Image Processing

Lecture 06: Color Image Processing - I

(Ch6 Color Image Processing)

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Contents of This Lecture

- ✓ Color fundamentals
- ✓ Color models
- Pseudo color processing
  - Intensity slicing
  - Gray level to color transform

Color Fundamentals

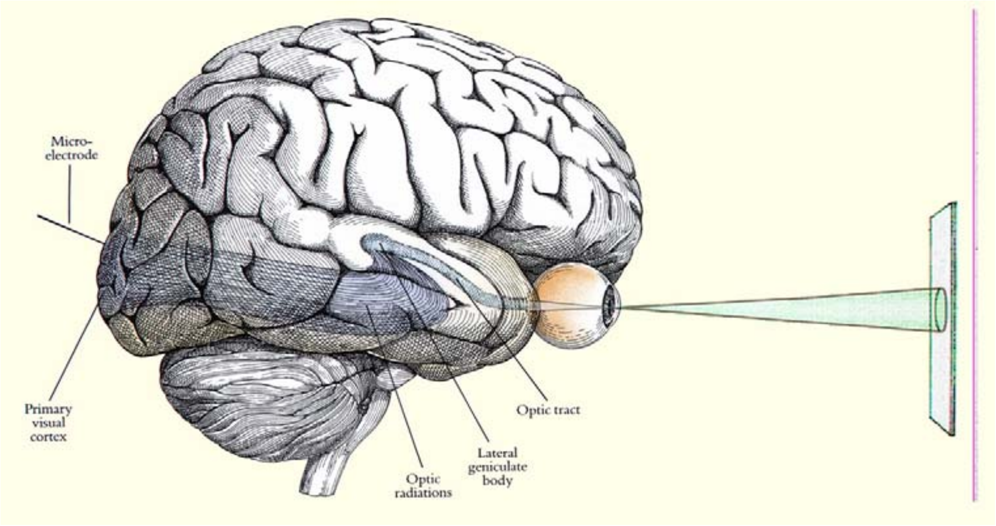
- **Motivation**
  - Color is a powerful descriptor that often simplifies object identification and extraction from a scene.
  - Humans can discern thousands of color shades and intensities, compared to only two dozen or so shades of gray.

Color Fundamentals

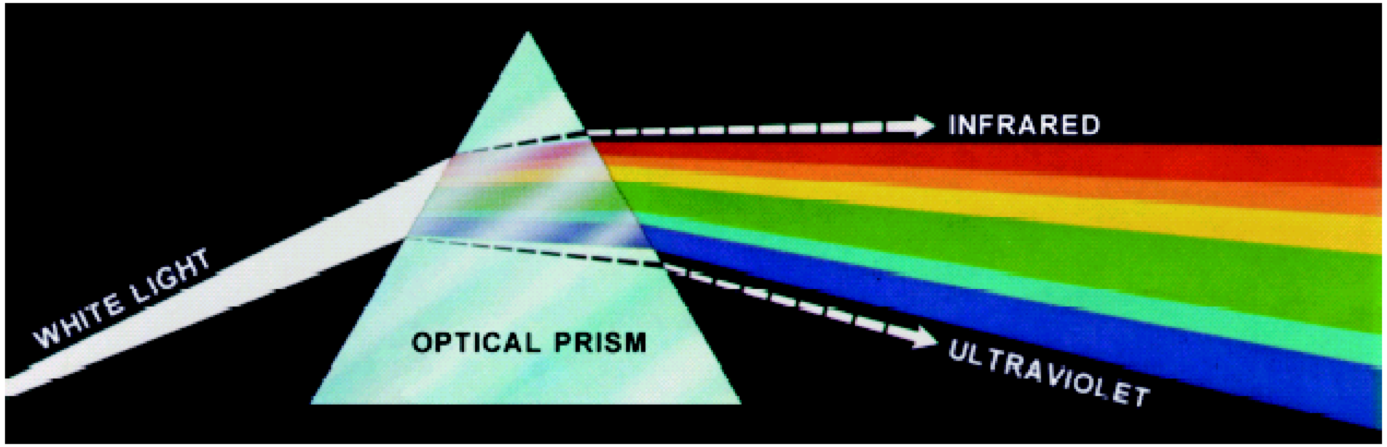
- **Full Color**
  - The images are acquired with a full color sensor, such as color TV camera, color scanner.
- **Pseudo Color**
  - Assigning colors to monochrome images, based on specified criterion.

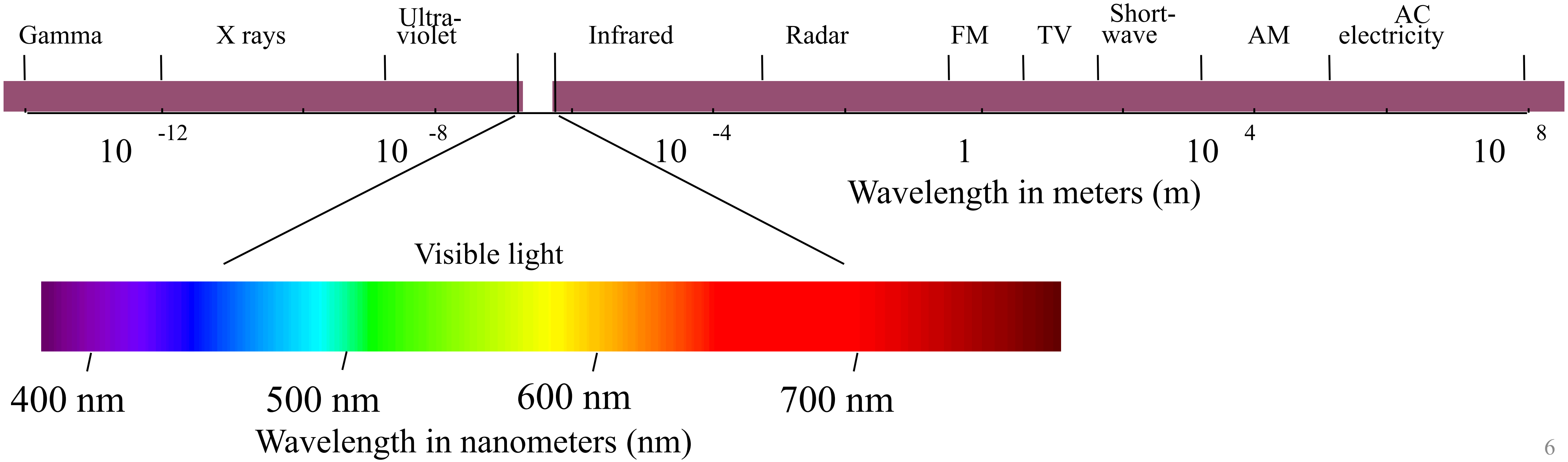
Color Fundamentals

- The process followed by the human brain in perceiving and interpreting color is a physiological-psychological phenomenon, which is not yet fully understood.
- The physical nature of color can be expressed on a formal basis supported by experimental and theoretical results.



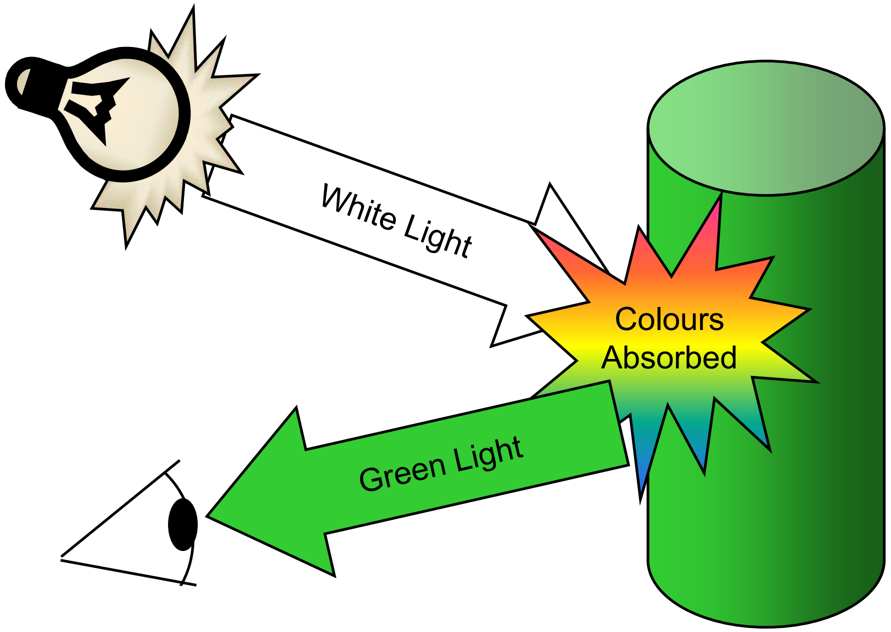
Color Fundamentals





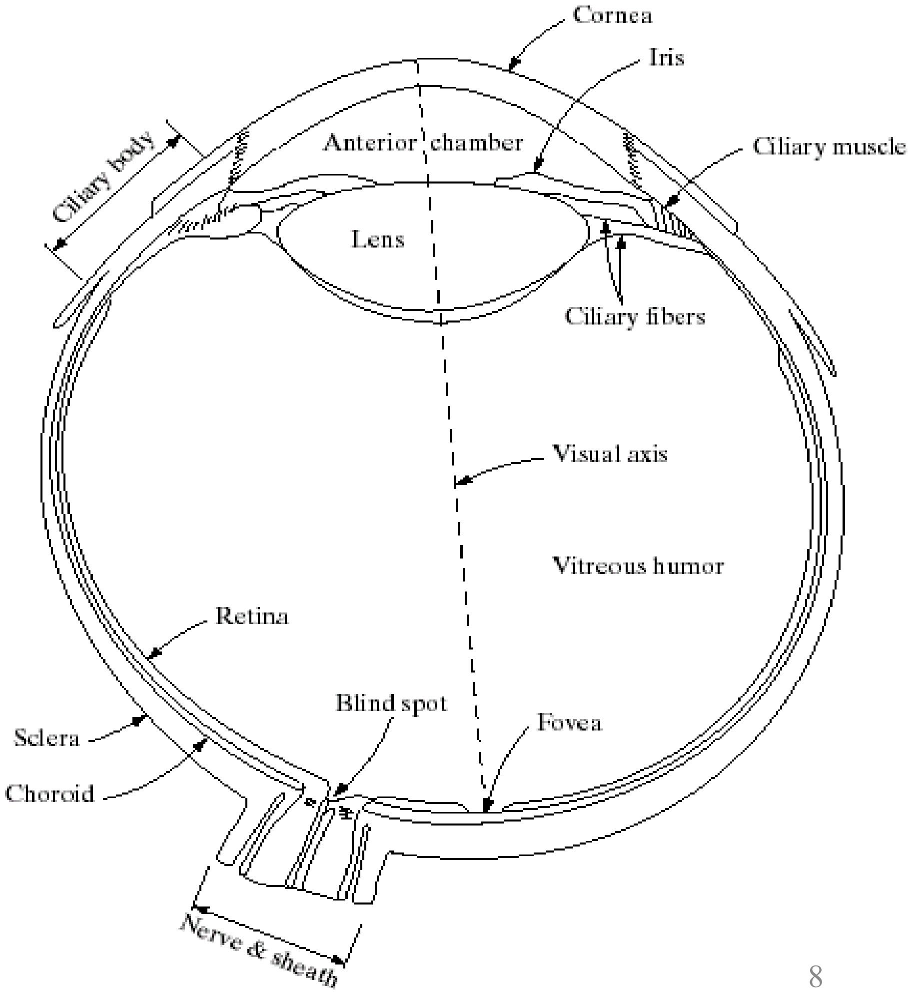
Color Fundamentals

- Light and Spectra
  - Visible light is an electromagnetic wave in the 400-700 nm range.
  - Most light we see is not one wavelength, but a combination of many wavelengths.
- The colors perceived in an object are determined by the nature of the light reflected by the object.
- A body that reflects light relatively balanced in all visible wavelengths appears white to the observer.



