# *Image Processing 05 Colors and Color Spaces Part 1*

SS 2020

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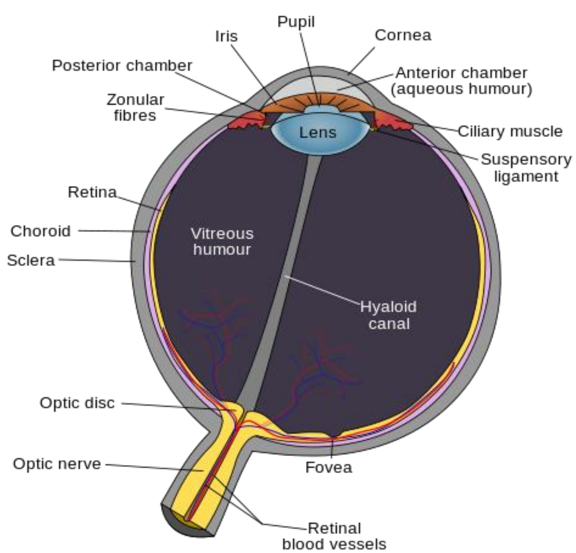
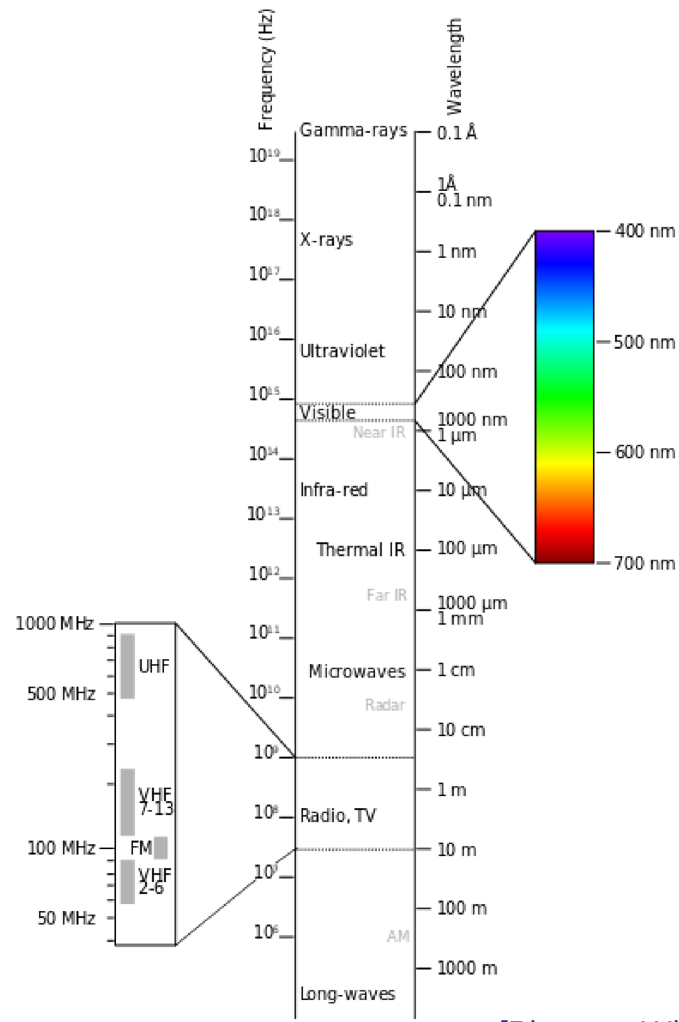
# Outline

- Part 1: Overview color & color spaces
- Part 1: RGB, CMY & CMYK
- Part 2: HSI
- Part 3: Color image processing

# Color

- Humans can discern thousands of color shades
(but only two dozen shades of gray)




[Pictures: Wikipedia]

# Retina

Retina: Netzhaut
Photo receptors: Fotorezeptor/Sehzelle
Rods: Stäbchen
Cones: Zapfen

- Remember, we have 3 types of cones (color receptors) in the retina:
  - L-cones (long-wavelength) (red)
  - M-cones (middle-wavelength) (green)
  - S-cones (short-wavelength) (blue)

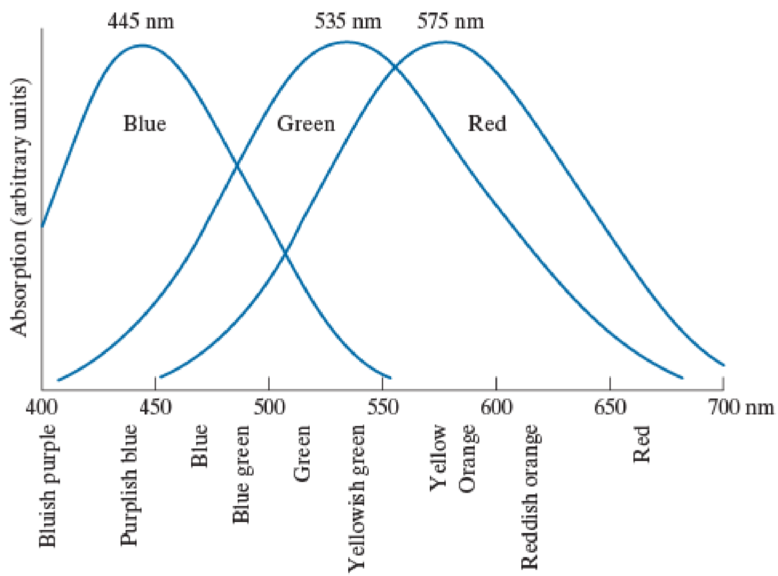
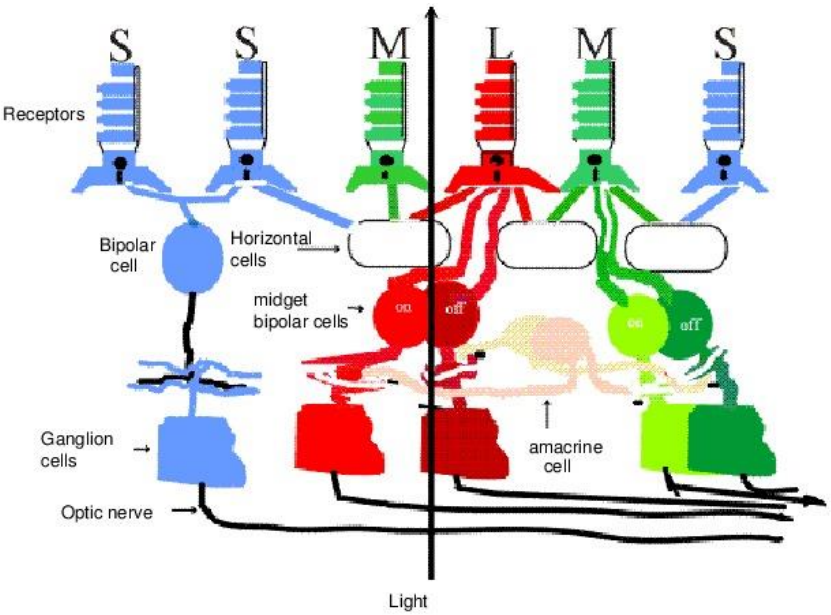



FIGURE 7.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.




