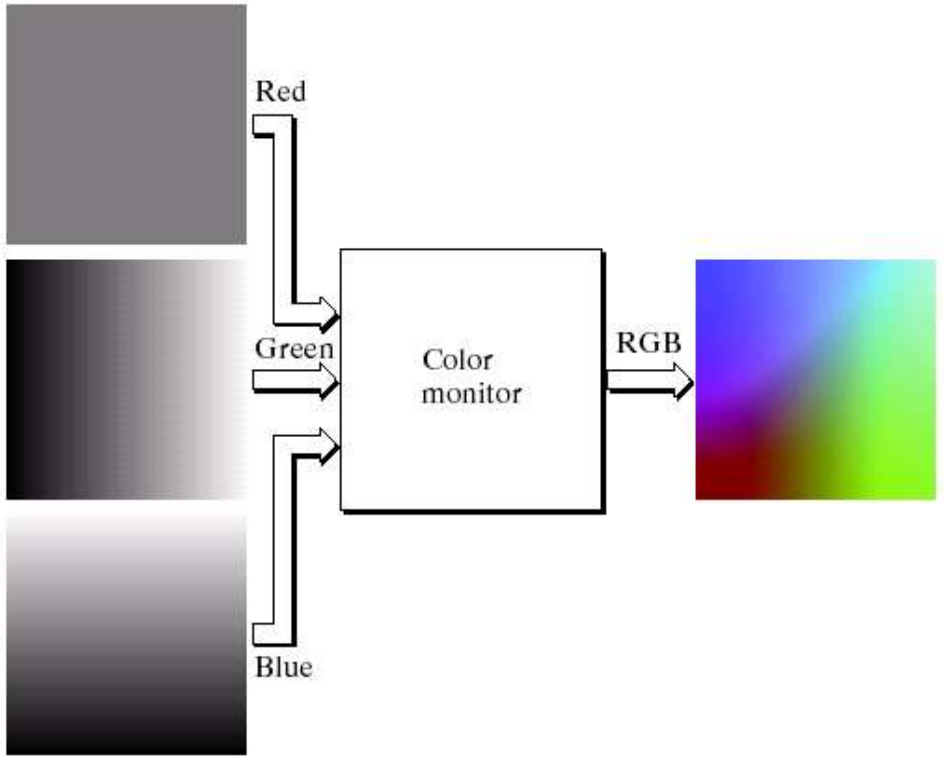


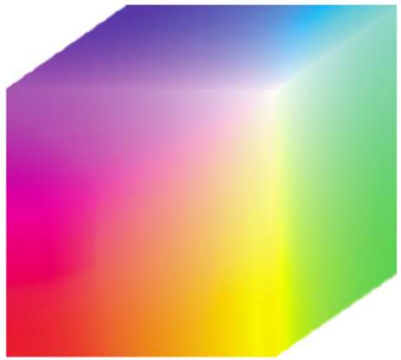
Figure 2.32: RGB color space with primary colors red, green, blue and secondary colors yellow, cyan, magenta. Gray-scale images with all intensities lie along the dashed line connecting black and white in RGB color space. © *Cengage Learning 2015.*

RGB color spaces

a
b

FIGURE 6.9
(a) Generating the RGB image of the cross-sectional color plane (127, G, B).
(b) The three hidden surface planes in the color cube of Fig. 6.8.





Color spaces

- One of the transformations between RGB and XYZ color space
- An XYZ to RGB conversion

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.24 & -1.54 & -0.50 \\ -0.98 & 1.88 & 0.04 \\ 0.06 & -0.20 & 1.06 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- An RGB to XYZ conversion

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.41 & 0.36 & 0.18 \\ 0.21 & 0.72 & 0.07 \\ 0.02 & 0.12 & 0.95 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

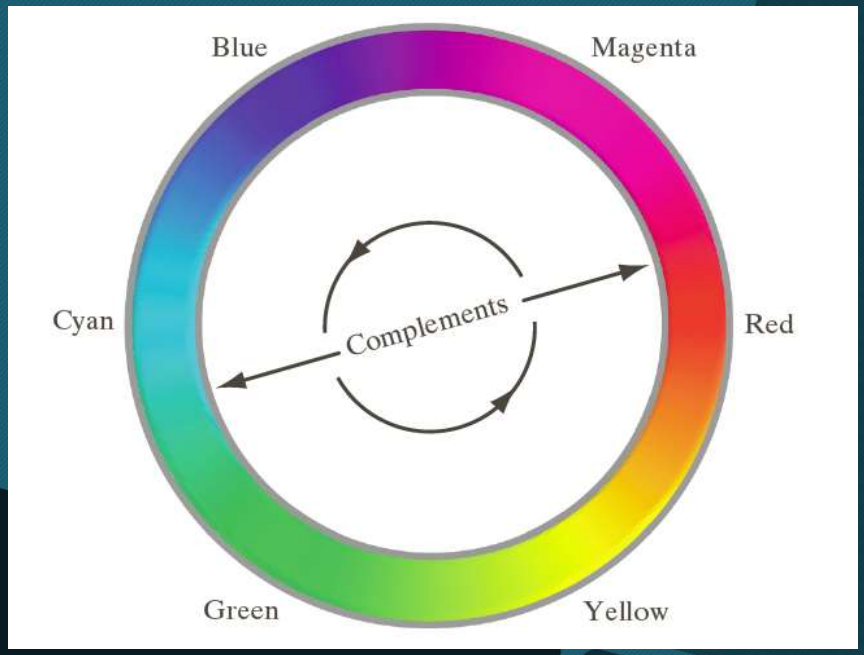
https://www.rapidtables.com/convert/color/index.html