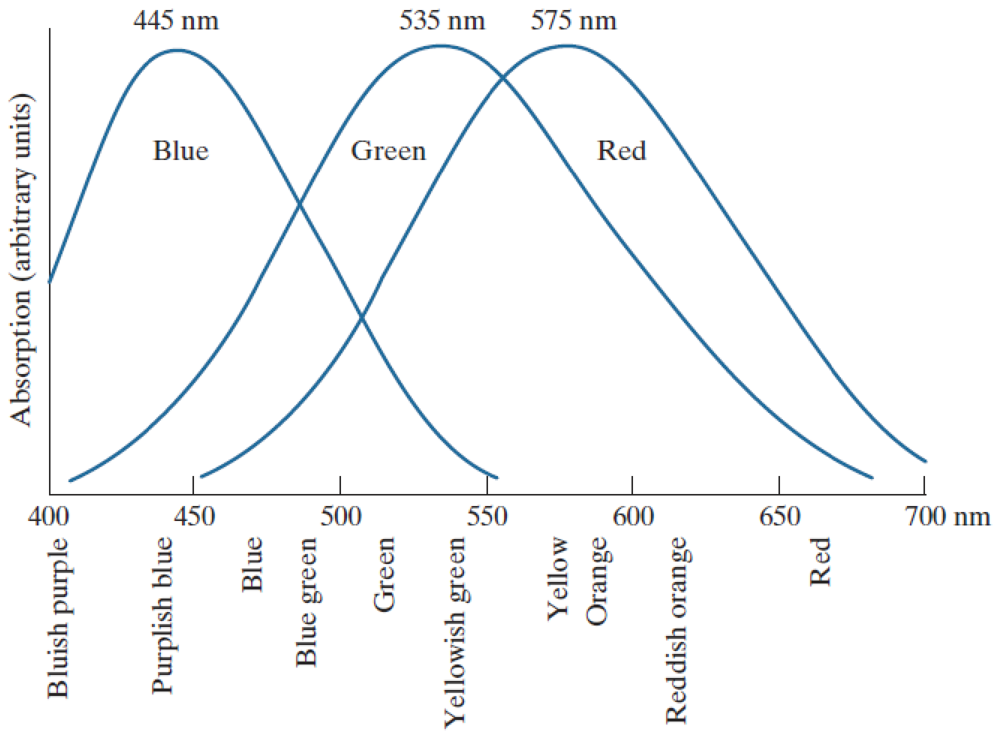
Color Fundamentals

- Human retinas have two types of photoreceptors
  - Cones
    - Cones are the sensors in the eye responsible for color vision
    - High light level, high acuity vision
    - Each type of cone has a different spectral response
  - Rods
    - Rods are more spread out and are sensitive to low levels of illumination



Color Fundamentals

- Detail experimental evidence has established that the 6 to 7 million cones in the human eye can be divided into three categories, corresponding roughly to RED, GREEN, and BLUE.
  - 65% --sensitive to red light
  - 33% --sensitive to green light
  - 2% --sensitive to blue light (but the blue cones are the most sensitive)



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

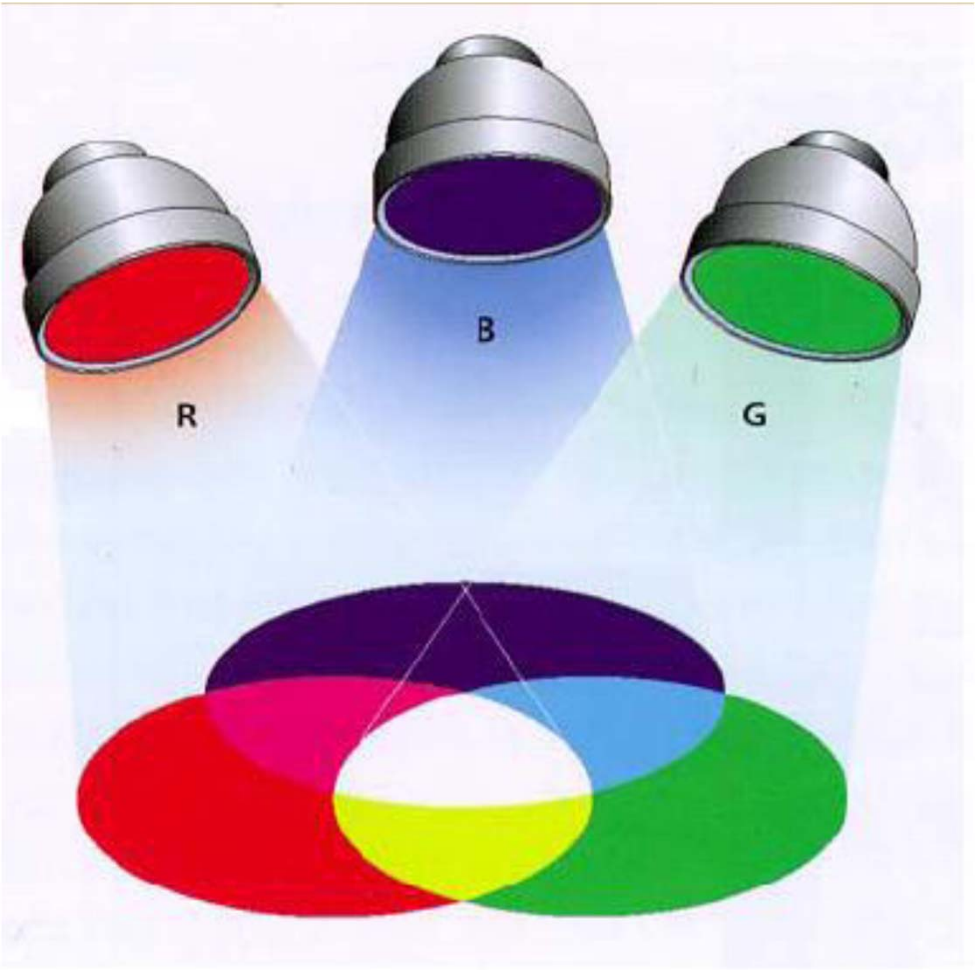
Color Fundamentals

- Due to these absorption characteristics of the human eyes, colors are seen as variable combinations of the primary colors: RED (R), GREEN (G), and BLUE (B).
- For purpose of standardization, the CIE (Commision Internationale de I'Eclairage) designated in 1931 the following specific wavelength values to the three primary colors:
    - Red: 700 nm
    - Green: 546.1 nm
    - Blue: 435.8 nm

Color Fundamentals

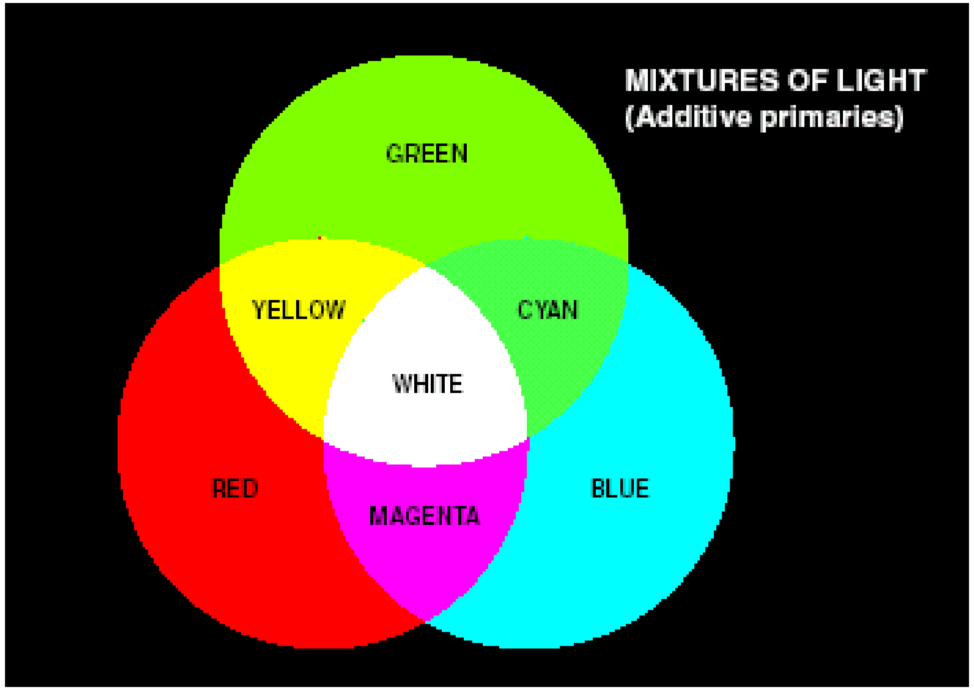
<u>Note:</u>

- No single color is called Red, Green, or Blue.
- It does not mean that these three fixed RGB components can generate all spectrum colors.
- Use the word *primary* has been widely misinterpreted to mean that the three standard primaries, when mixed in various intensity proportions, can produce all visible colors.



Color Fundamentals

- The primary colors can be added to produce the secondary colors of light:
  - Magenta = Red + Blue
  - Cyan = Green + Blue
  - Yellow = Red + Green

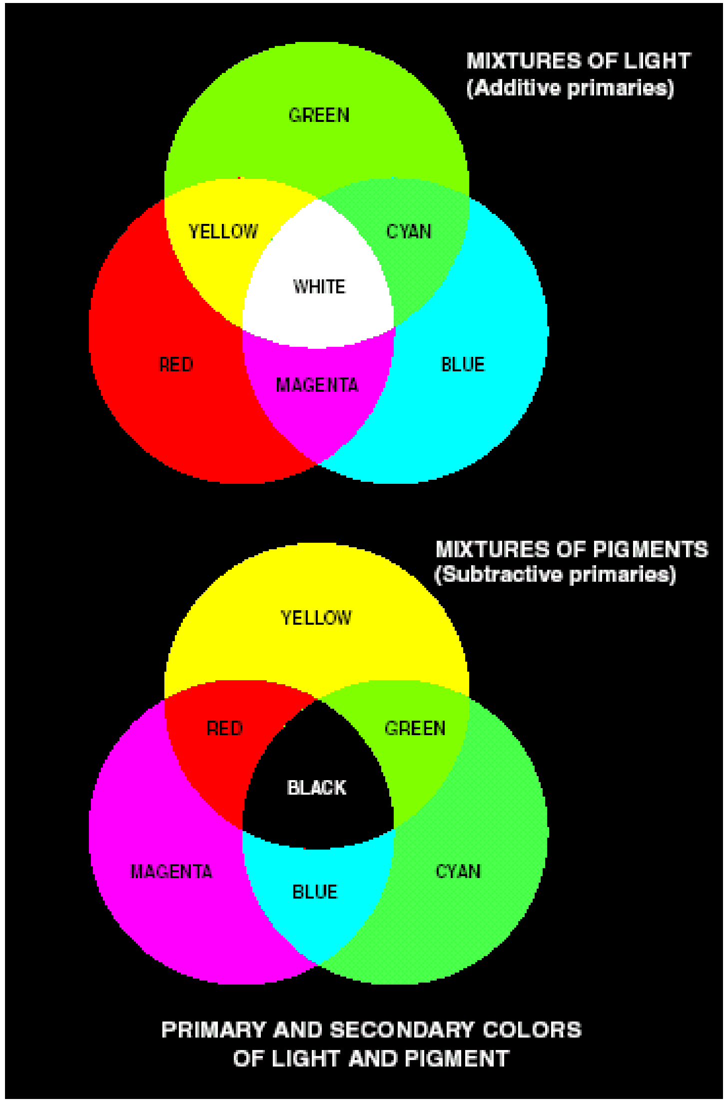


- Mixing the three primaries, or a secondary with its opposite primary color, in the right intensities produces white light.

Color Fundamentals

- Note: The difference of the primary colors of light and the primary colors of pigments or colorants.

- Primary colors of pigments:
  - Magenta = Red + Blue
  - Cyan = Green + Blue
  - Yellow = Red + Green



Color Fundamentals

- The characteristics used to distinguish one color from another are:
  - Hue
    - ➢Hue represents dominant color as perceived by an observer.
    - ➢An attribute associated with the dominant wavelength in a mixture of light waves.
    - ➢Thus, when we call an object red or yellow, we are specifying its hue.
  - Saturation
    - ➢The pure spectrum colors are fully saturated, colors such as pink (red and white) are less saturated.
    - ➢Saturation is inversely proportional to the amount of white light added.
  - Brightness (Intensity)
    - ➢Embody the chromatic notion of intensity

Color Fundamentals

- Hue and saturation taken together are called *chromaticity*.
- Therefore, a color may be characterized by its **brightness** and **chromaticity**.
- The amounts of red, green, and blue needed to form any particular color are called the *tristimulus* values and are denoted X, Y, and Z, respectively.