The retina

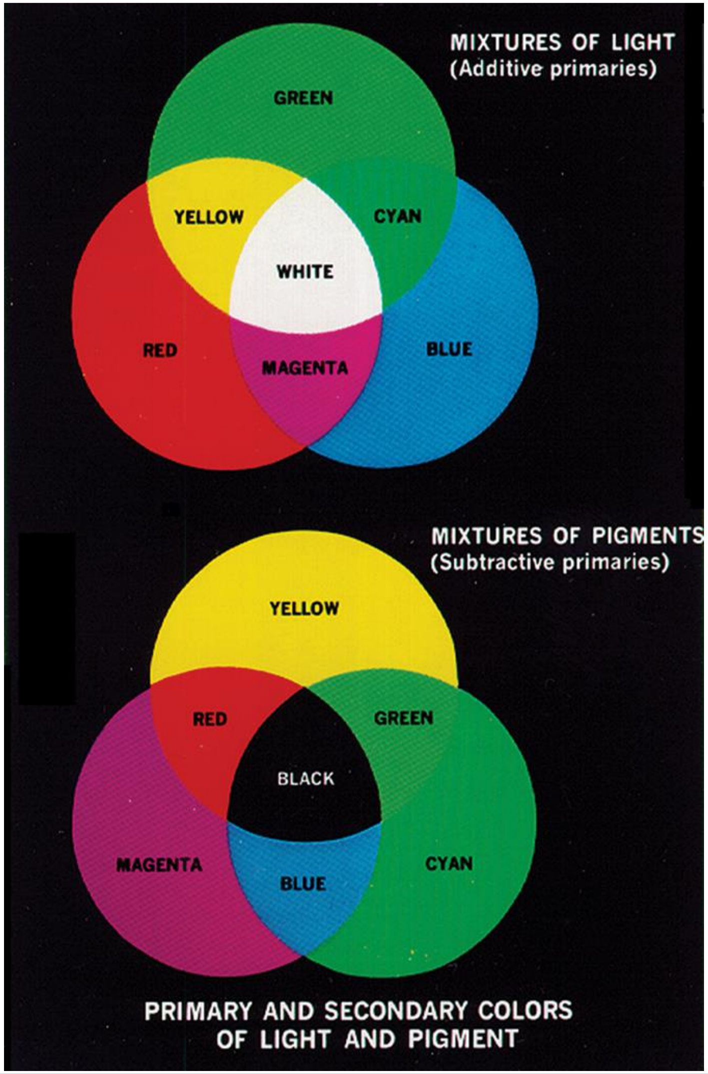
# Primary and secondary colors

- Primary colors of light: red, green, blue
- Secondary colors of light: magenta, cyan, yellow. Obtained by adding primary colors

- Primary colors of pigments: magenta, cyan, yellow
- Secondary colors of pigments: red, green, blue

a
b

**FIGURE 7.4** Primary and secondary colors of light and pigments. (Courtesy of the General Electric Co., Lighting Division.)



# *Color*

Color often simplifies object identification

Where are the apples?

[Picture: http://steinigergarten.blogspot.de/2014/10/apfelsortenbestimmung-und-apfelernte.html]

# Color Spaces

Some popular color spaces:

- RGB
- CMY/CMYK
- HSV/HSI/HSL
- Color-opponent spaces, e.g. LAB

- there are many more…

2 CIE
- 2.1 CIE 1931 XYZ
- 2.2 CIELUV
- 2.3 CIELAB
- 2.4 CIEUVW

3 RGB
- 3.1 RGB
- 3.2 sRGB
- 3.3 Adobe RGB
- 3.4 Adobe Wide Gamut RGB
- 3.5 Other RGB spaces

4 Luma plus chroma/chrominance
- 4.1 YIQ, YUV, YDbDr
- 4.2 YPbPr, YCbCr
- 4.3 xvYCC

5 Hue and saturation
- 5.1 HSV
- 5.2 HSL

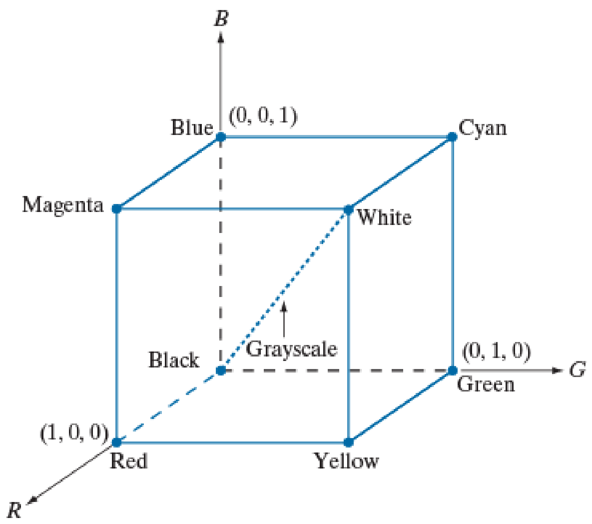
6 CMYK
- 6.1 CMYK

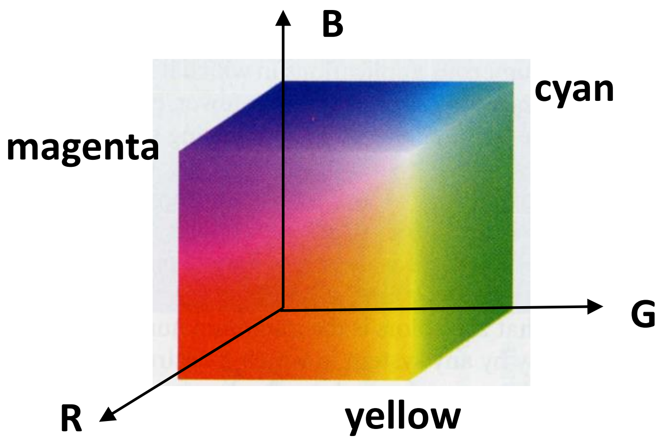
[Wikipedia]

# RGB

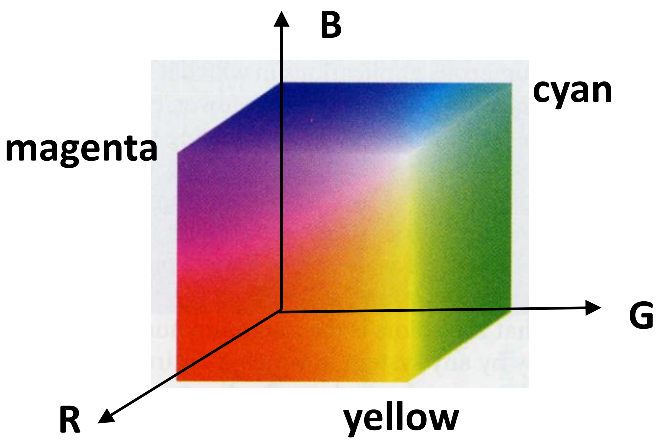
RGB is the most common color space in computer vision.