https://www.w3schools.com/colors/colors_converter.asp

Color spaces

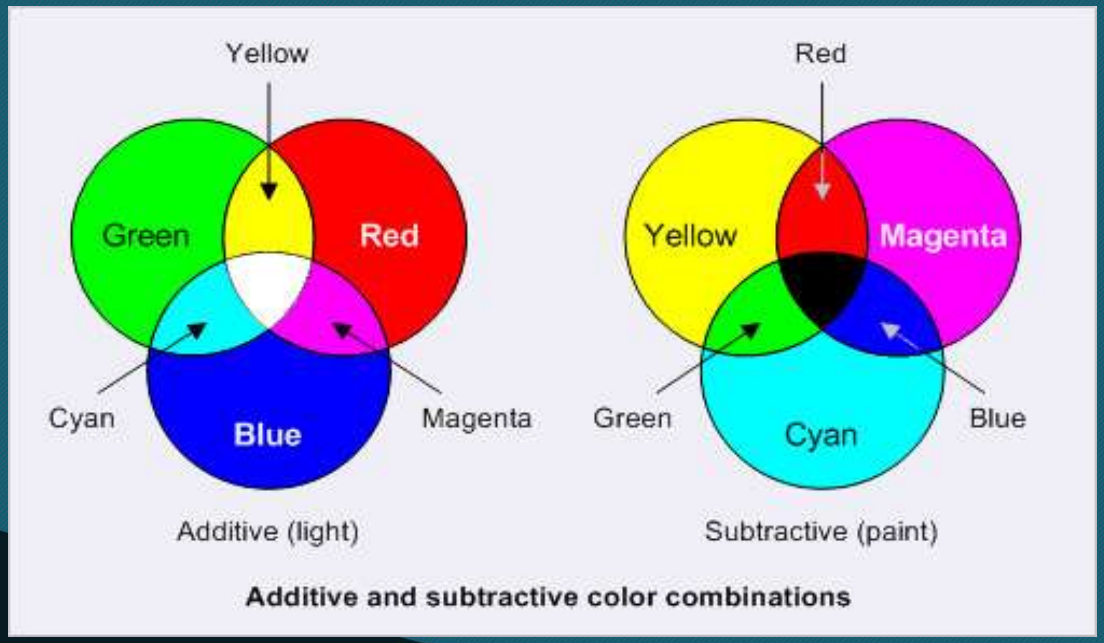
- CMY color model uses subtractive color mixing which is used in printing processes.
- Cyan (青綠色), magenta (洋紅色), and yellow (黃色) are the secondary colors of light of the primary colors of pigments (顏料).
- An RGB to CMY conversion

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



Color spaces

- CMYK (K: black) stores ink values for black in addition.

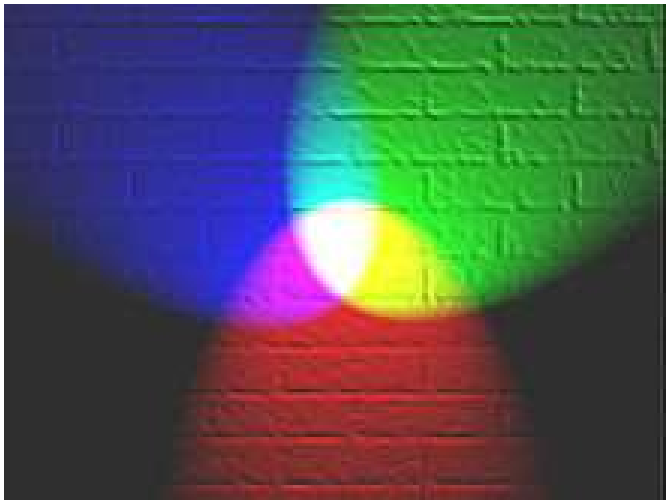


Additive and subtractive color combinations

減色法
https://zh.wikipedia.org/wiki/%E6%B8%9B%E8%89%B2%E6%B3%95

Color Fundamentals

Additive color (加色法)



加色法是描述那些由不同顏色的光混合形成新顏色的情形。

https://en.wikipedia.org/wiki/Additive_color

https://zh.wikipedia.org/wiki/%E5%8A%A0%E8%89%B2%E6%B3%95

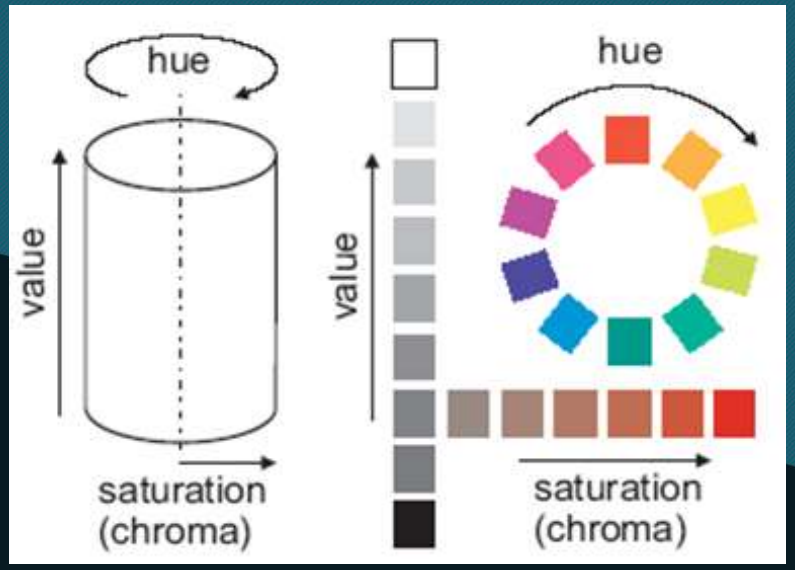
Subtractive color(減色法)