Color Fundamentals

- A color is then specified by its *trichromatic* coefficients:

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

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

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

$$x + y + z = 1$$

Color Fundamentals

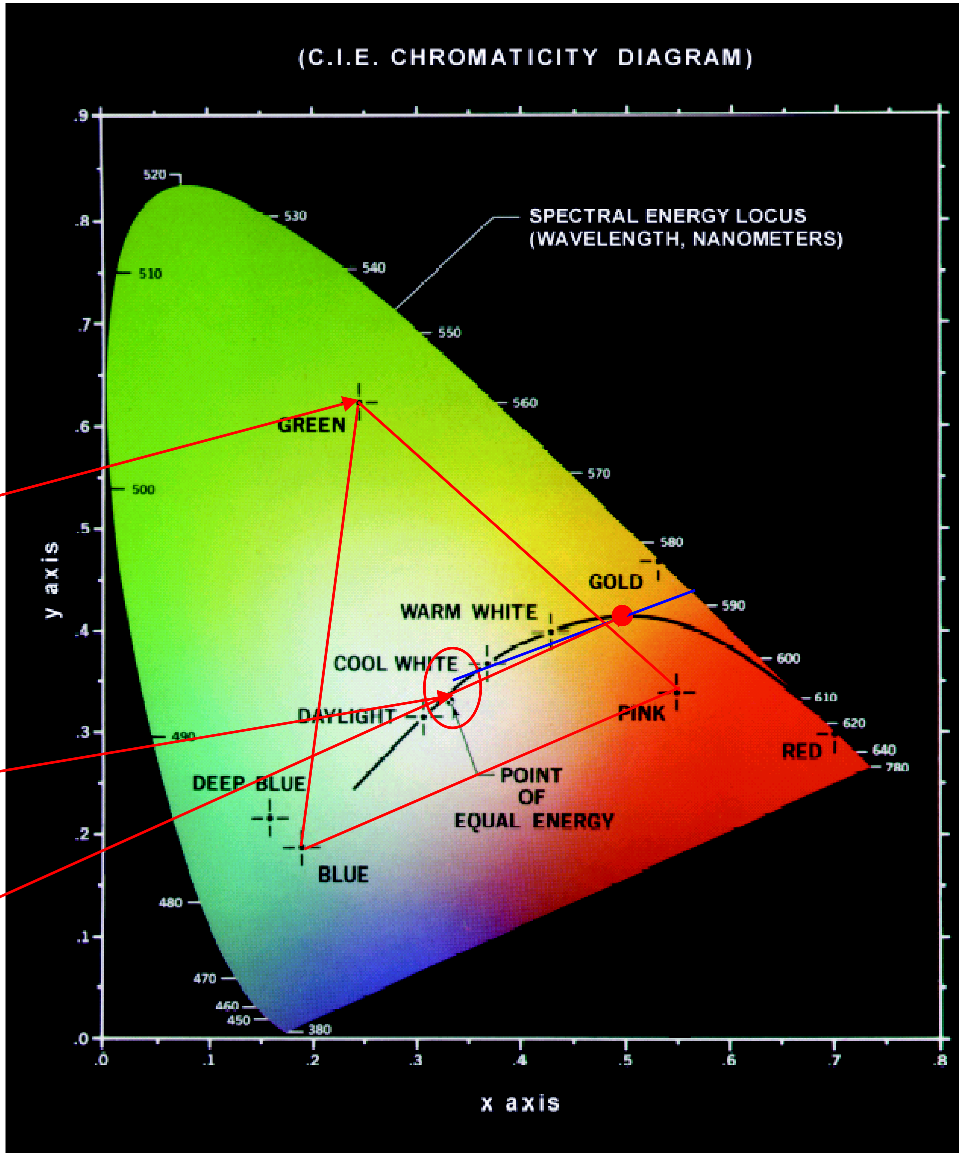
- Another way for specifying colors is to use the CIE chromaticity diagram.
  - X axis: Red
  - Y axis: Green

$$x + y + z = 1$$

Point GREEN:
x=25%, y=62%, then z=13%

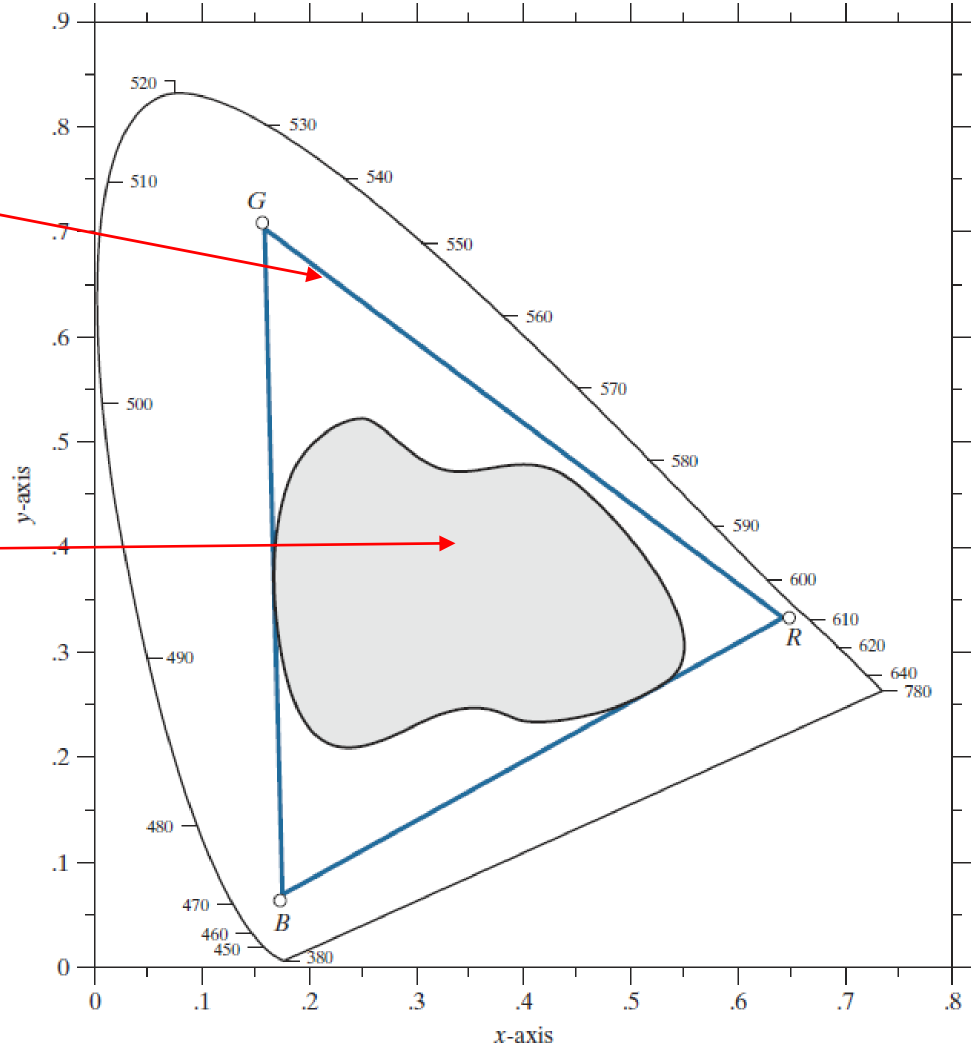
Saturation=0

Saturation=66%



Color Fundamentals

- Typical range of colors produced by RGB monitors.
- The color represented by high quality color printing devices.



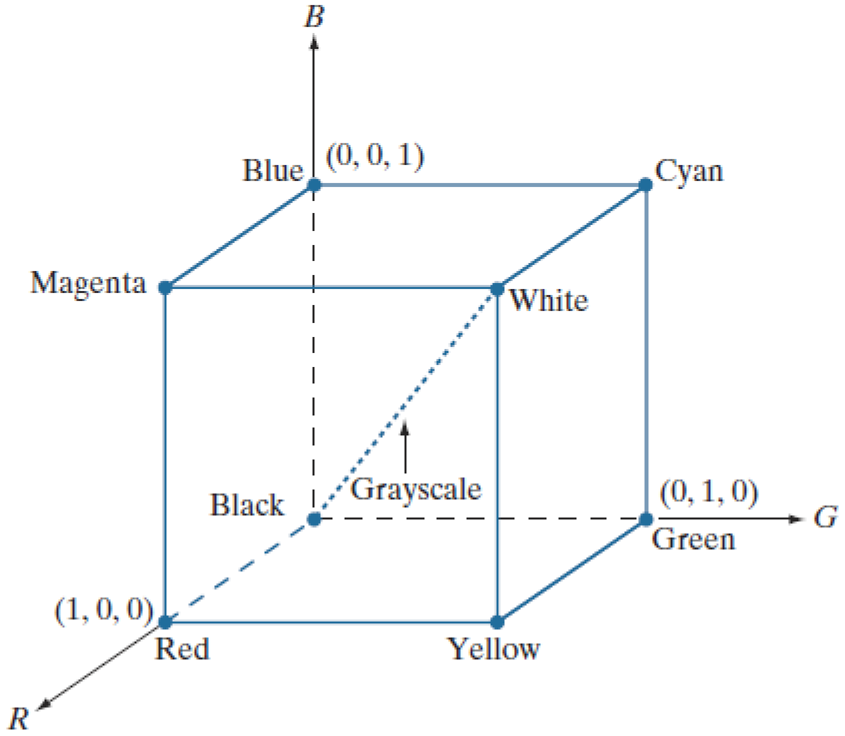
Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).

Color Models

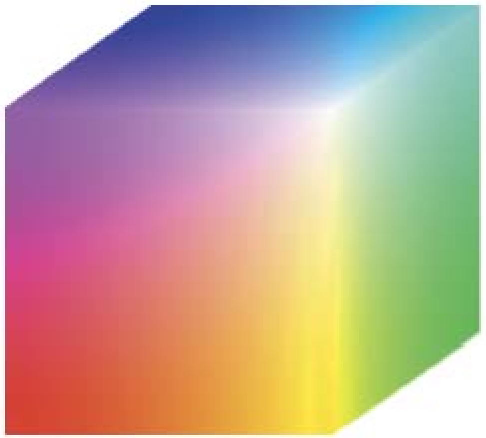
- Color model is also called color space, color system, which is used to facilitate the specification of colors in some standard.
- Two types of color models:
  - Hardware oriented: such as printer, monitor
  - Application oriented: such as animation, medical image processing
- Typical color models:
  - RGB model
  - CMY or CMYK model
  - HSI model
  - YIQ and YUV models
  - Many other color models, Lab, HSV, HSB, …

Color Models

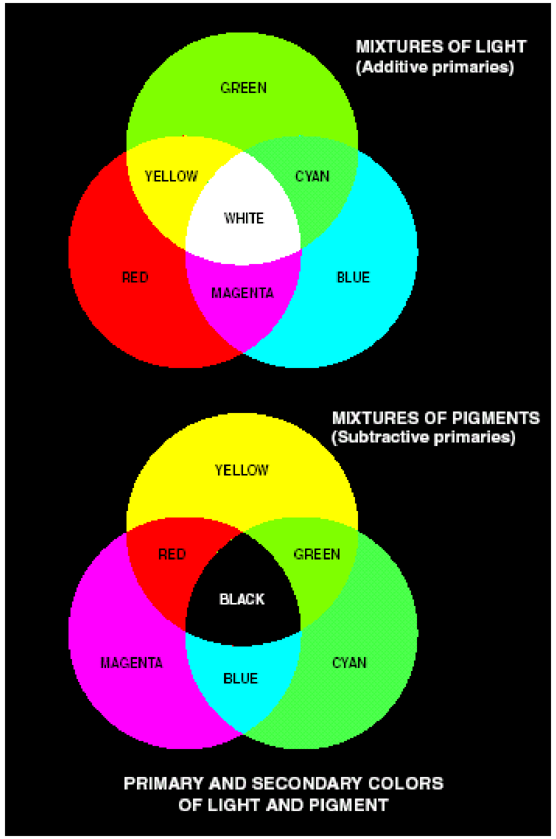
- Assumption is that all color values are normalized to the range of [0, 1].



Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).