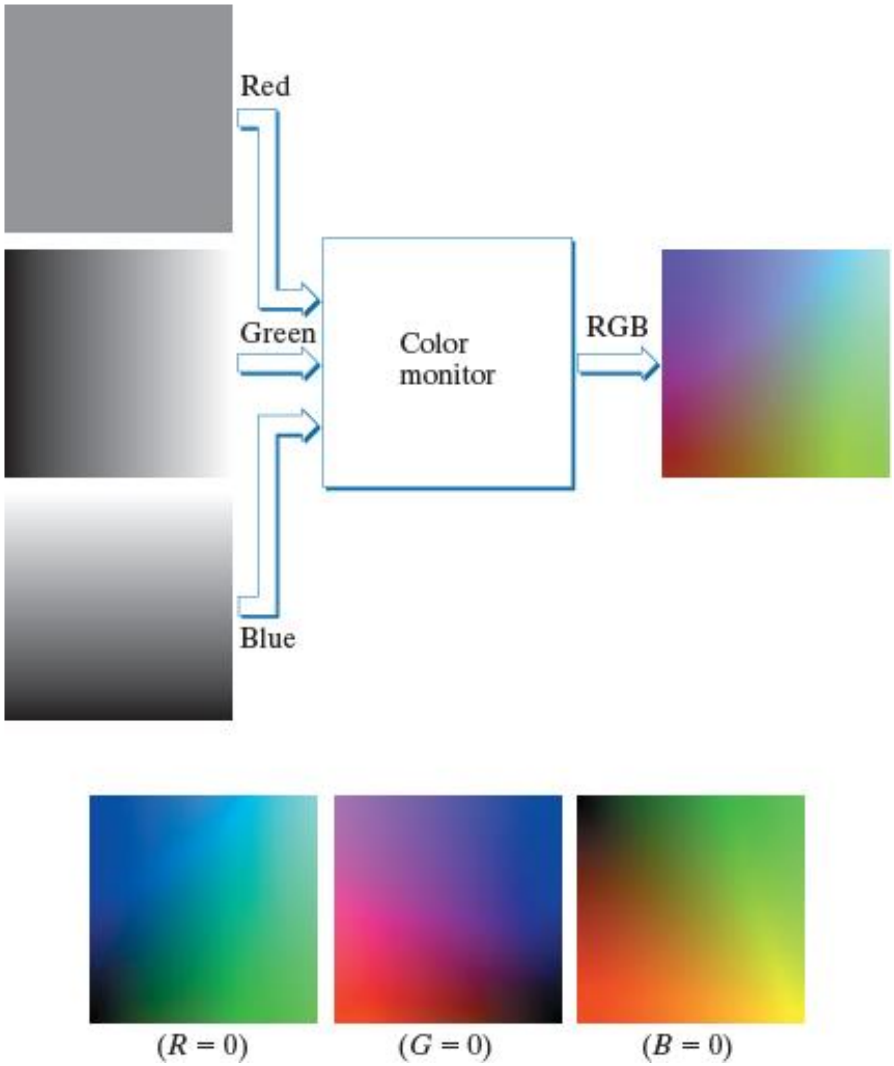
Different colors are generated by adding different portions of red (R), green (G), and blue (B).



# RGB



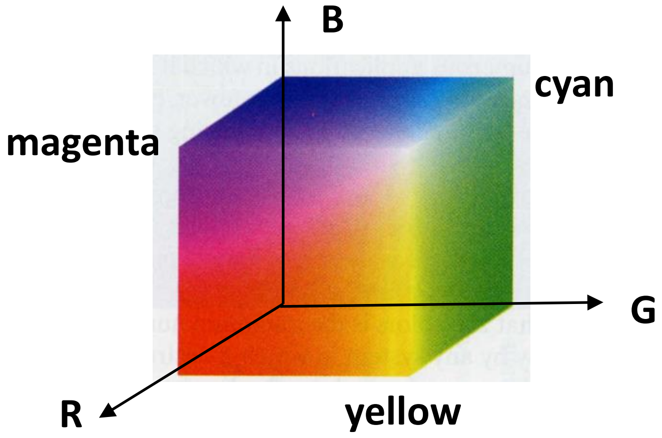

a
b

**FIGURE 7.9**
(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. 7.8.

# Color spaces

- How many colors can we represent if each channel is encoded by 8 bits?

- $256^3 = 16{,}777{,}216$ colors



# RGB

- In color (e.g. RGB) images, each pixel has 3 components: red, green, blue
- Written as column vector:

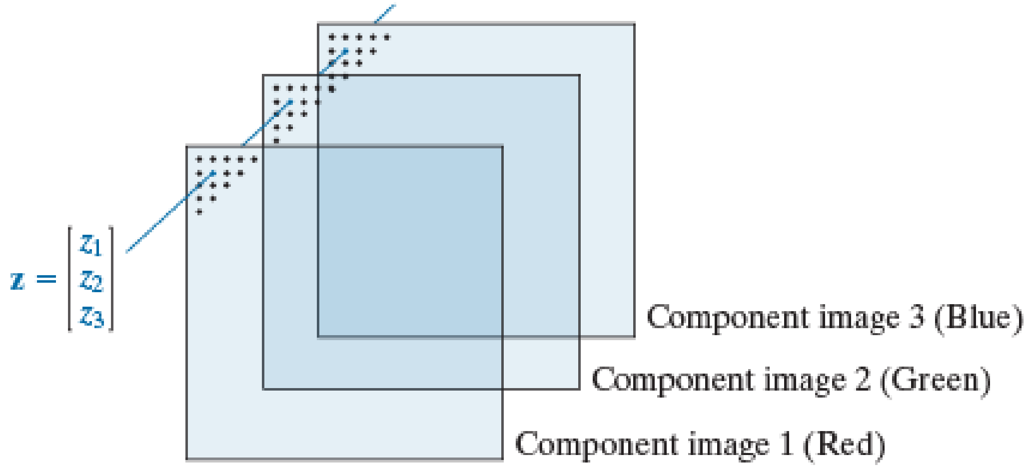



**FIGURE 2.43** Forming a vector from corresponding pixel values in three RGB component images.

# RGB

- In multi-spectral imaging, this is extended to n dimensions:

$$\mathbf{Z} = \begin{bmatrix} Z_1 \\ Z_2 \\ \vdots \\ Z_n \end{bmatrix}$$

# RGB Images of a Natural Scene

The RGB channels of a color image are rendered as grey value intensity images:

**R+G+B**

**R**

**G**

**B**

# RGB

This image shows Lena:
https://en.wikipedia.org/wiki/Lenna

It is a standard test image in image processing.

However, originally it was cropped from the Playboy.

There is some controversy about using this image, see next slide.

We will therefore try to avoid this image in this lecture

a b
c d

**FIGURE 7.36**
(a) RGB image.
(b) Red component image.
(c)Green component.
(d) Blue component.

# The Lena image

The history of the Lena image:

“Alexander Sawchuk estimates that it was in June or July of 1973 when he, then an assistant professor of electrical engineering at the University of Southern California Signal and Image Processing Institute (SIPI), along with a graduate student and the SIPI lab manager, was hurriedly searching the lab for a good image to scan for a colleague's conference paper. They got tired of their stock of usual test images, dull stuff dating back to television standards work in the early 1960s. They wanted something glossy to ensure good output dynamic range, and they wanted a human face. Just then, somebody happened to walk in with a recent issue of *Playboy*. The engineers tore away the top third of the centerfold so they could wrap it around the drum of their Muirhead wirephoto scanner, which they had outfitted with analog-to-digital converters (one each for the red, green, and blue channels) and a Hewlett Packard 2100 minicomputer. The Muirhead had a fixed resolution of 100 lines per inch and the engineers wanted a 512×512 image, so they limited the scan to the top 5.12 inches of the picture, effectively cropping it at the subject's shoulders.” (Wikipedia: Lenna)

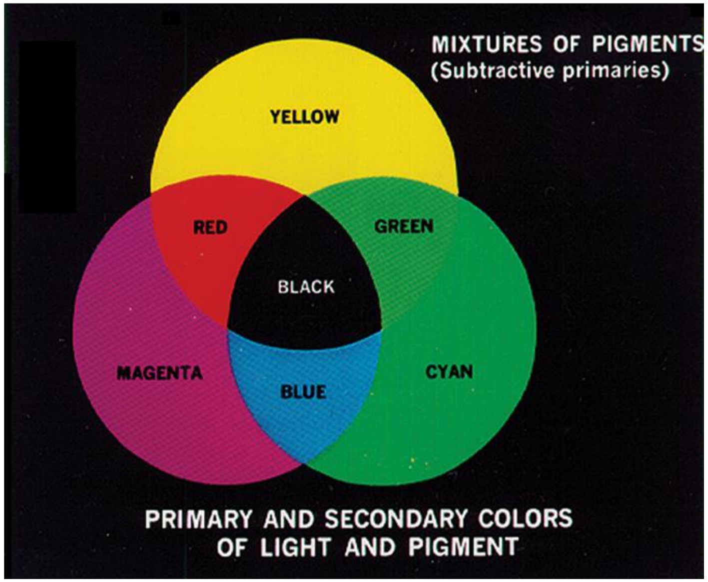
# *The Lena image*

“The use of the image has produced controversy because *Playboy* is "seen (by some) as being degrading to women",[10] and the Lenna photo has been pointed to as an example of sexism in the sciences, reinforcing gender stereotypes.
In a 1999 essay on reasons for the male predominance in computer science, applied mathematician Dianne P. O'Leary wrote:
Suggestive pictures used in lectures on image processing ... convey the message that the lecturer caters to the males only. For example, it is amazing that the "Lena" pin-up image is still used as an example in courses and published as a test image in journals today.