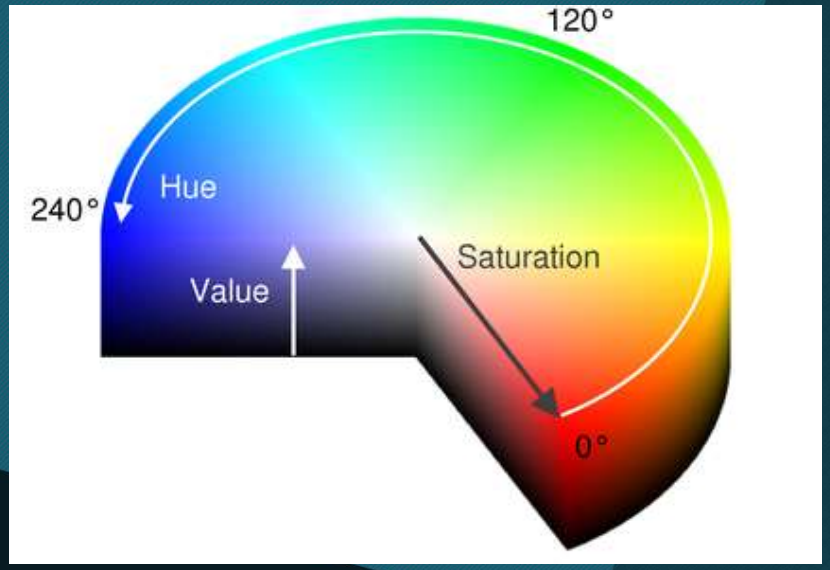
減色法模型解釋了塗料，染料，墨水和天然色素的混合物產生的顏色，每個顏色會減去（即吸收）某些波長的光並向其他反射。表面所顯示的顏色取決於它反映在電磁波譜的顏色。

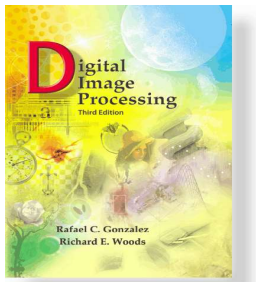
https://zh.wikipedia.org/wiki/%E6%B8%9B%E8%89%B2%E6%B3%95

Color spaces

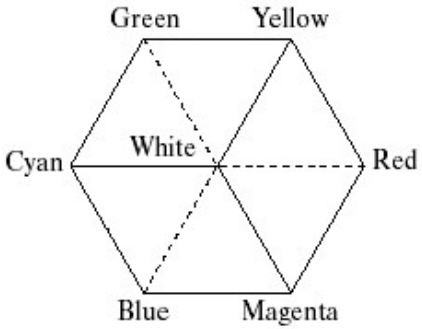
- HSV color model (Hue, Saturation, and Value)
  - HSV color model is illustrated as a cylinder.
  - HSV v.s. HSL: https://en.wikipedia.org/wiki/HSL_and_HSV