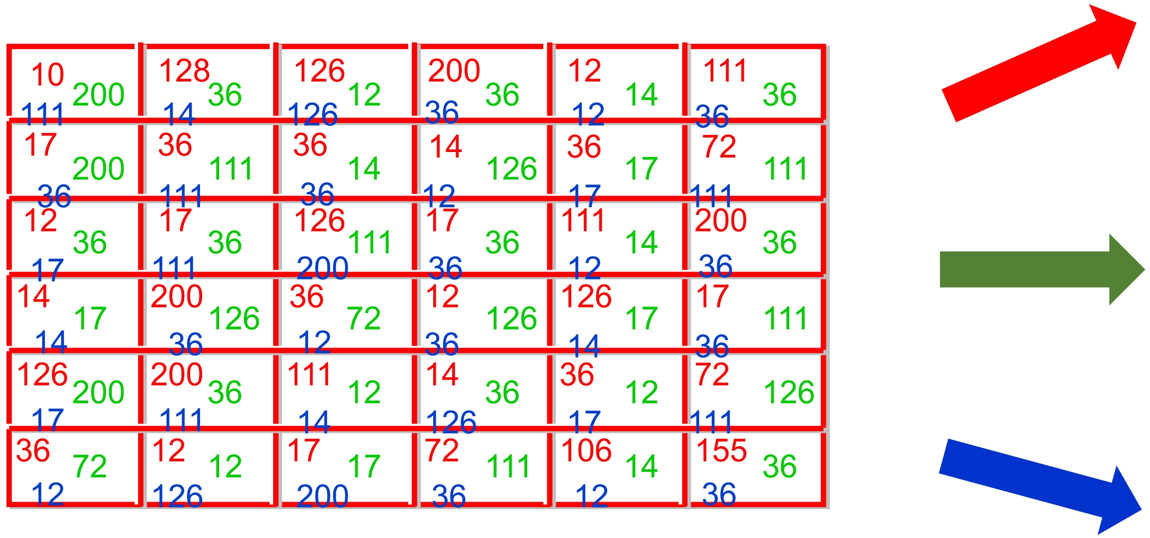
A 24-bit RGB color cube



RGB Image

- Images represented in RGB color model consist of three component images, one for each primary color.
- When being fed into RGB monitor, these three images combine to produce a composite color image.
- Pixel depth: the number of bits used to represent each pixel in RGB space.
- Consider each R, G and B components with 8-bits pixel depth. Then the color image is full color with 24 bits, representing $(2^8)^3$=16772216 number of colors.

RGB Image

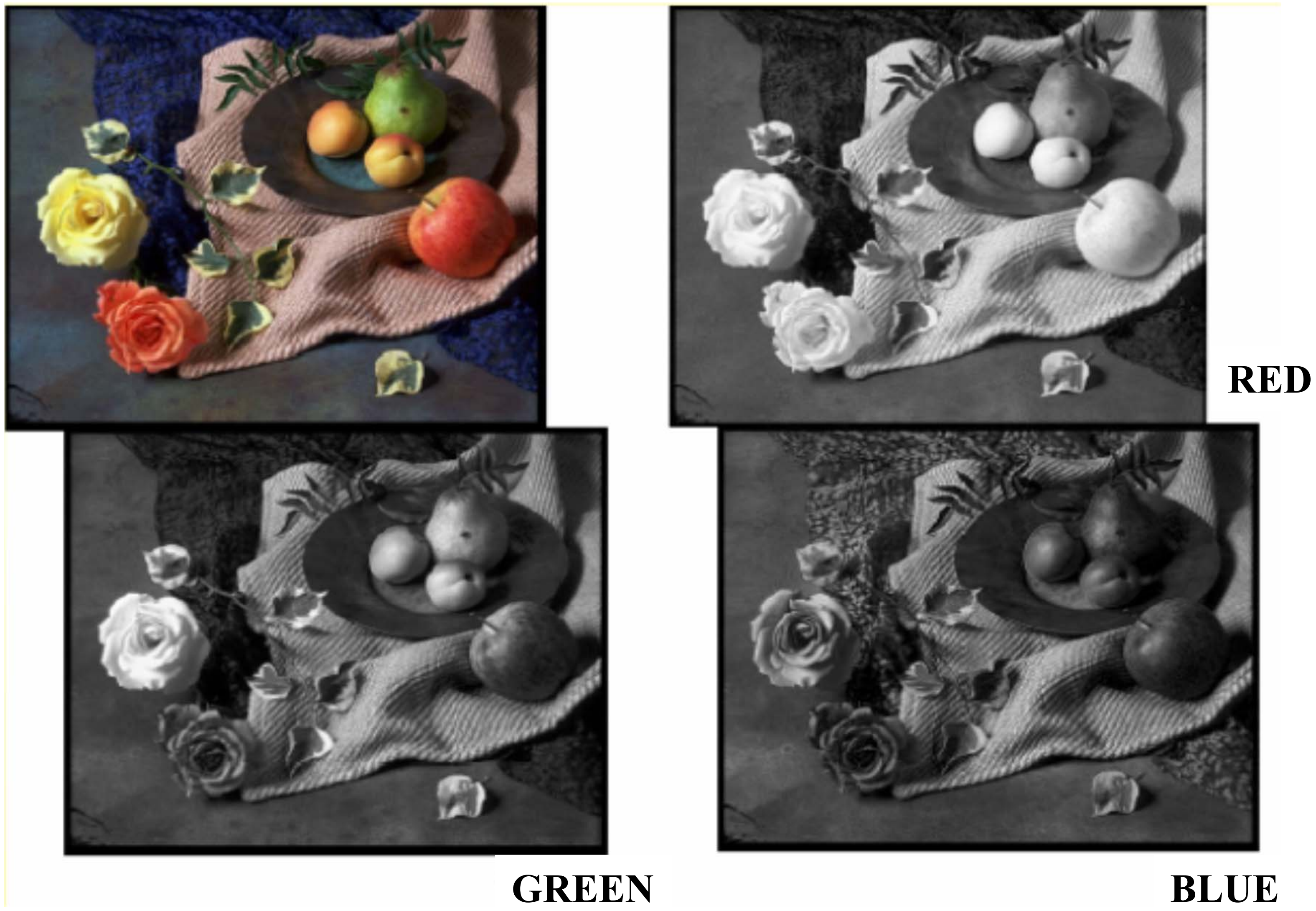


10	128	126	200	12	111
17	36	36	14	36	72
12	17	126	17	111	200
14	200	36	12	126	17
126	200	111	14	36	72
36	12	17	72	106	155

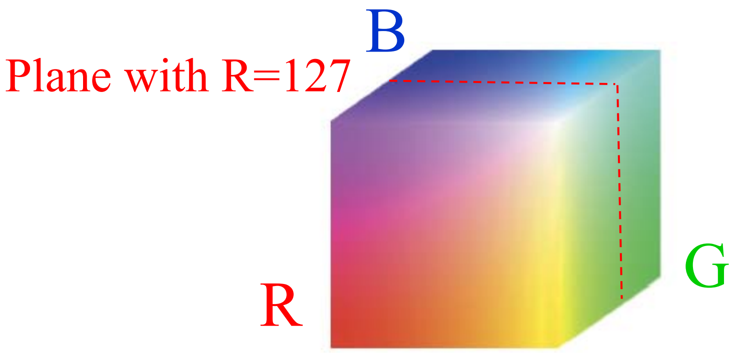
200	36	12	36	14	36
200	111	14	126	17	111
36	36	111	36	14	36
17	126	72	126	17	111
200	36	12	36	12	126
72	12	17	111	14	36

111	14	126	36	12	36
36	111	36	12	17	111
17	111	200	36	12	36
14	36	12	36	14	36
17	111	14	126	17	111
12	126	200	36	12	36