# CMY

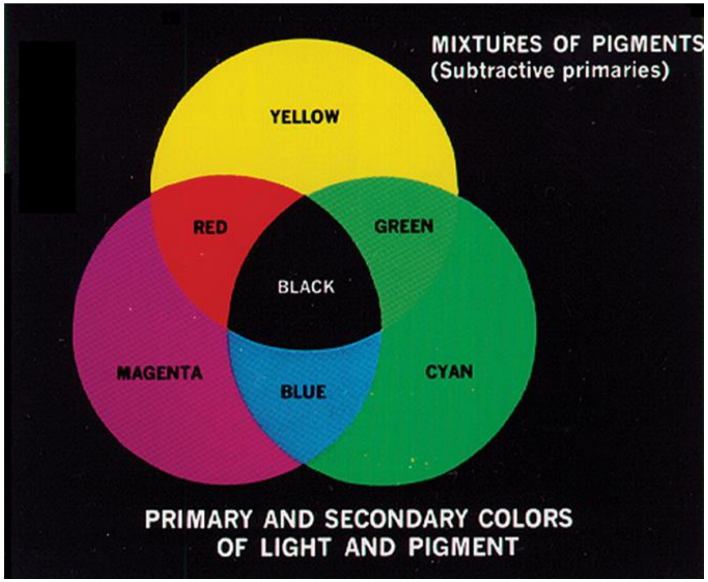
- The CMY color space: a subtractive model for printing
- Name: from primary colors of pigments: Cyan, Magenta, Yellow

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



# CMY-K

- In theory: cyan + magenta + yellow = black
- In practice, it gives rather brown
- To produce true black, add black color channel K
- Result: CMYK color model (four-color printing)




- From CMY to CMYK:

$$K = \min(C, M, Y)$$
$$C = (C - K)/(1 - K)$$
$$M = (M - K)/(1 - K)$$
$$Y = (Y - K)/(1 - K)$$

- Except for pure black, where K=1, C=M=Y=0

# CMY

- From CMYK to CMY:

$$C = C * (1 - K) + K$$

$$M = M * (1 - K) + K$$

$$Y = Y * (1 - K) + K$$

- Most color printers require CMYK input or perform an RGB to CMYK conversion internally

# Outline

- Part 1: Overview color & color spaces
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# *Image Processing 05 Colors and Color Spaces Part 2*

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# *Outline*

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# HSL/HSV/HSI

Hue-Saturation color spaces:

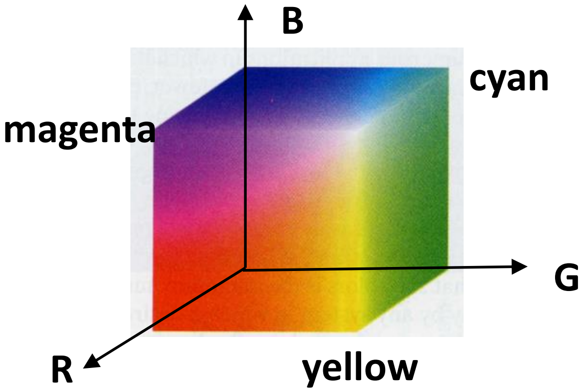
- HSL: Hue-Saturation-Lightness/Luminosity
- HSV/HSB: Hue-Saturation-Value/Brightness
- HSI: Hue-Saturation-Intensity

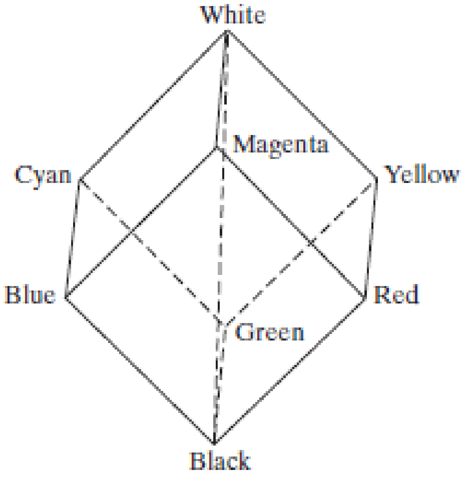
- HSL/HSV/HSI vary in how the intensity/brightness value is computed.
- According to Gonzales/Woods, we cover here HSI

[Image: Gonzalez/Woods 2017]

# HSL/HSV/HSI

- Hue-saturation color spaces are a re-arrangement of RGB geometry:

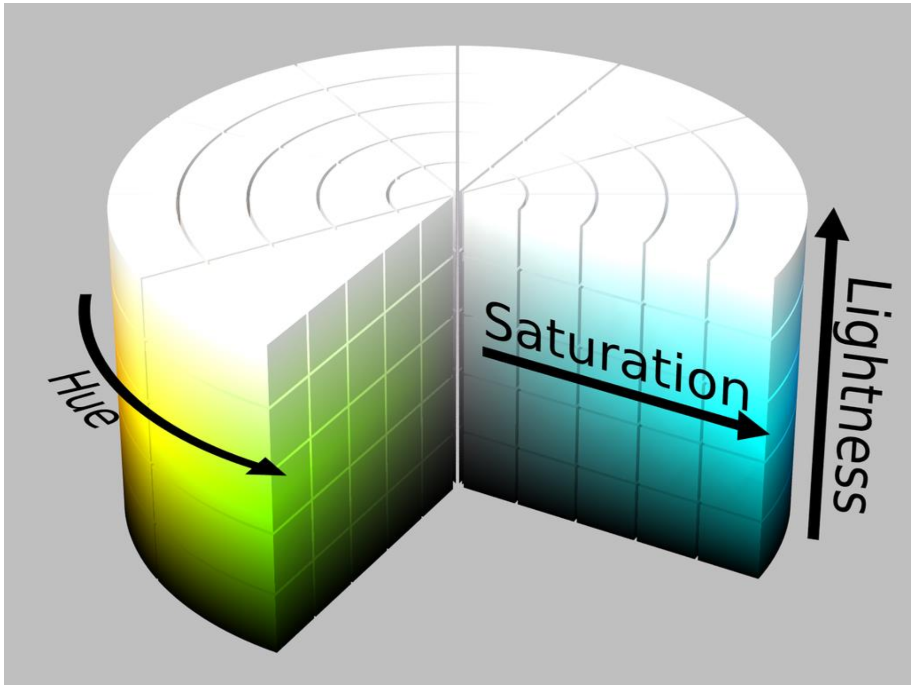


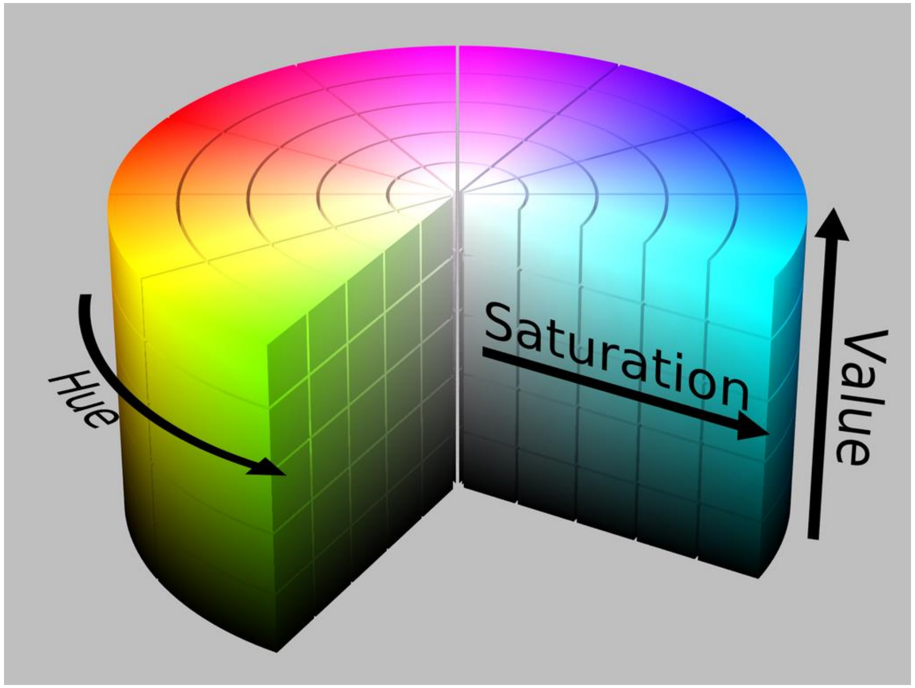




7.10 Conceptual relationships between the RGB and HSI color models.

[Image: Gonzalez/Woods 2017]

# HSL/HSV



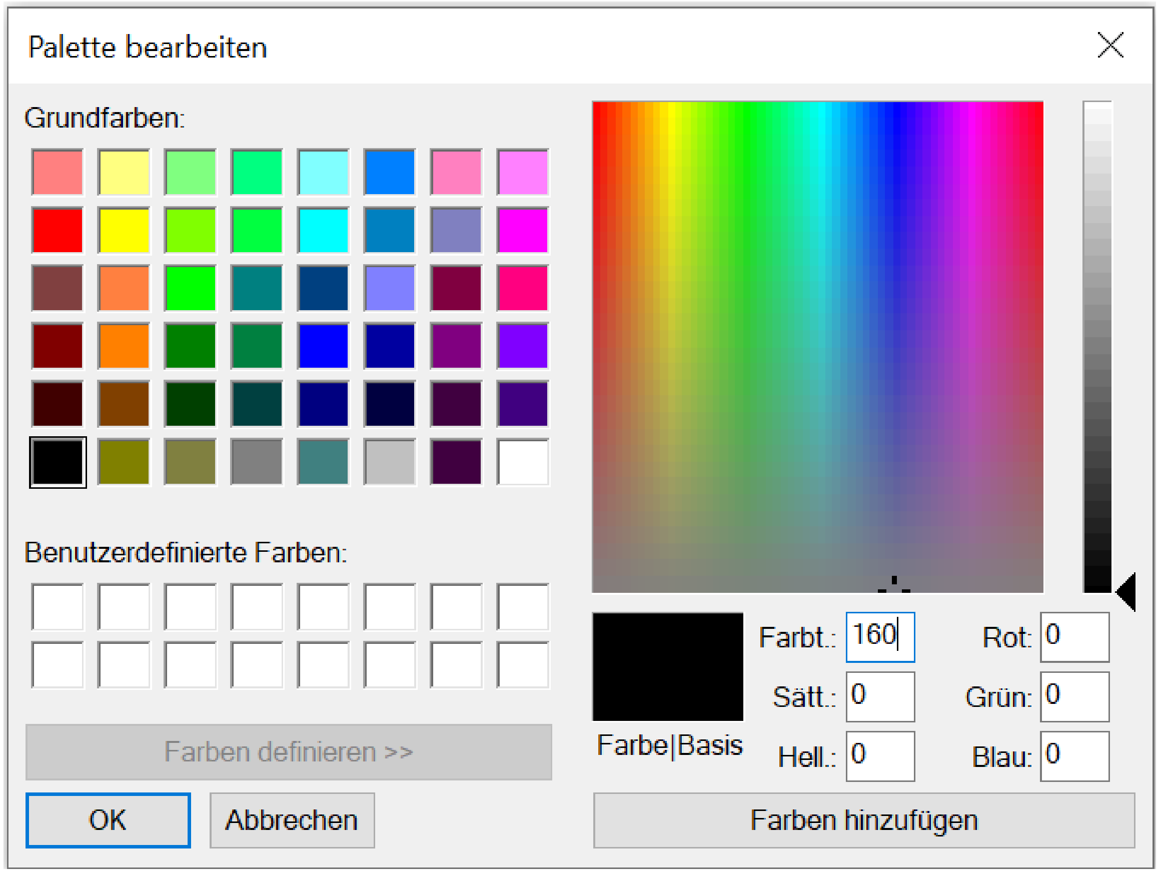

More intuitive than RGB

Better choice for selecting colors!

[Wikipedia]

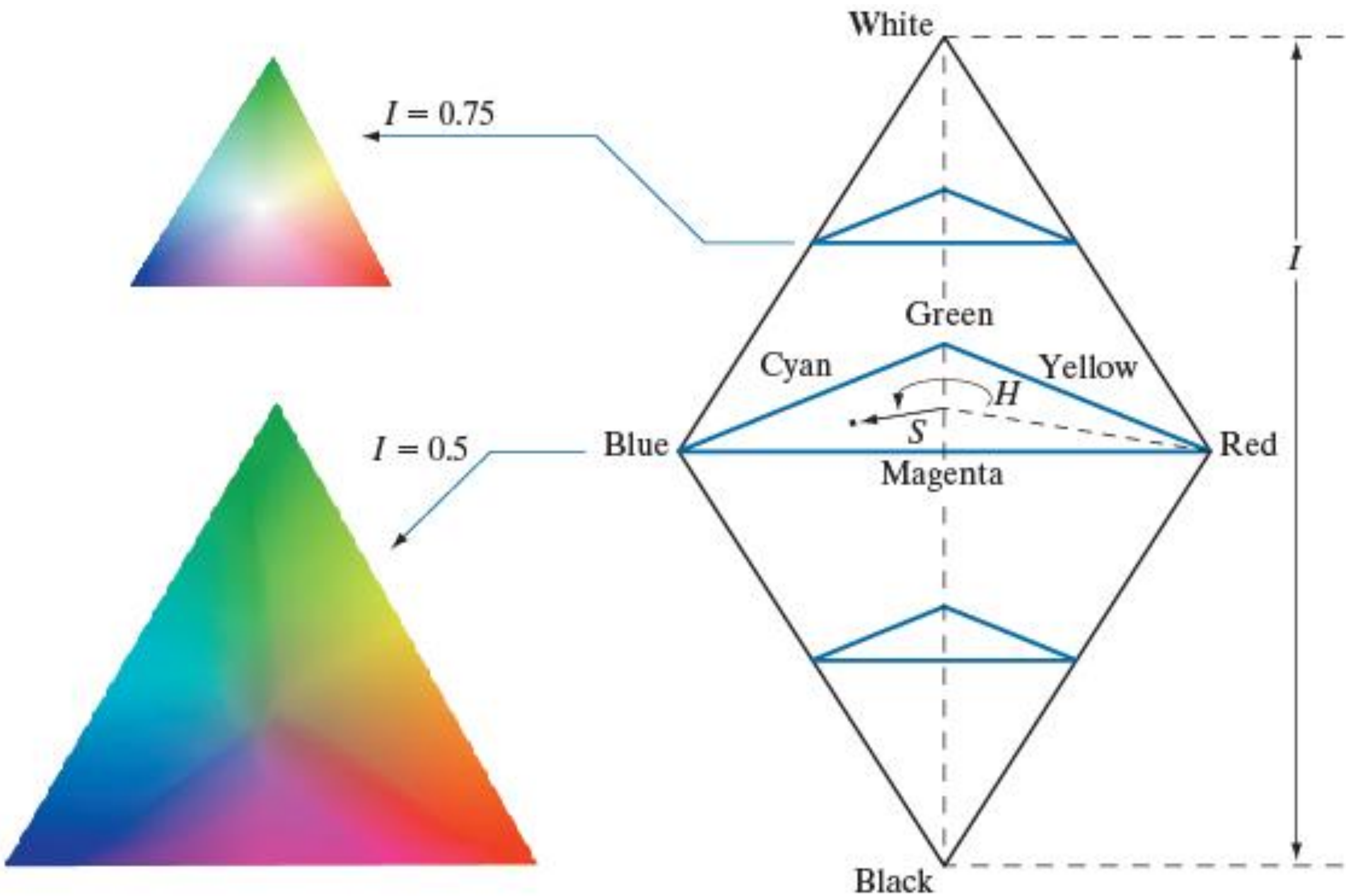
# HSL/HSV/HSI

Color selection in Paint:




[Image: Gonzalez/Woods 2017]

# HSI

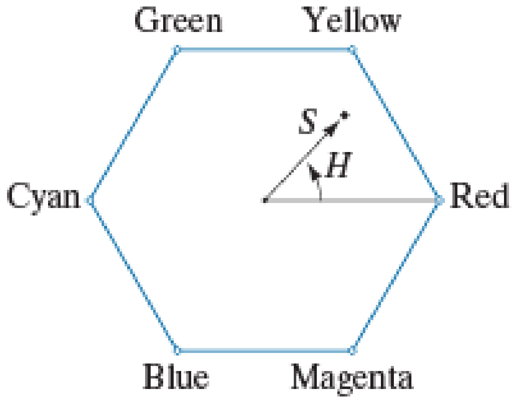


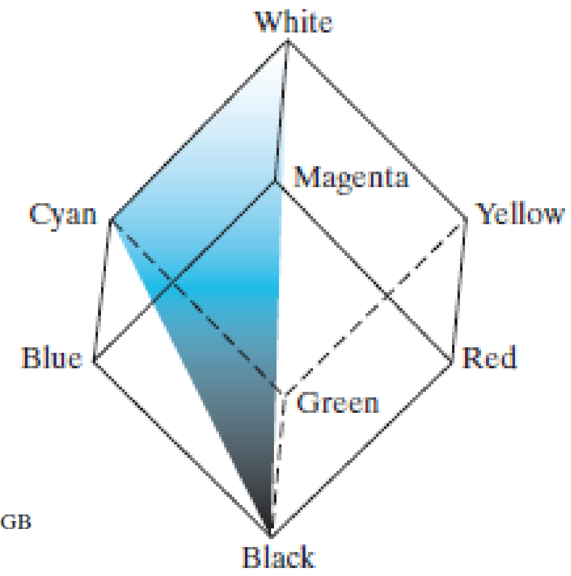

a
b

**FIGURE 7.12**
The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

# HSI

- Hue is encoded in the angle from the vertical intensity axis:
- All planes going through the vertical axis show only one hue value (with different intensities and saturations)
- Here the example for hue value „cyan“:

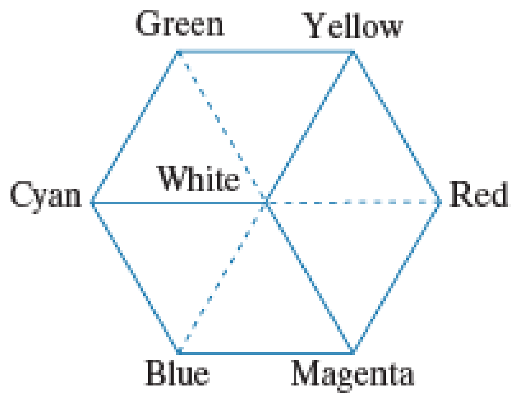



a b
**FIGURE 7.10** Conceptual relationships between the RGB and HSI color models.

# HSI

- The HSI color planes may be visualized as hexagon, but also as triangle or circle:



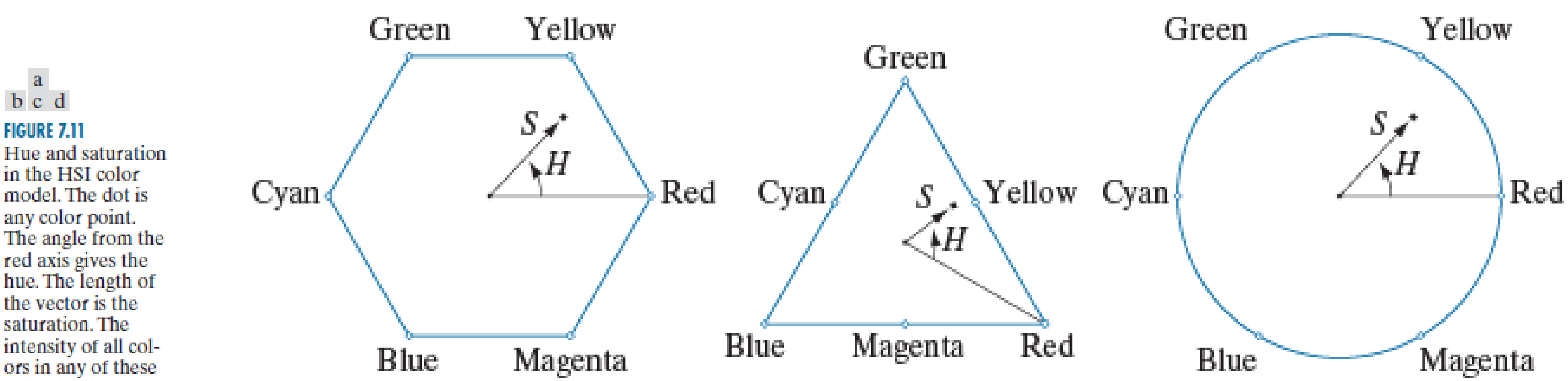
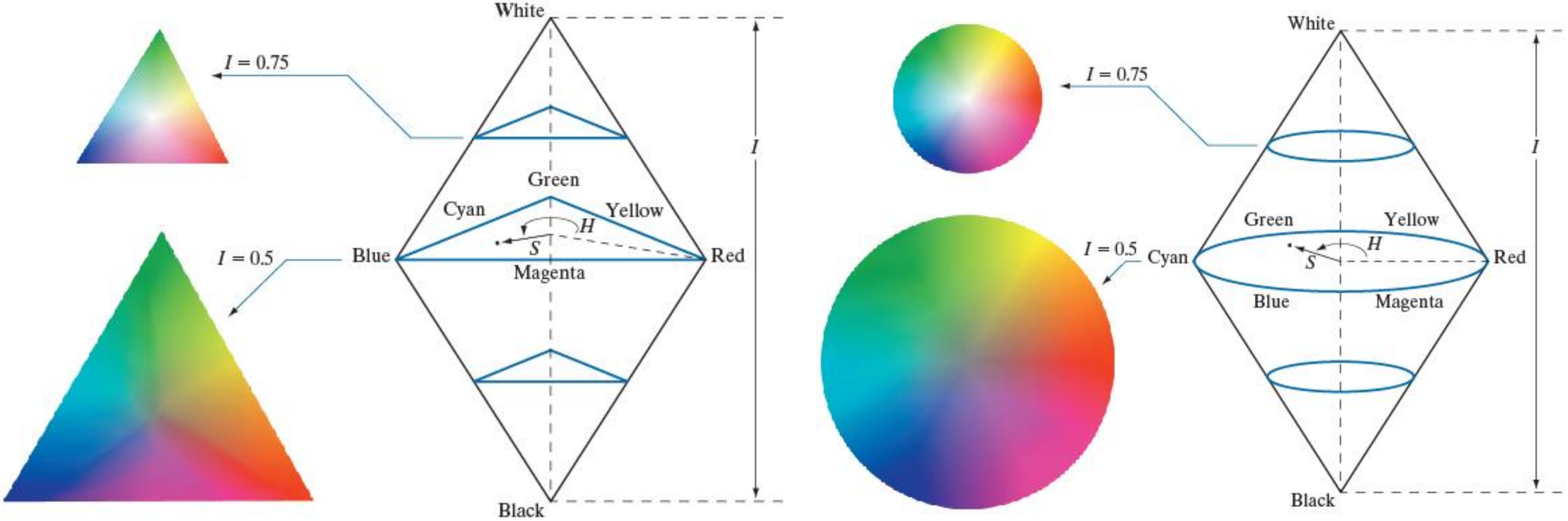




**FIGURE 7.11** Hue and saturation in the HSI color model. The dot is any color point. The angle from the red axis gives the hue. The length of the vector is the saturation. The intensity of all colors in any of these planes is given by the position of the plane on the vertical intensity axis.