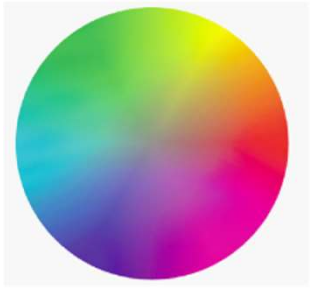




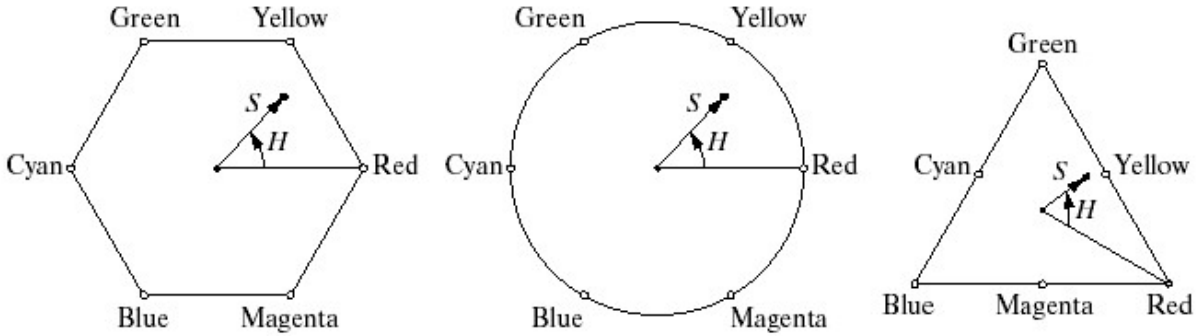


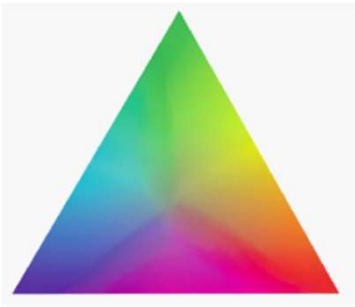
Color Models -- HSI Model





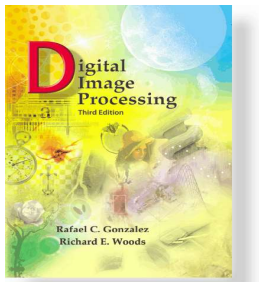
H: Hue
S: Saturation
I: Intensity



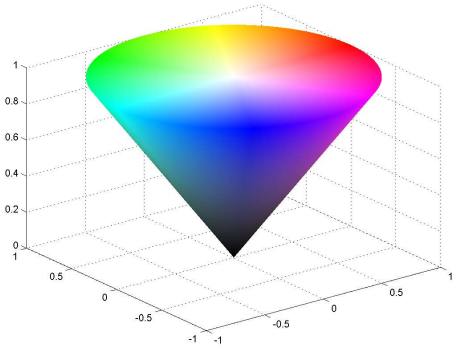


a
b c d

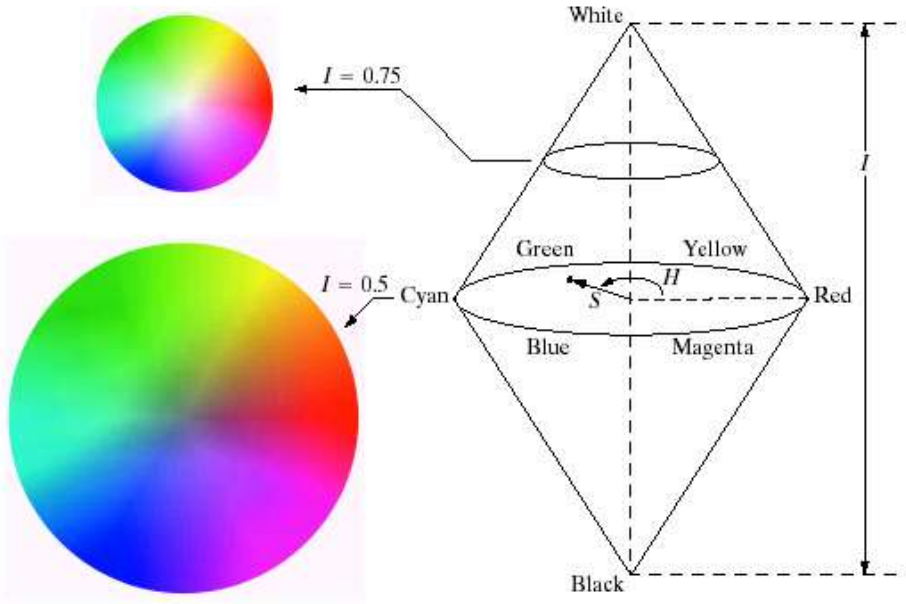
FIGURE 6.13 Hue and saturation in the HSI color model. The dot is an arbitrary color point. The angle from the red axis gives the hue, and the length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

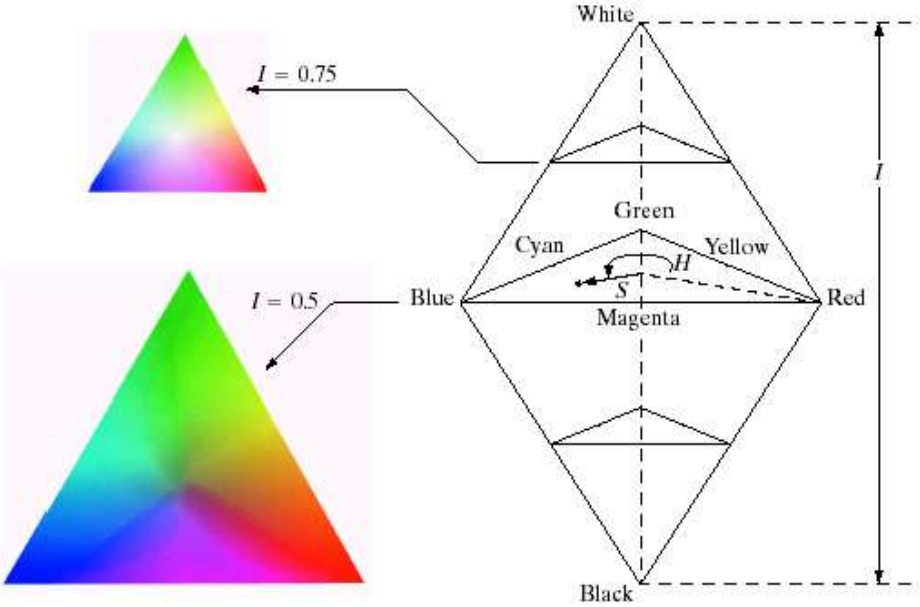


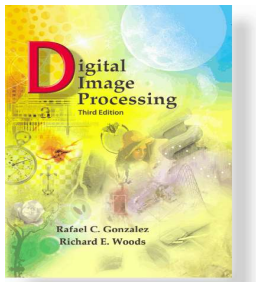
Color Models -- HSI Model



https://nerd.nu/forums/topic/2632-forum-game-google-image-war/?page=7







Color Models -- HSI Model

- Figure 6.15 shows the hue, saturation, and intensity images for the RGB values shown in Figure 6.8.

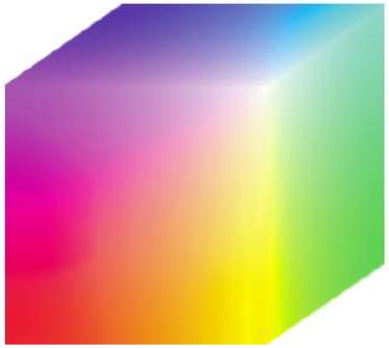
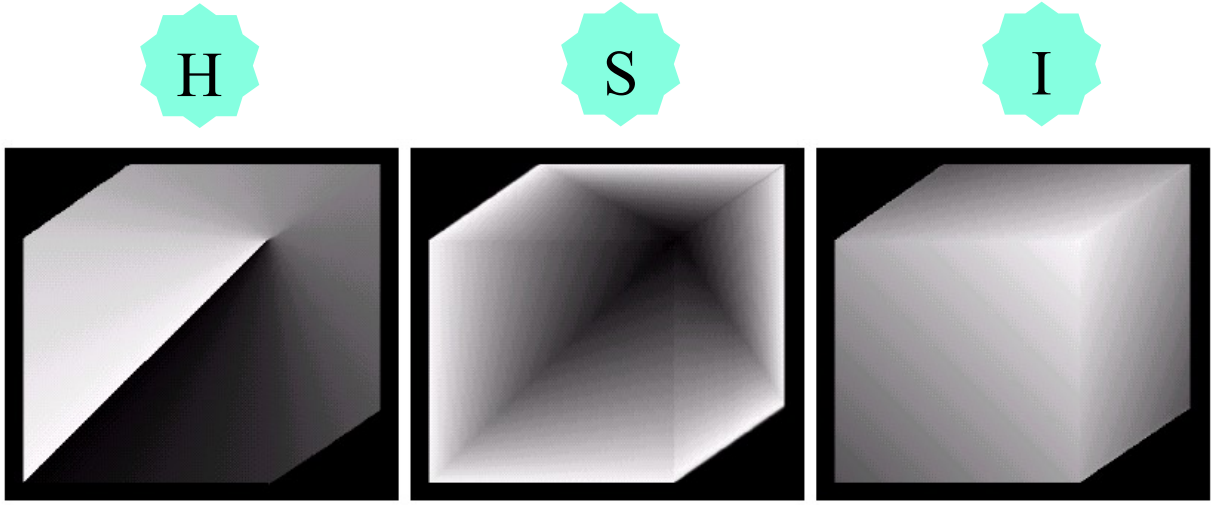
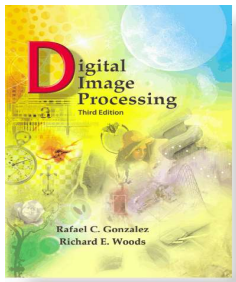


FIGURE 6.8 RGB 24-bit color cube.