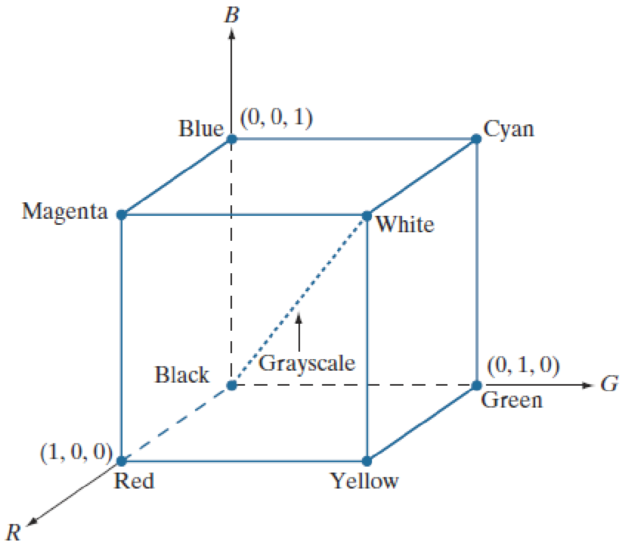
RGB Image

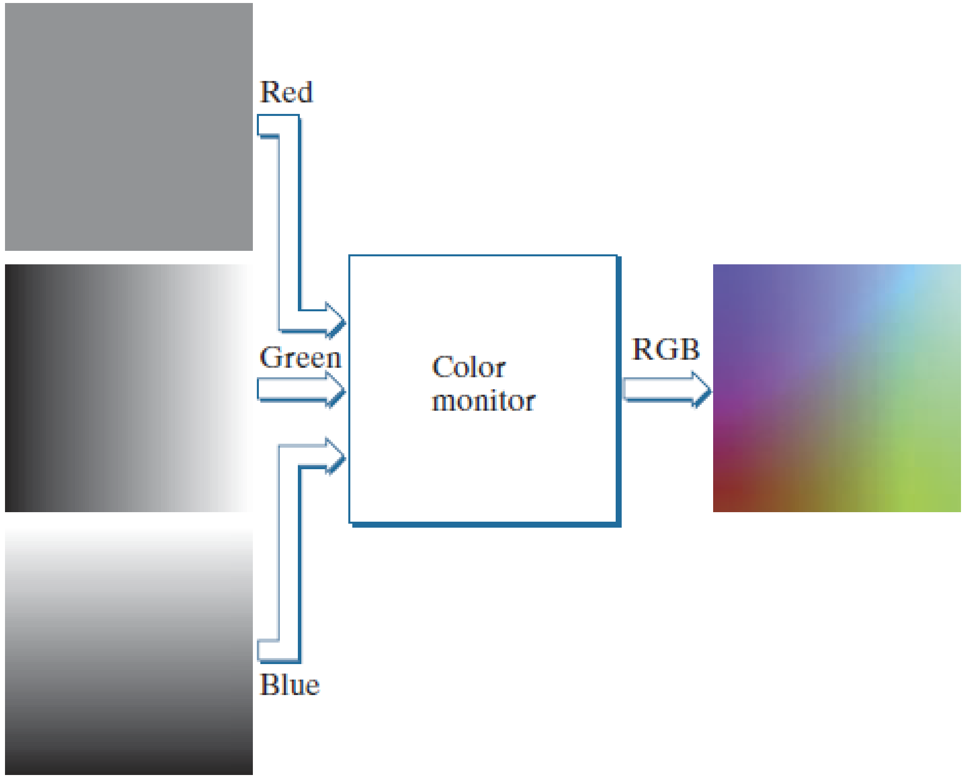


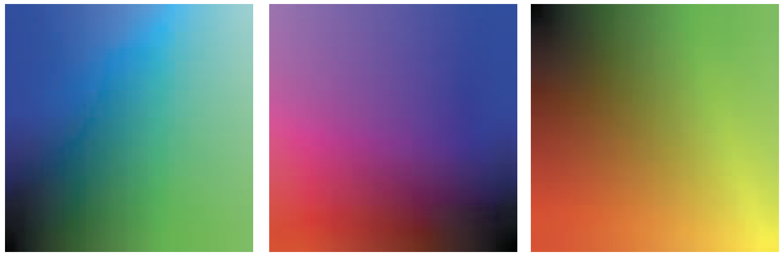
Color Models



A 24-bit RGB color cube

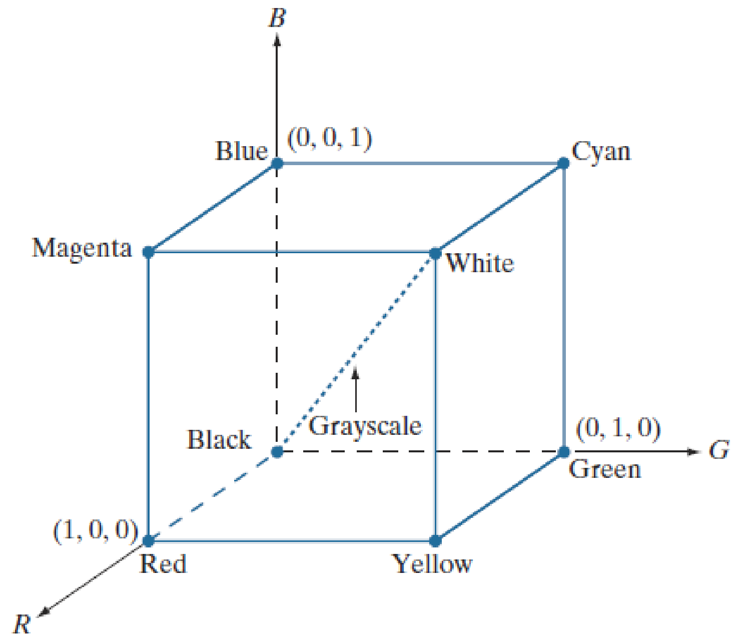






$(R = 0)$ $(G = 0)$ $(B = 0)$

Color Models

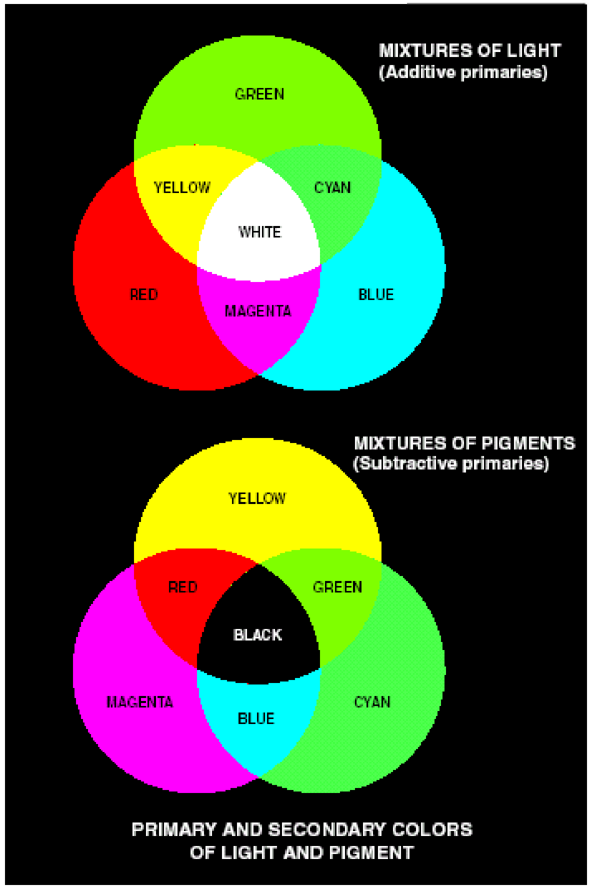


	Nominal Range	White	Yellow	Cyan	Green	Magenta	Red	Blue	Black
R	0 to 255	255	255	0	0	255	255	0	0
G	0 to 255	255	255	255	255	0	0	0	0
B	0 to 255	255	0	255	0	255	0	255	0

Color Models

- CMY and CMYK color models——For printers
  - Cyan, magenta, and yellow are the secondary colors of light, or the primary colors of pigments.
  - Assumpting all color values have been normalized to the range [0, 1].

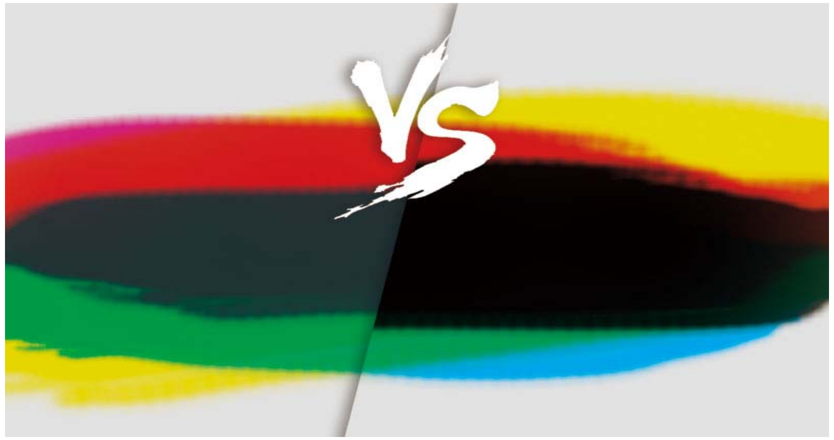
$$\begin{pmatrix} C \\ M \\ Y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} R \\ G \\ B \end{pmatrix} \qquad \begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} C \\ M \\ Y \end{pmatrix}$$



- For example, when a surface coated with cyan pigment is illuminated with white light, no red light is reflected from the surface. That is cyan subtracts red light from reflected white light. ($C = 1 - R$)

Color Models

- CMYK color models
  - K is true black.
  - Equal amounts of pigment primaries should produce black.
  - In practice, combining these colors for printing produces a muddy looking black.
  - So a fourth color K is added to produce true black.
  - It is the so-called four-color printer.



Color Models

- The conversion from CMY to CMYK begins by letting:

$$K = \min(C, M, Y)$$

- If K=1, then we have pure black, with no color contributions, from which it follows that: $C = 0, M = 0, Y = 0$

Otherwise:

$$C = (C - K)/(1 - K)$$

$$M = (M - K)/(1 - K)$$

$$Y = (Y - K)/(1 - K)$$

C, M, and Y on the right side are in the CMY color system; C, M, and Y on the left are in the CMYK system.

Color Models

- The conversions from CMYK back to CMY are:

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

C, *M*, and *Y* on the right side are in the CMYK color system; *C*, *M*, and *Y* on the left are in the CMY system.

- Because we can convert both ways between CMY and RGB, we can use those equations as a “bridge” to convert between RGB and CMYK, and vice versa.

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

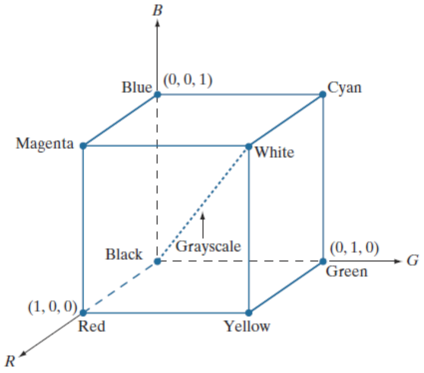
Color Models

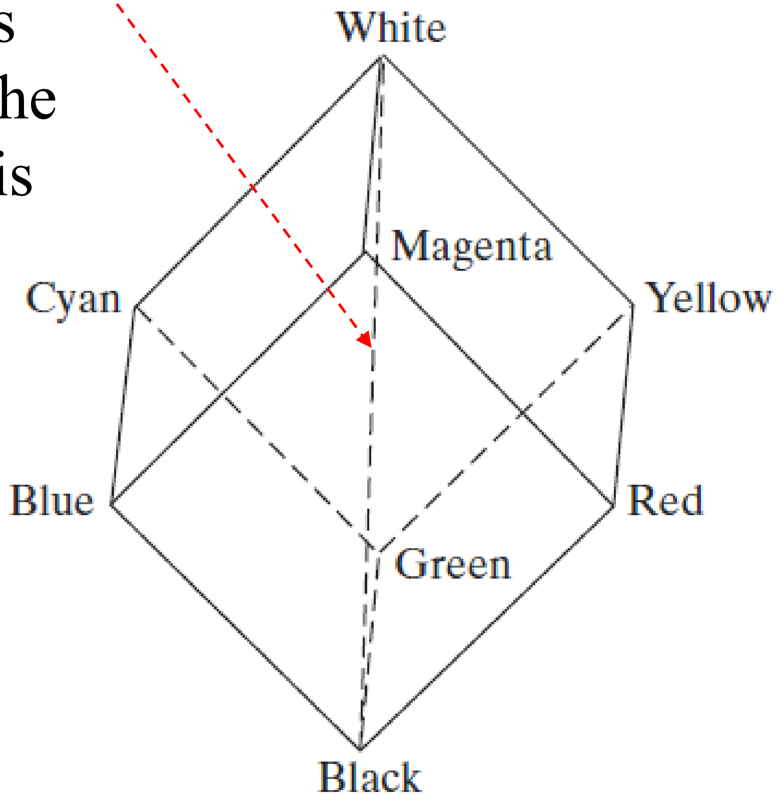
- Changing from RGB to CMY color model is very easy. And these systems are ideally suited for hardware implementations.
- However, RGB and CMY are not well suited for describing colors for human interpretation.
- When humans view a color object, we describe it by its hue, saturation, and brightness/intensity.
- So, HSI model is introduced.

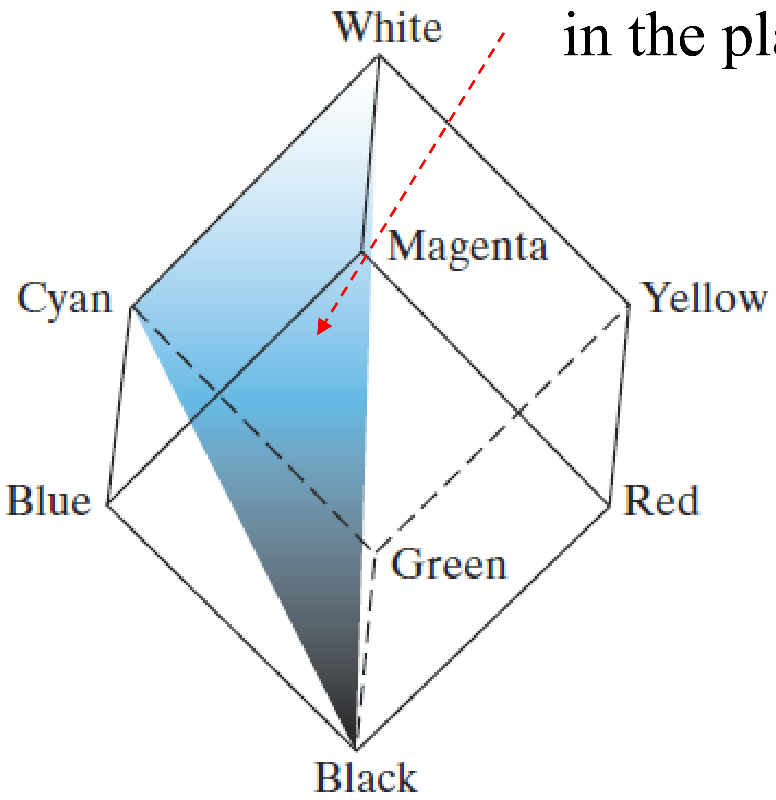
Color Models

Intensity axis: Saturation is zero along the intensity axis

Hue is the same in the plane





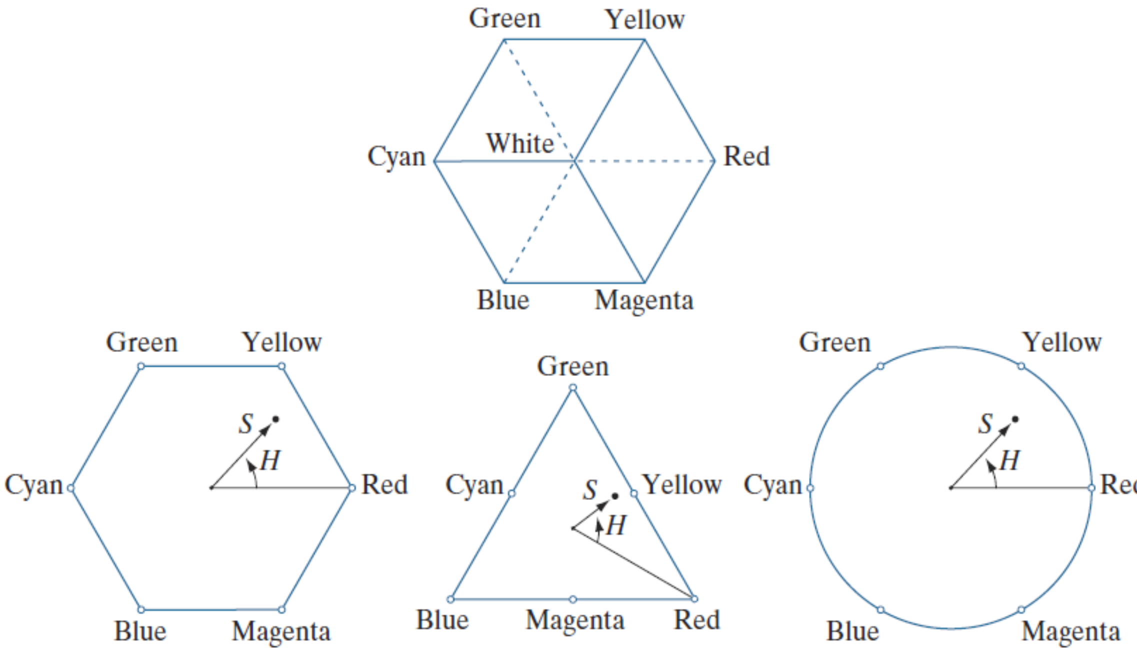


Conceptual relationships between the RGB and HSI color models.