# HSI




a
b

**FIGURE 7.12**
The HSI color model based on (a) triangular, and (b) circular color planes. The triangles and circles are perpendicular to the vertical intensity axis.

# HSI

- Conversion from RGB to HSI:

$$I = \frac{1}{3}(R + G + B)$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R, G, B)]$$

$$H = \begin{cases} \theta & \text{if } B \leq G \\ 360 - \theta & \text{if } B > G \end{cases}$$

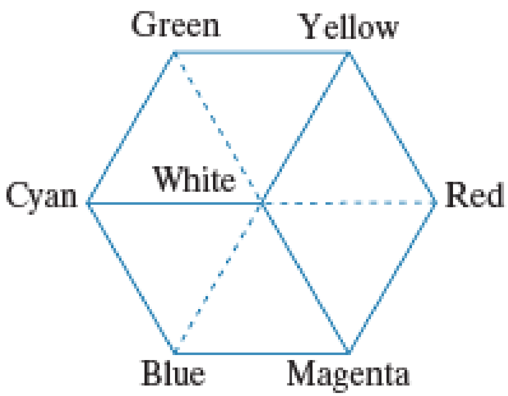
$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G) + (R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{1/2}} \right\}$$

(in practice: add a small constant to the denominator of the last equation to avoid dividing by 0 when R=G=B)

# HSI

- Conversion from HSI to RGB:
- Distinguish three sectors of the color space for the conversion

$$\boldsymbol{RG\ sector}\ (0^\circ \leq H < 120^\circ):$$




$$B = I(1-S)$$

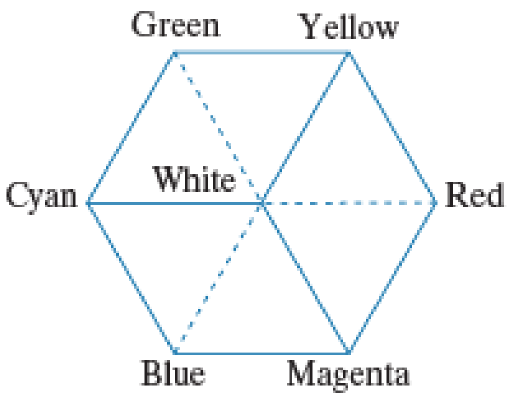
$$R = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$G = 3I - (R+B)$$

# HSI

- From HSI to RGB:

$$\boldsymbol{GB\ sector}\ (120^\circ \leq H < 240^\circ): \quad H = H - 120^\circ$$




$$R = I(1 - S)$$

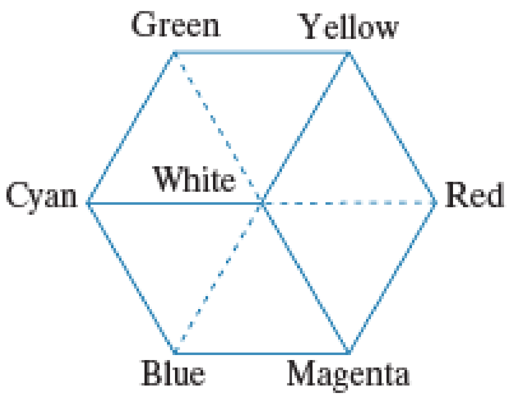
$$G = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$B = 3I - (R + G)$$

# HSI

- From HSI to RGB:

$$\boldsymbol{BR\ sector}\ \ (240^\circ \leq H \leq 360^\circ):\quad H = H - 240^\circ$$




$$G = I(1 - S)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^\circ - H)}\right]$$

$$R = 3I - (G + B)$$

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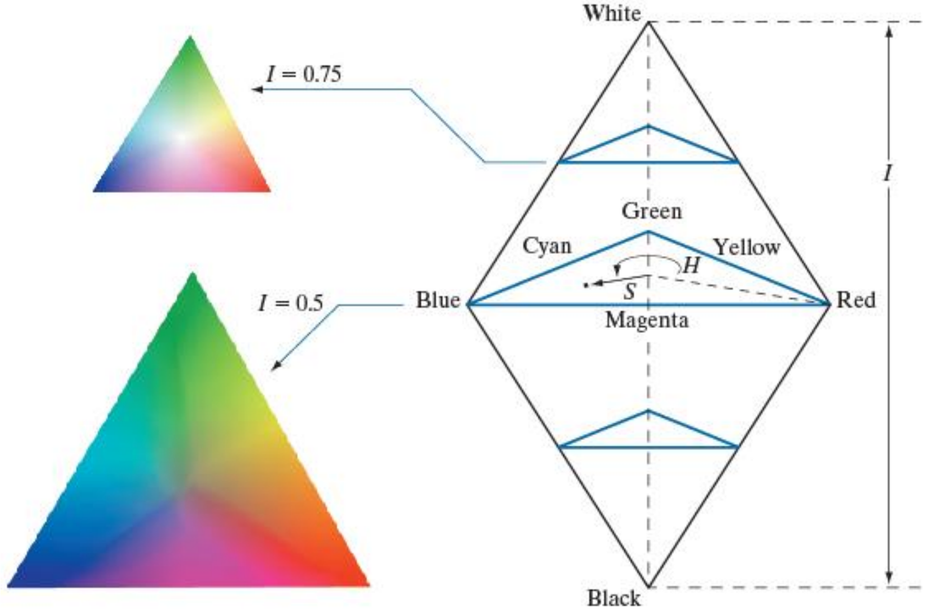

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# *Image Processing 05 Colors and Color Spaces Part 3*

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# *Outline*

- Part 1: Overview color & color spaces
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# Overview of our Color Spaces