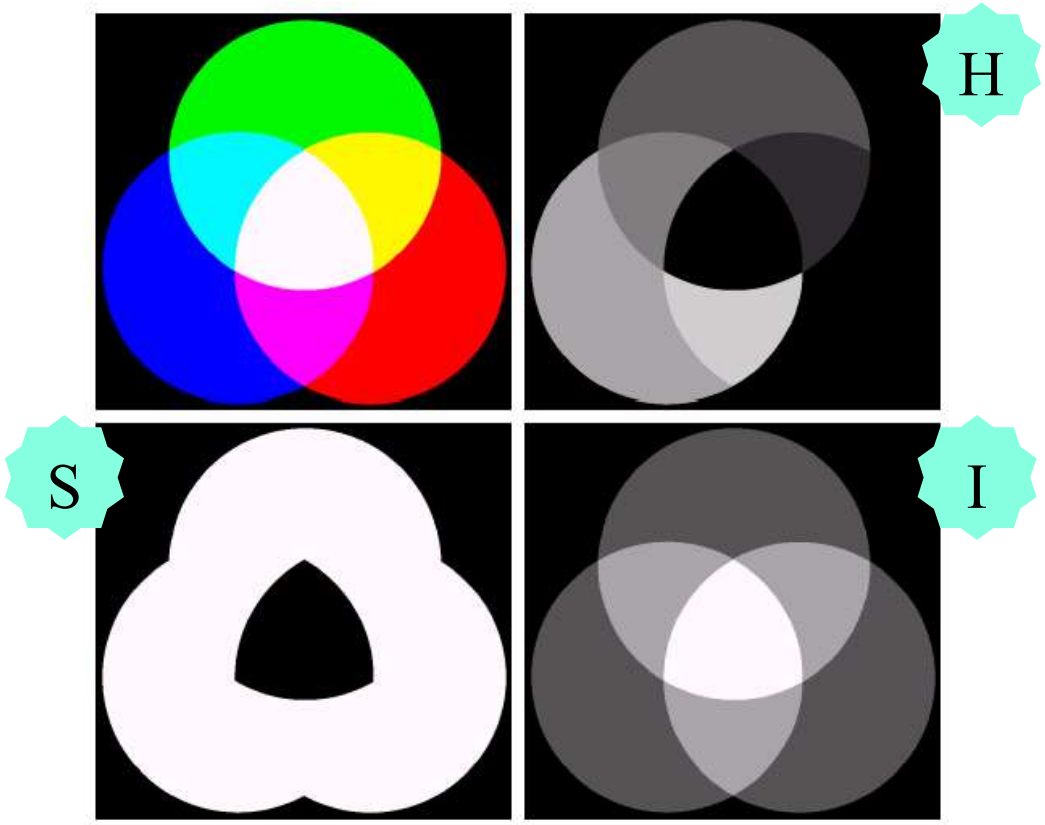


a b c

FIGURE 6.15 HSI components of the image in Fig. 6.8. (a) Hue, (b) saturation, and (c) intensity images.

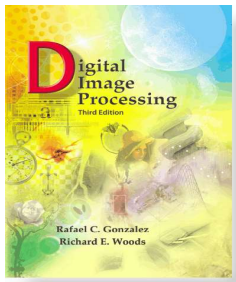


Color Models -- HSI Model

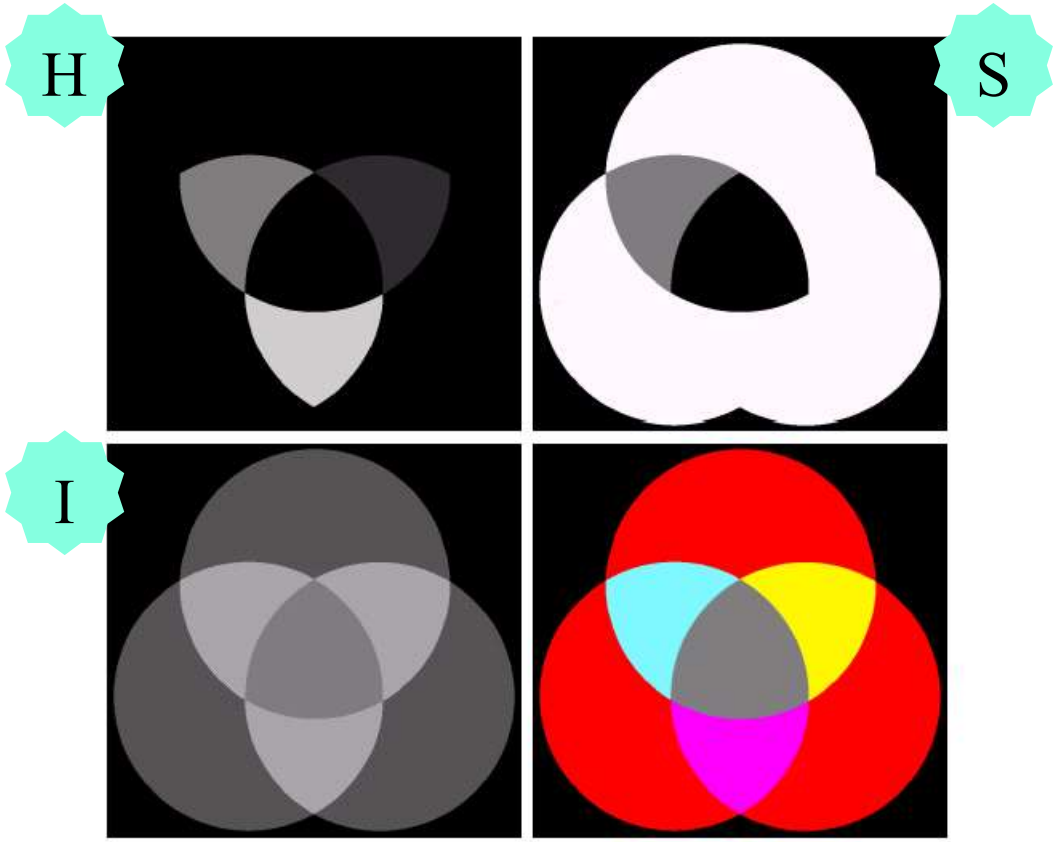


a b
c d

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.