Color Models

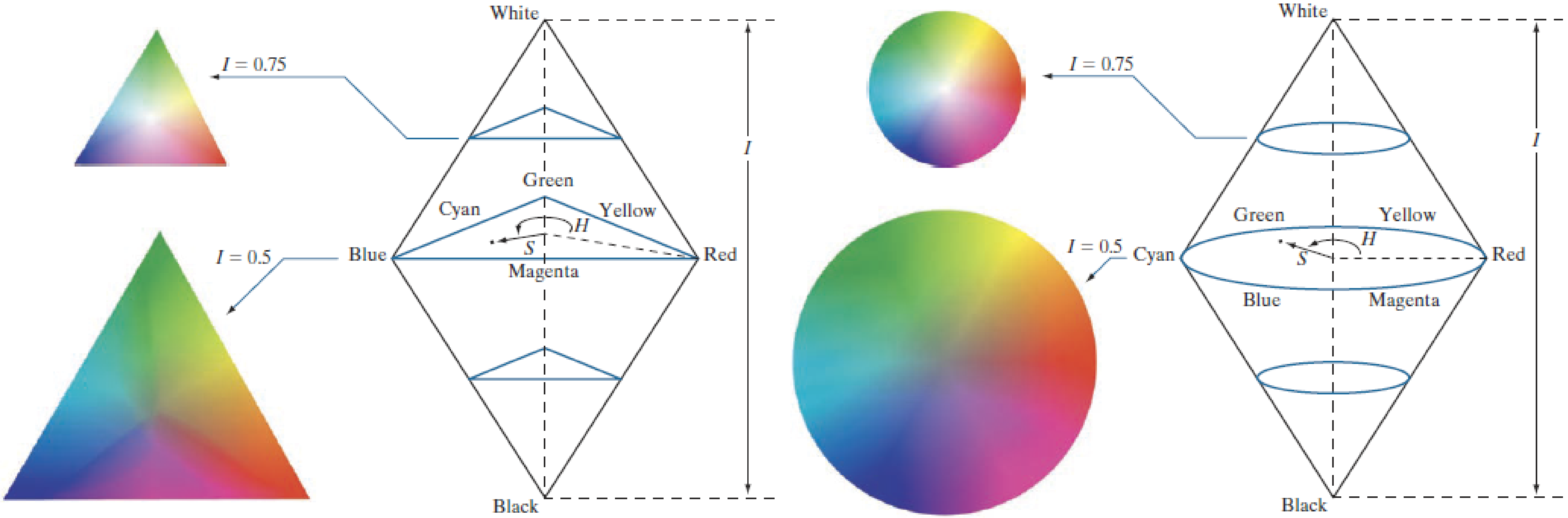
- HSI can be obtained from the RGB color cube.

- HSI space
  - a vertical intensity axis,
  - the locus of color points that lie on planes perpendicular to this axis,
  - its boundary is either a triangular or hexagonal shape.



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.

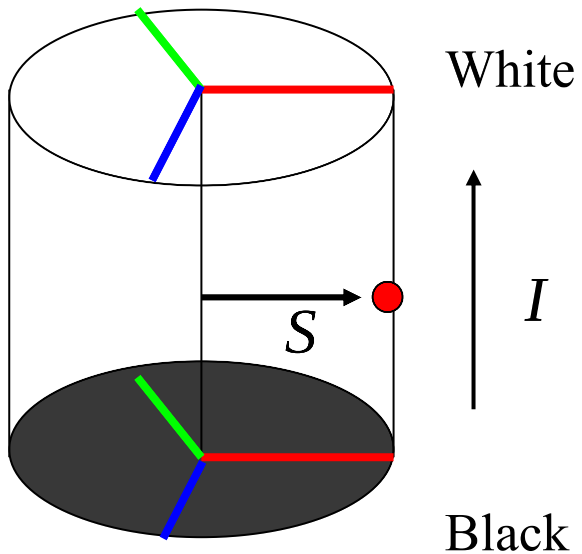
Color Models



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

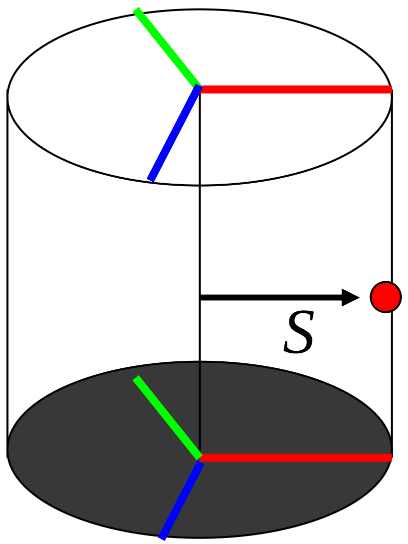
Color Models

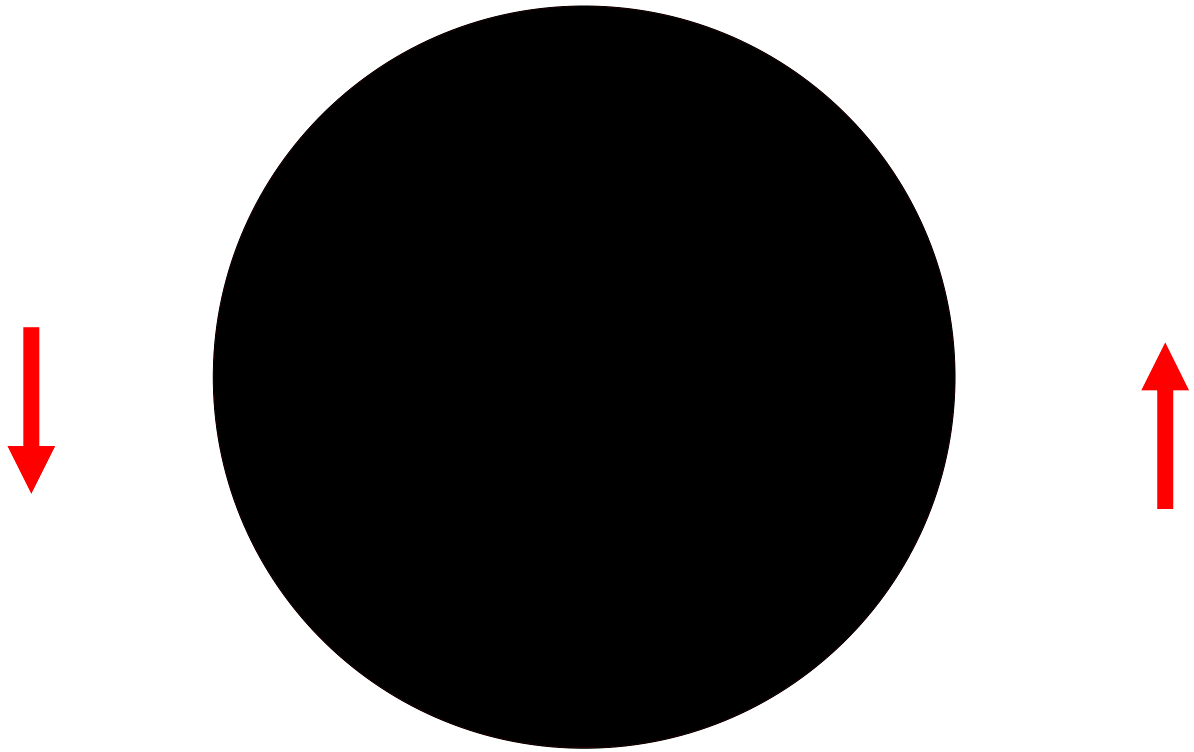
- The shape of color space has not effect to HSI model.



- Imagine the red point:
  - moves up or down (change of *I*)
  - rotates in clockwise or counter-clockwise (change of *H*)
  - moves to the center (change of *S*)