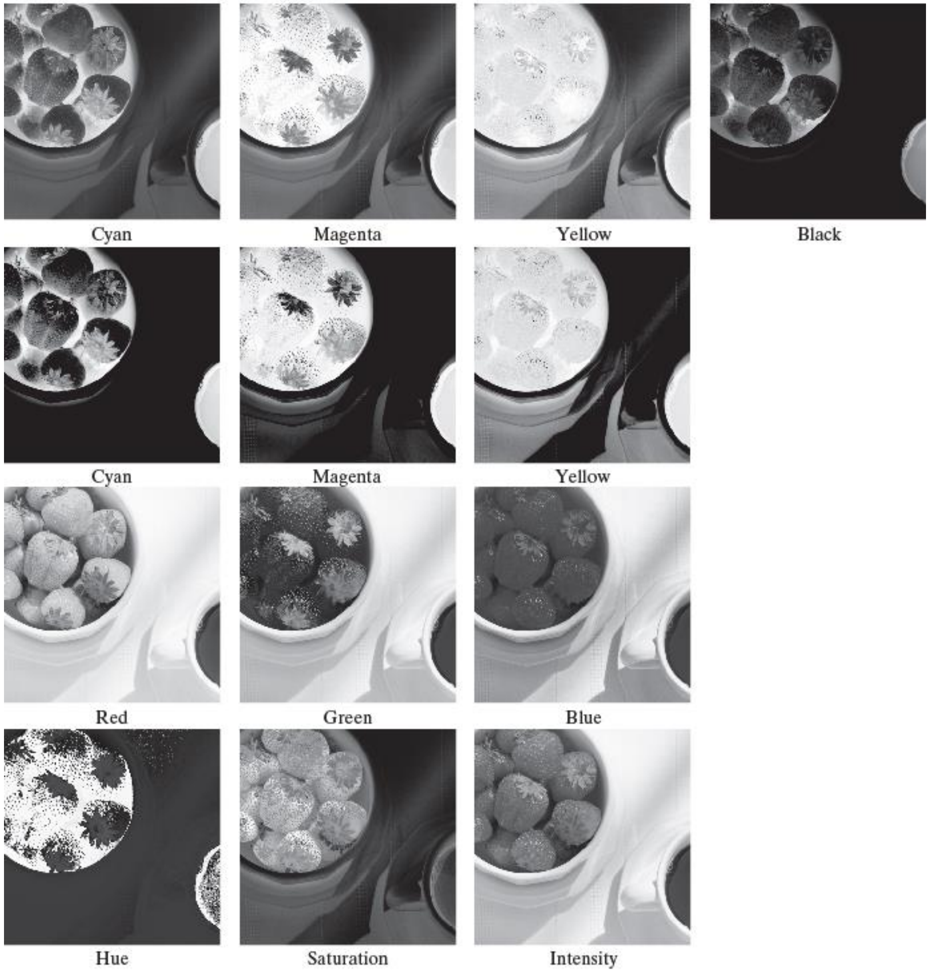
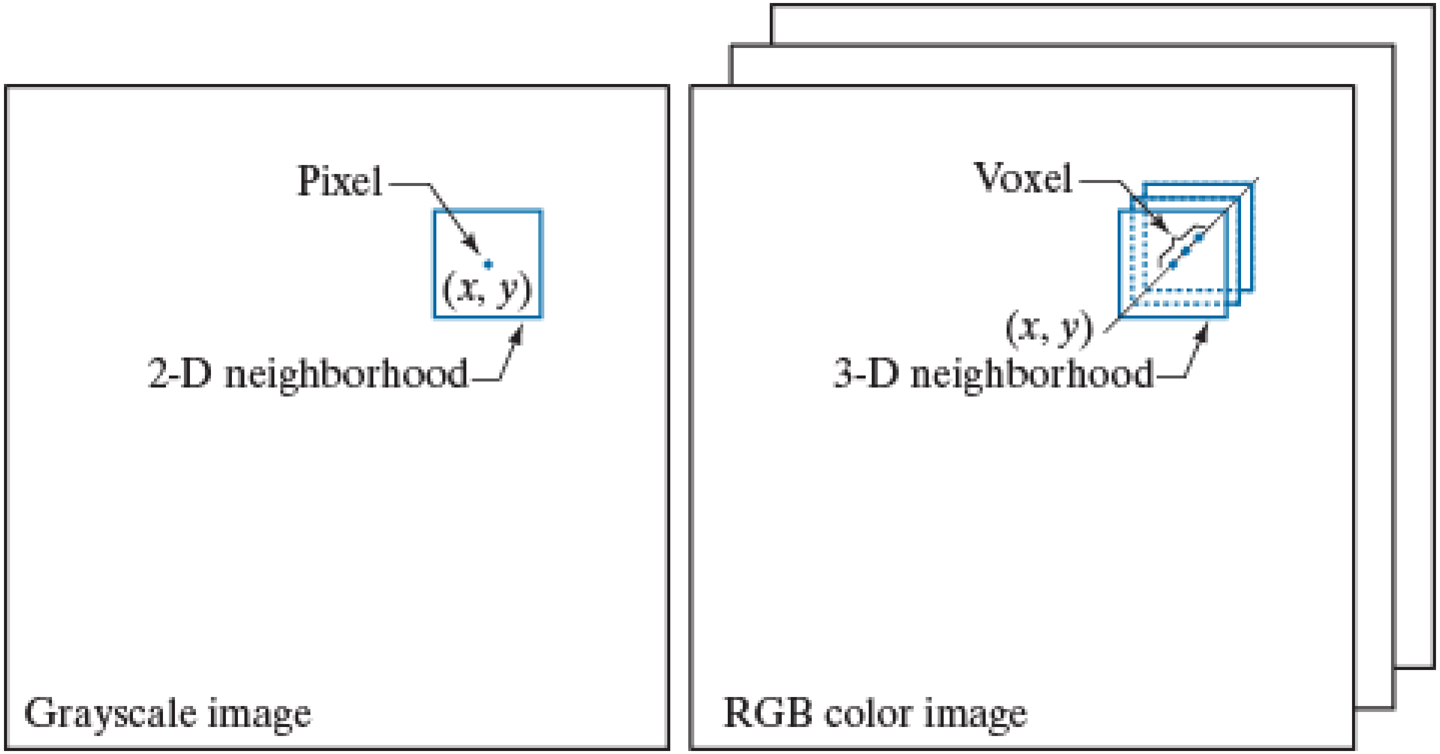



**FIGURE 7.28** A full-color image and its various color-space components. (Original image courtesy of MedData Interactive.)

# Image processing on color images




a b

**FIGURE 7.27** Spatial neighborhoods for grayscale and RGB color images. Observe in (b) that a *single* pair of spatial coordinates, (x, y), addresses the same spatial location in all three images.

$$\mathbf{C} = \begin{bmatrix} C_R \\ C_G \\ C_B \end{bmatrix} = \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \mathbf{C}(x,y) = \begin{bmatrix} C_R(x,y) \\ C_G(x,y) \\ C_B(x,y) \end{bmatrix} = \begin{bmatrix} R(x,y) \\ G(x,y) \\ B(x,y) \end{bmatrix}$$

# Image processing on color images

Two approaches for IP on color images:

- Process each color channel separately, form a new color image from the processed channels
- Operate directly on 3D vectors of color pixels (voxels)

Let us look at an example of the first category…

# Image Transformations

- The intensity transformations of lecture 04 can be directly applied to the n channels of a multi-channel image (for color images, n=3):

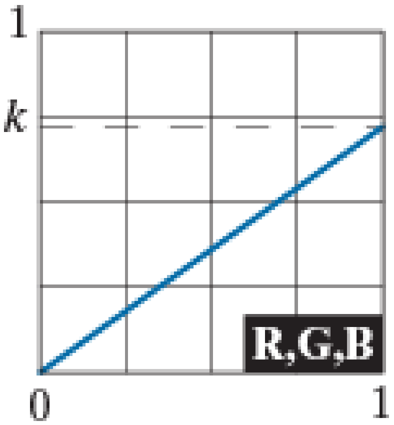
$$s_i = T_i(r_i) \quad i = 1, 2, \ldots, n$$

- we can use a different transformation function T for each channel
- Every transformation can be applied to any color model

# Image Transformations

- Example: decrease intensity of a color image by 30%

- RBG space: $s_i = kr_i \quad i = 1, 2, 3$

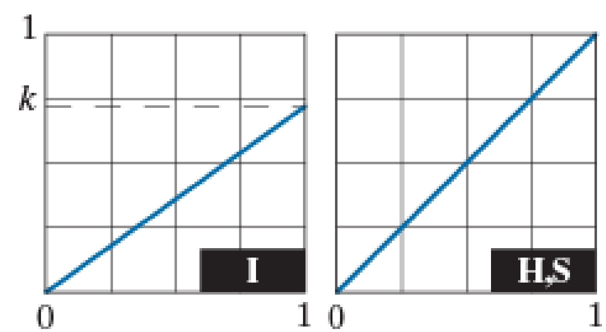


# Image Transformations

- Example: decrease intensity of a color image by 30%

- HSI space: we need to change only the intensity channel

$$s_3 = kr_3$$



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