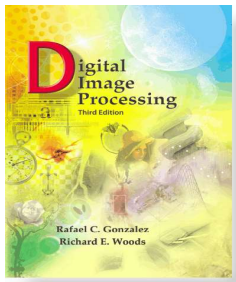


Color Models -- HSI Model



a b
c d

FIGURE 6.17 (a)–(c) Modified HSI component images. (d) Resulting RGB image. (See Fig. 6.16 for the original HSI images.)



Color Transformations RGB<->HSI<->CMYK


Full color


Cyan


Magenta


Yellow


Black


Red

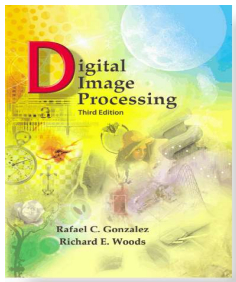

Green


Blue

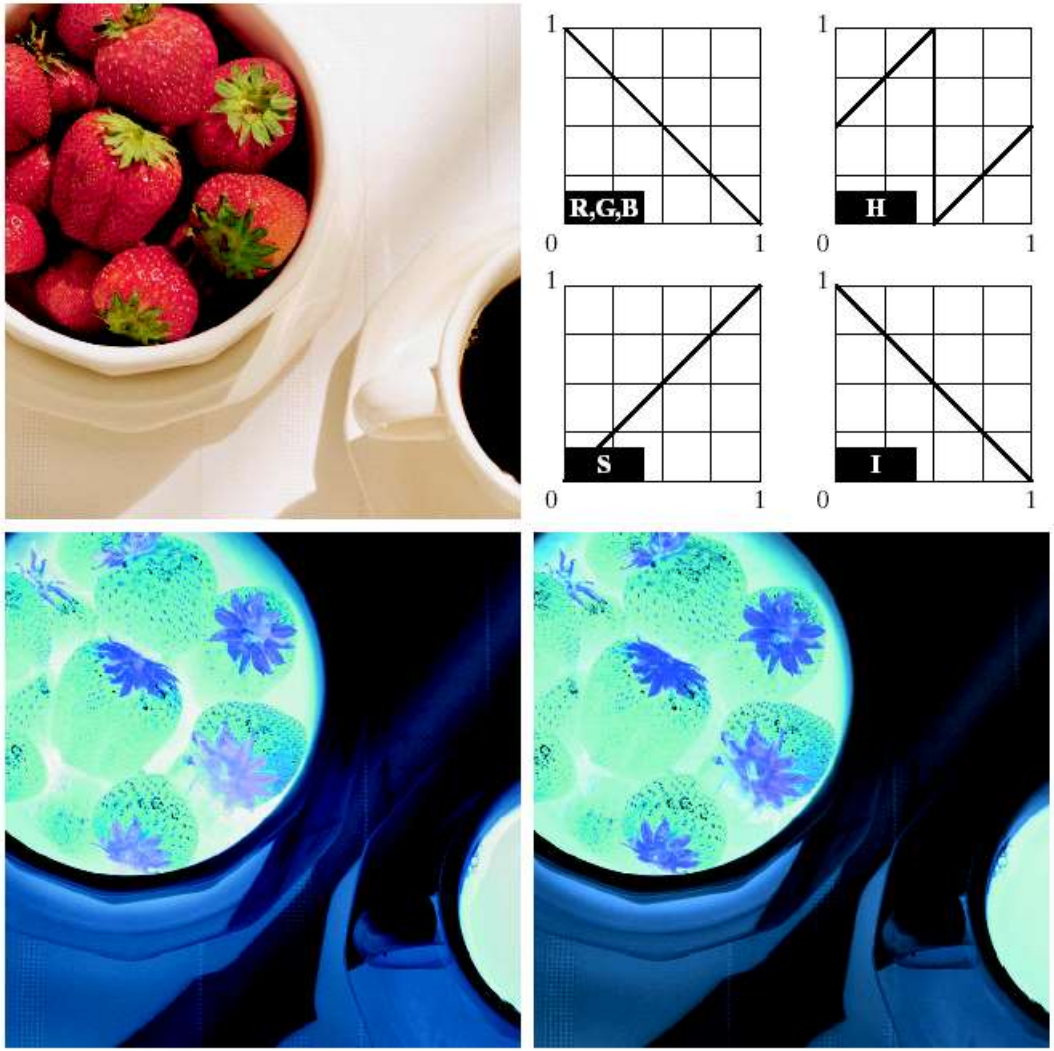

Hue


Saturation


Intensity

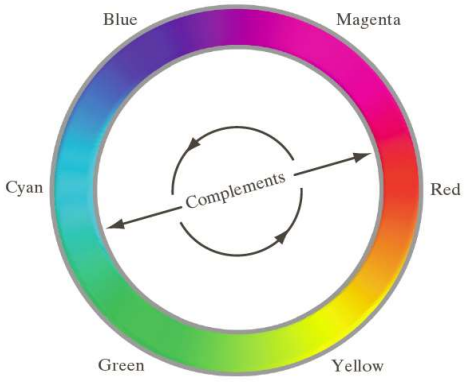


Color Complement Transformations



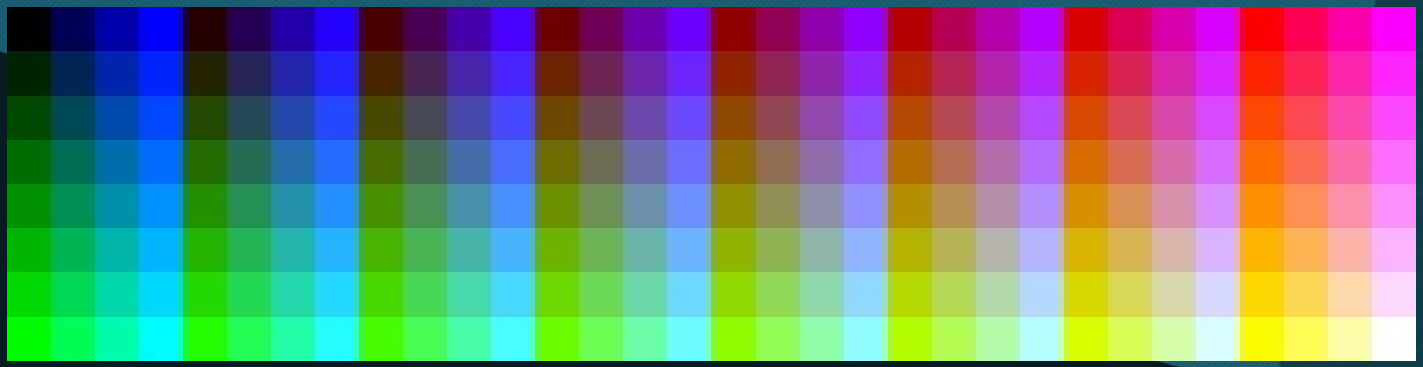
a b
c d