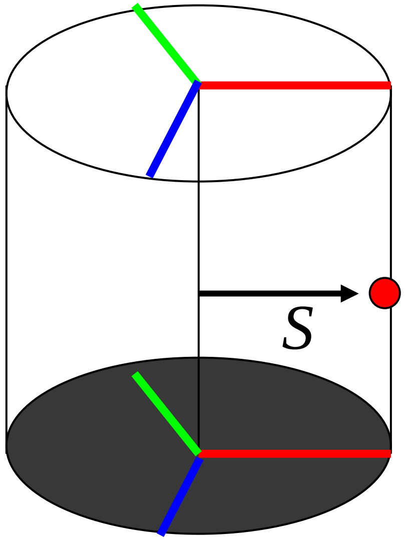
Color Models

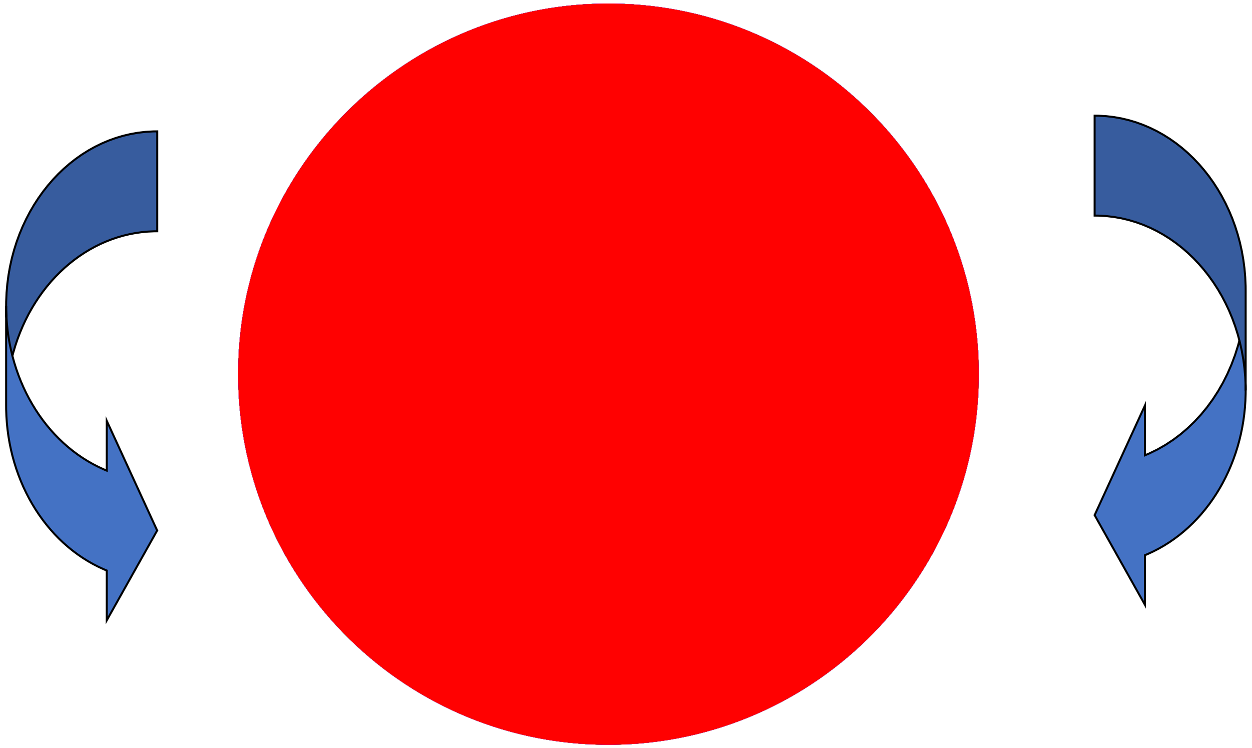




moves up or down

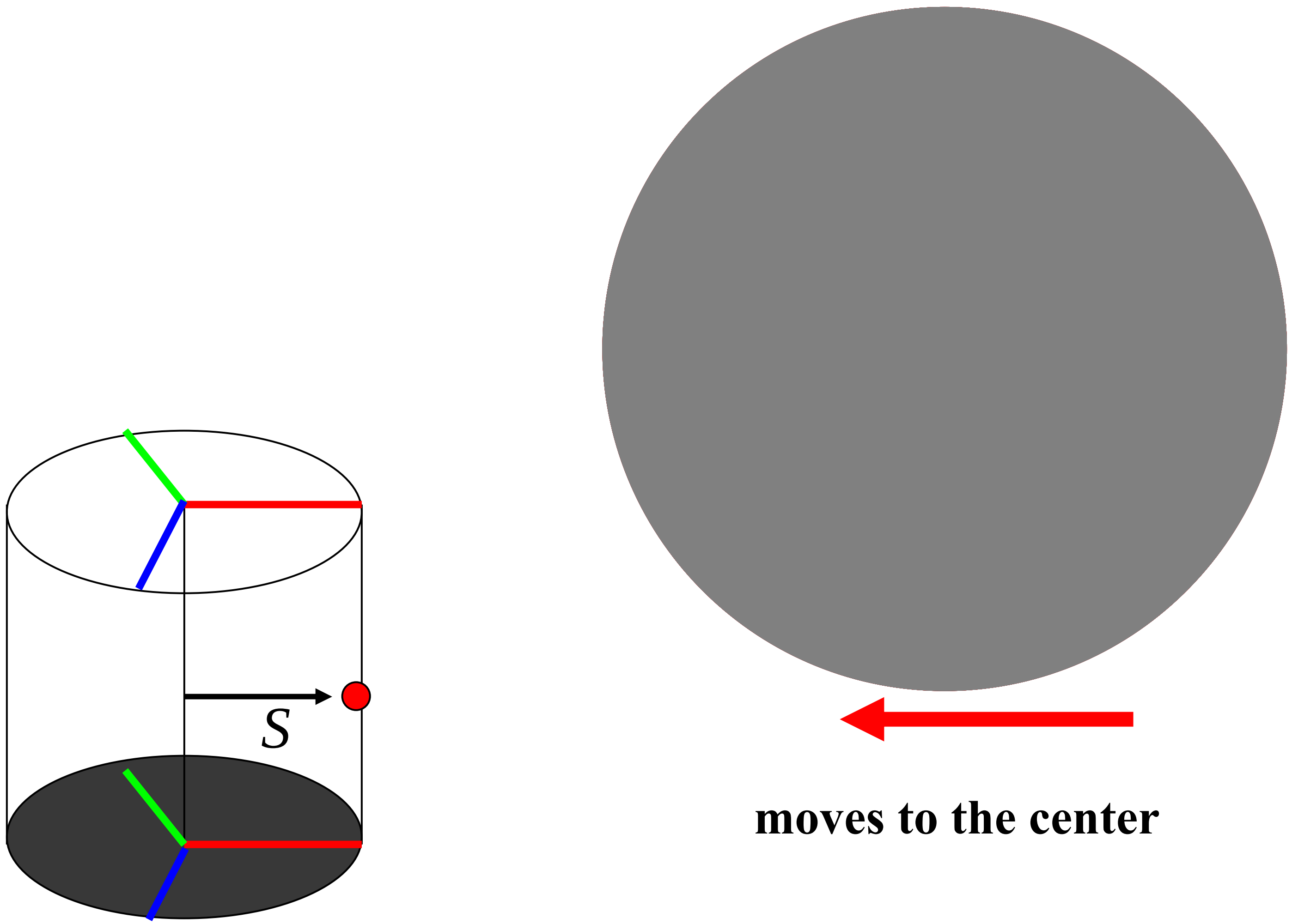
Color Models





rotates in clockwise or counter-clockwise

Color Models



moves to the center

Color Models

- Converting colors from RGB to HSI (R,G,B are normalized)

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

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

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

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

Color Models

- Converting colors from HSI to RGB

$$H = H \times 360^\circ$$

RG sector $(0^\circ \le H < 120^\circ)$

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

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

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

GB sector $(120^\circ \le H < 240^\circ)$

$$H = H - 120^\circ$$

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

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

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

BR sector $(240^\circ \le H < 360^\circ)$

$$H = H - 240^\circ$$

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

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

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

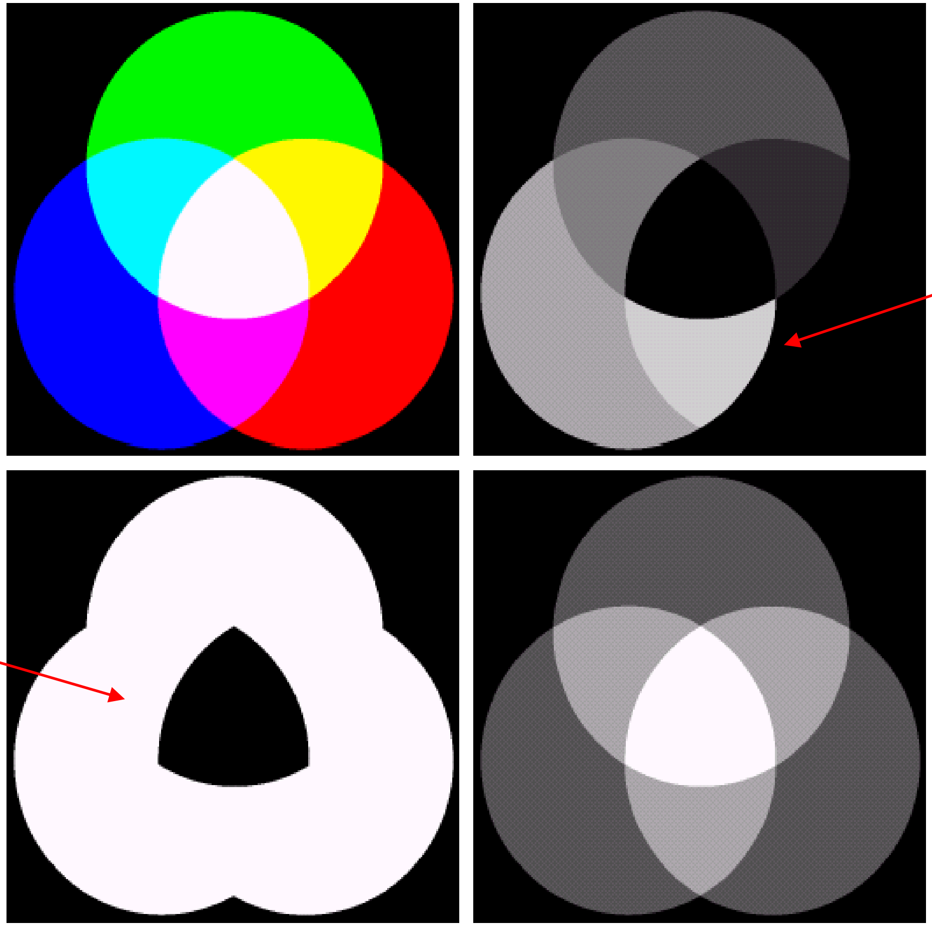
Color Models

RGB

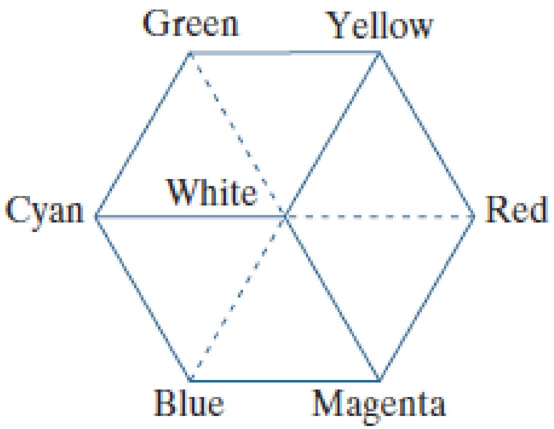
Hue

Saturation

Intensity



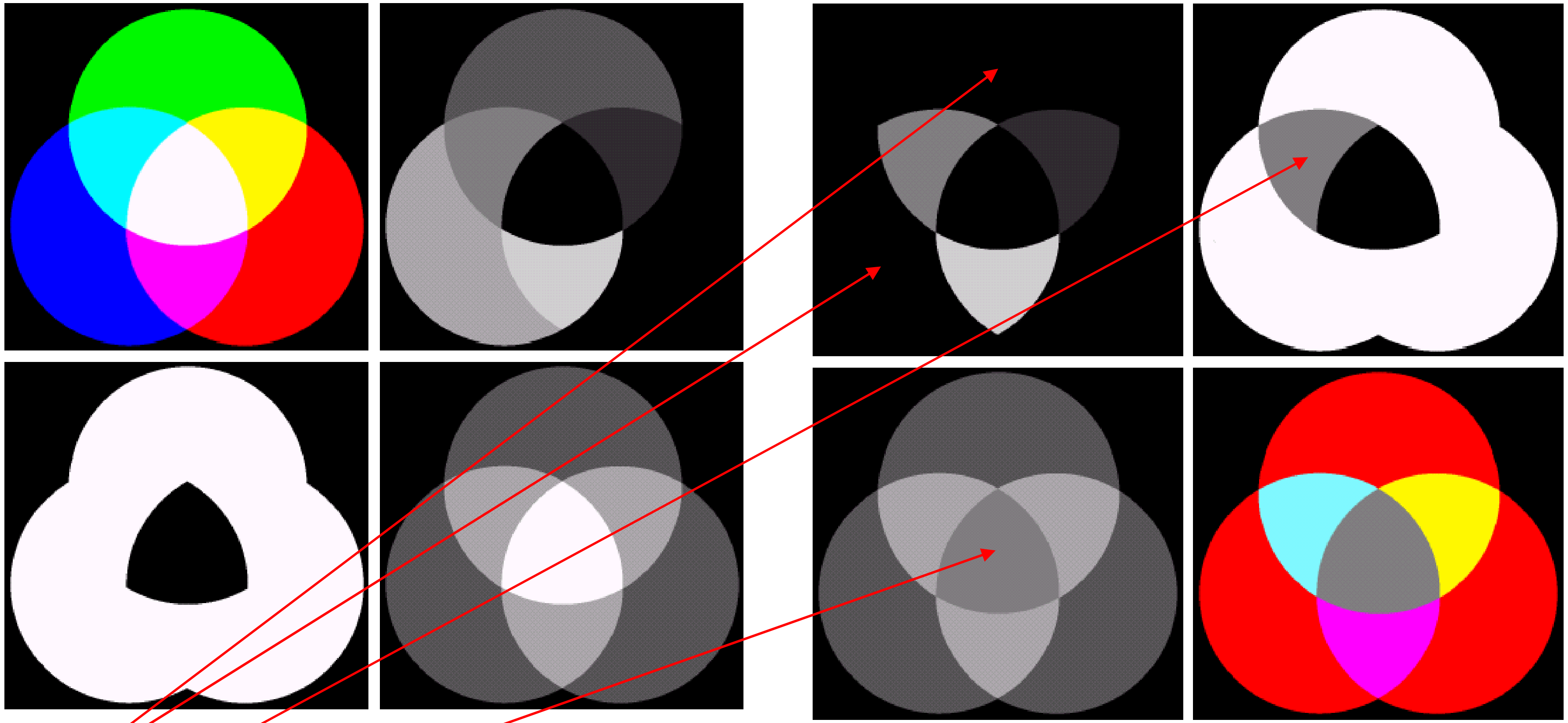
Value of hue corresponds to angles with RED. Then Red area is 0 in Hue component.



The saturation of primary Red, Green, Blue are 1. Then these three areas are white.

Color Models

Modified HSI component images



Resulting RGB image

a. Obtained by changing the pixels corresponding to blue and green regions to 0.
b. Reduced by half the saturation of the cyan region in component S.
c. Reduced by half the intensity of the central white region in the intensity image.

YIQ and YUV Color Model

- **YIQ** is the color model used for color TV in America (NTSC) .

  Y is luminance, **I** & **Q** are color (I=red/green, Q=blue/yellow).
- **YUV** is the color model used for color TV in China (PAL), and in video.