FIGURE 6.33 Color complement transformations. (a) Original image. (b) Complement transformation functions. (c) Complement of (a) based on the RGB mapping functions. (d) An approximation of the RGB complement using HSI transformations.

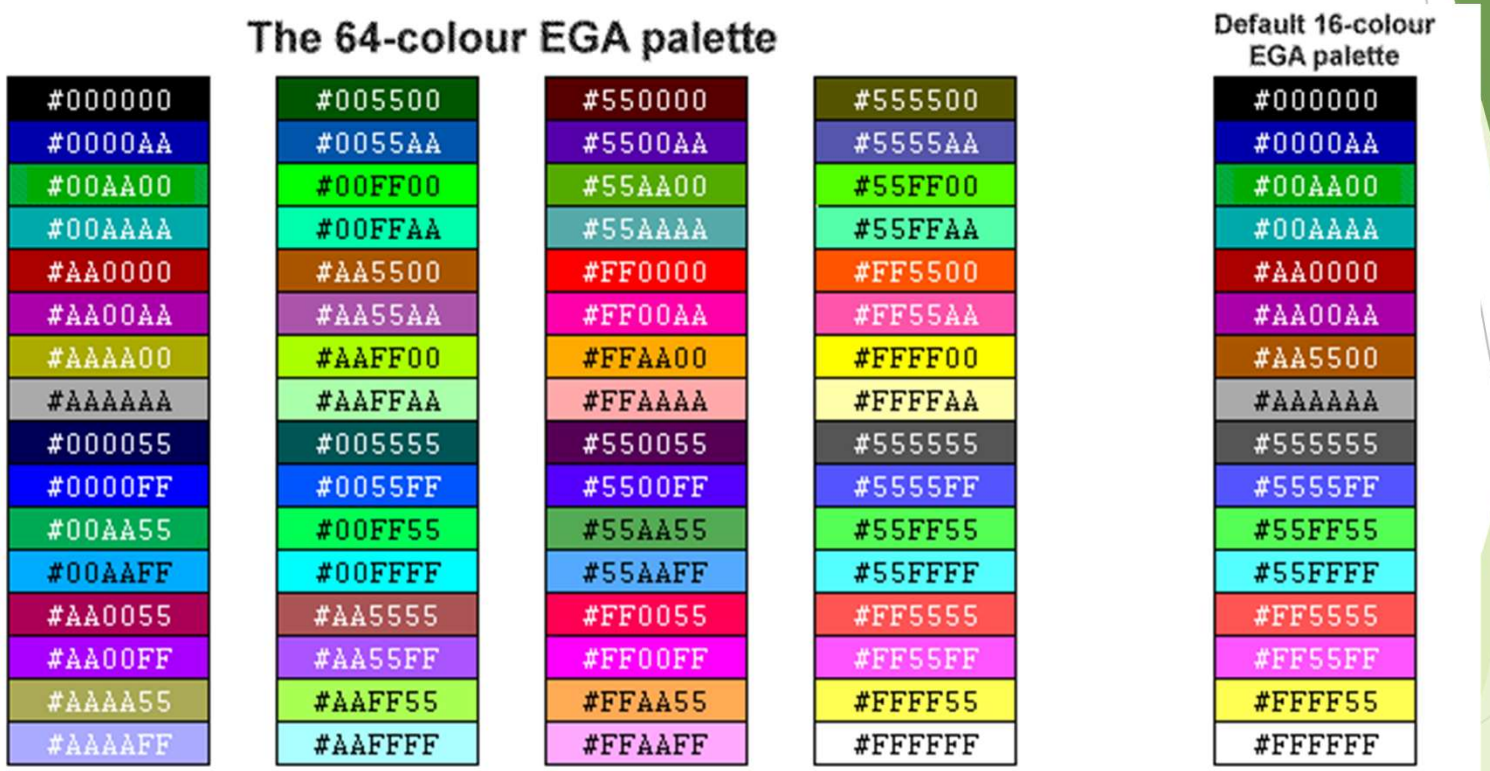


Palette images

- Palette images (indexed images;調色板) provide a simple way to reduce the amount of data needed to represent an image.
  - The pixel values constitute a link to a lookup table (palette; 調色板).
  - The table contains as many entries as the range of possible values in the pixels which is typically 8 bits (256 values).
  - For example, (8-bit color, with three bits of red, three bits of green, and two bits of blue)



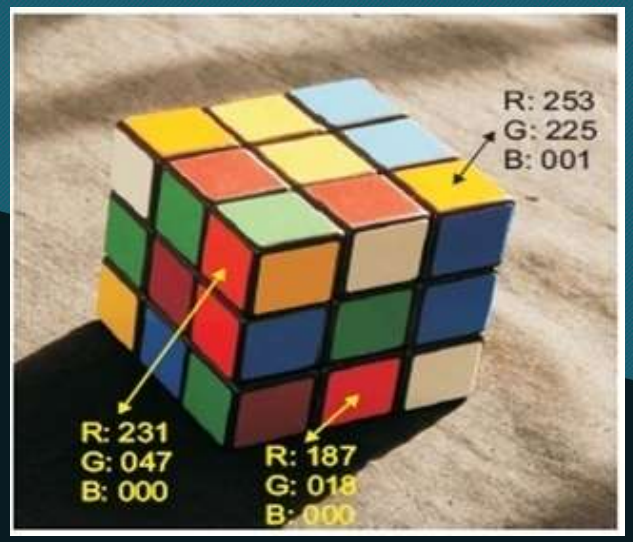
Palette images

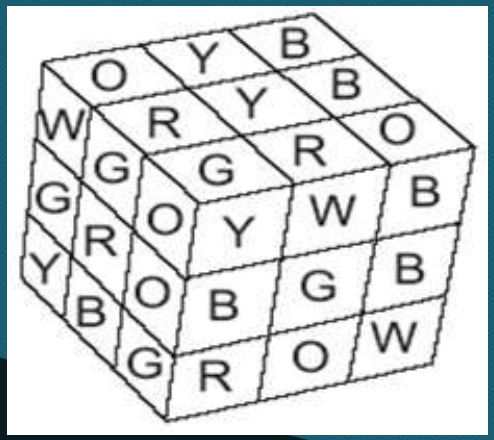


http://www.technologyuk.net/computing/computer-systems/display-adapter.shtml

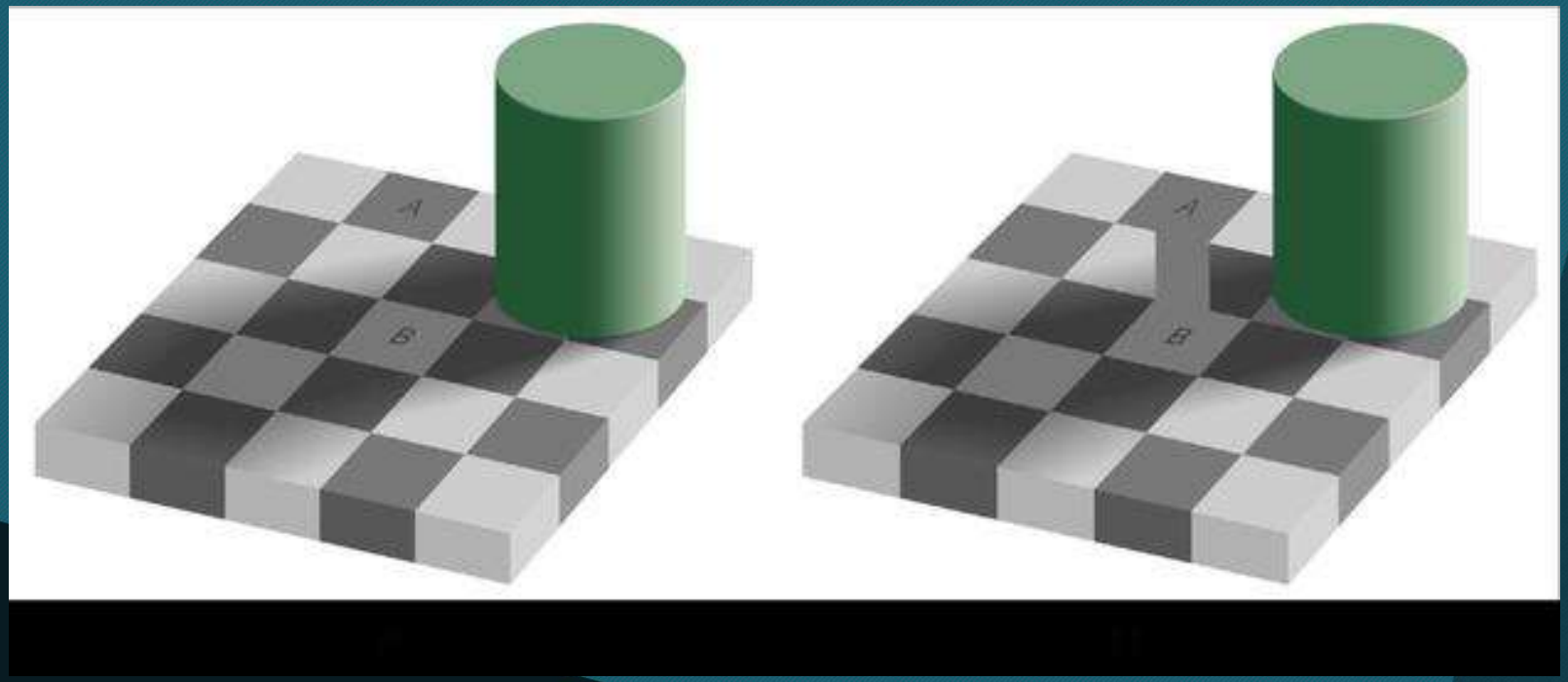
Color constancy

- Color constancy (顏色恆定)
  - Surfaces have different colors and brightness when viewed under different lights.
  - The human vision system is able to abstract to a certain degree from the illumination changes and perceive several instances of a particular color as the same.





Visual illusions VS Color constancy



https://www.youtube.com/watch?v=-sAoJgJUA8Y

https://www.youtube.com/watch?v=z9Sen1HTu5o