  Y is luminance, U and V are blue and red as in YIQ.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.30 & 0.59 & 0.11 \\ 0.60 & -0.28 & -0.32 \\ 0.21 & -0.52 & 0.31 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

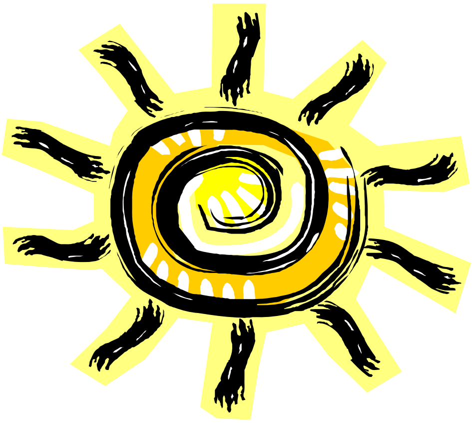
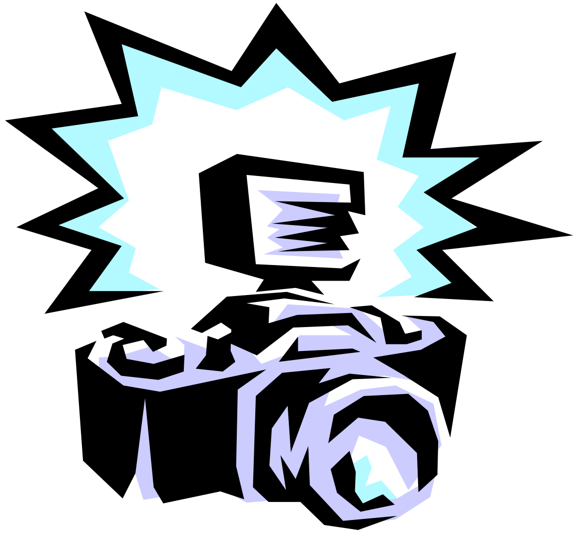
$$Y = 0.299\ R + 0.587\ G + 0.114\ B$$

$$U = 0.492(\ B - Y\ )$$

$$V = 0.877(\ R - Y\ )$$

Problem in Color Image

- When processing colour images, the following problems have to be dealt with:
  - ➢The images are vectorial → 3 or 4 numbers are associated with each pixel.
  - ➢The colours recorded by a camera are heavily dependent on the lighting conditions.

Problem in Color Image

- The lighting conditions of the scene have a large effect on the colours recorded.

Image taken lit by a flash.

Image taken lit by a tungsten lamp.

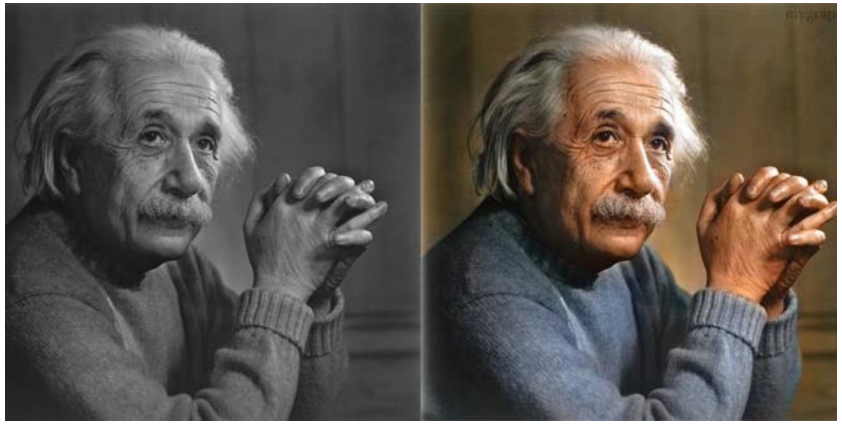
Problem in Color Image

- Knowing just the RGB values is not enough to know everything about the image.
- The R, G and B primaries used by different devices are usually different.
- For scientific work, the camera and lighting should be calibrated.

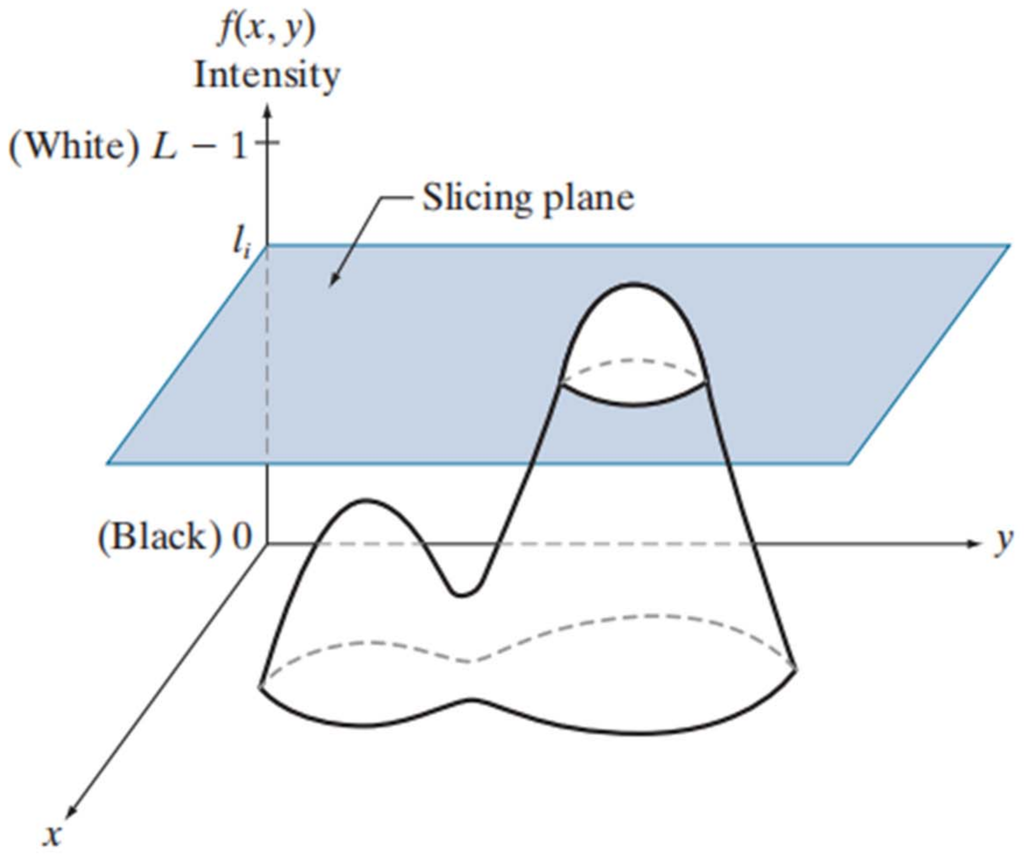
Pseudo Color Processing

- The principle of pseudo color is for human visualization and interpretation of gray scale events in an image.

- Pseudo color processing
  - Intensity slicing
  - Gray level to color transform



Intensity Slicing

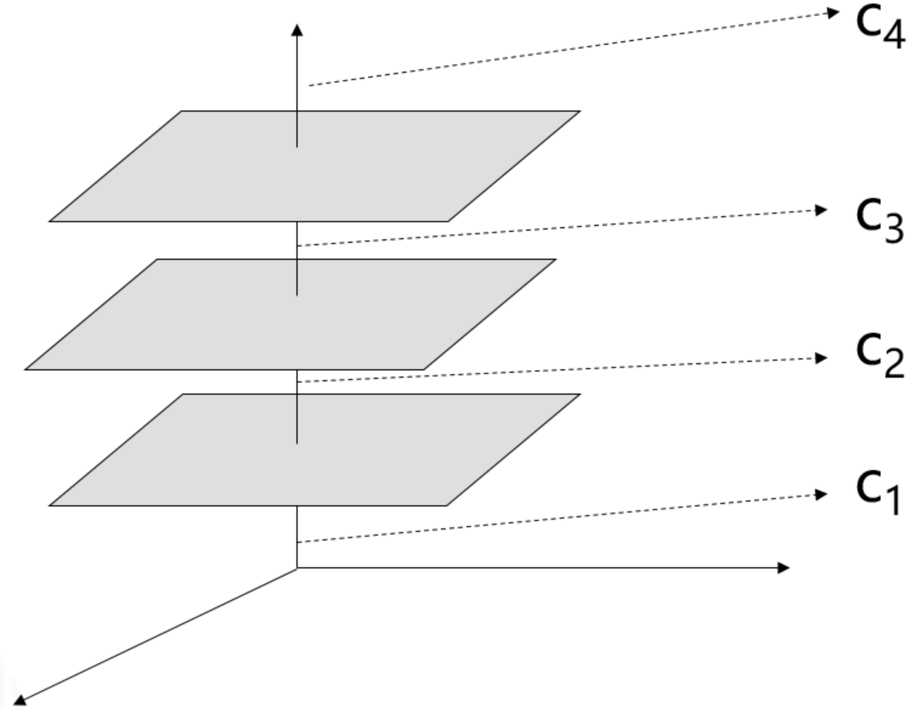


$$\text{if } f(x,y) \in I_k, \text{ let } f(x,y) = c_k$$

Any pixel whose gray level is above the plane will be coded with one color, and pixel below the plane will be coded with another color.

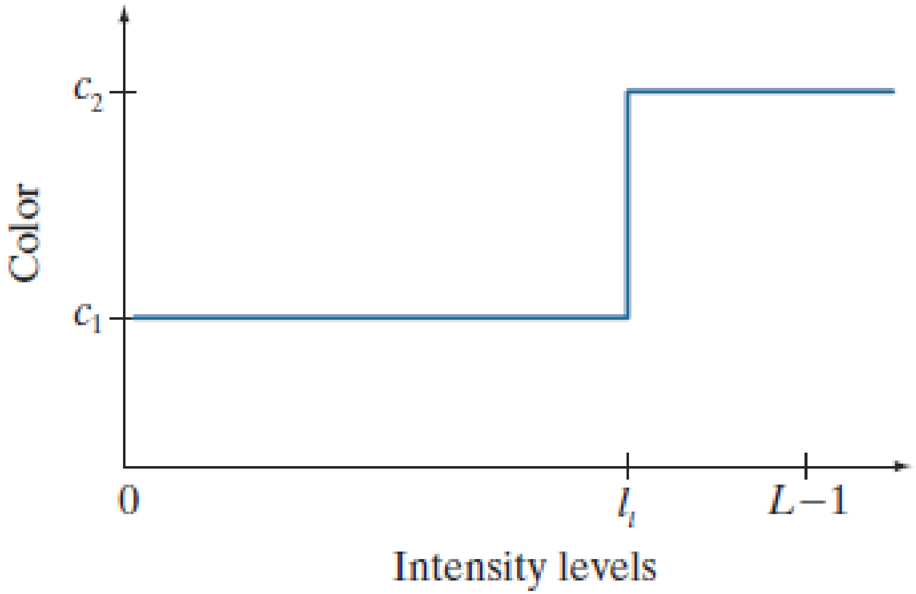
Intensity Slicing

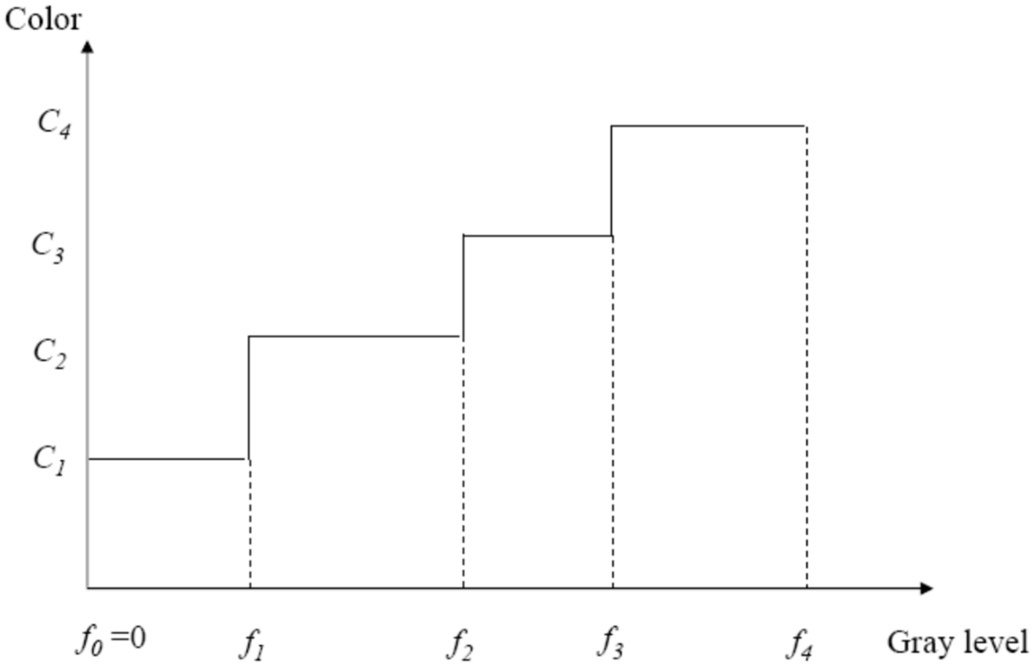
- Let $[0, L-1]$ represent the gray scale, let level l_0 represent black $[f(x,y)=0]$.
- Let level l_{L-1} represent white $[f(x,y)=L-1]$.
- Suppose that P planes perpendicular to the intensity axis are defined at level $l_1, \ldots, l_P$.
- Assuming that $0 < P < L-1$, the P planes partition the gray scale into $P+1$ intervals $V_1, V_2, \ldots, V_{P+1}$.



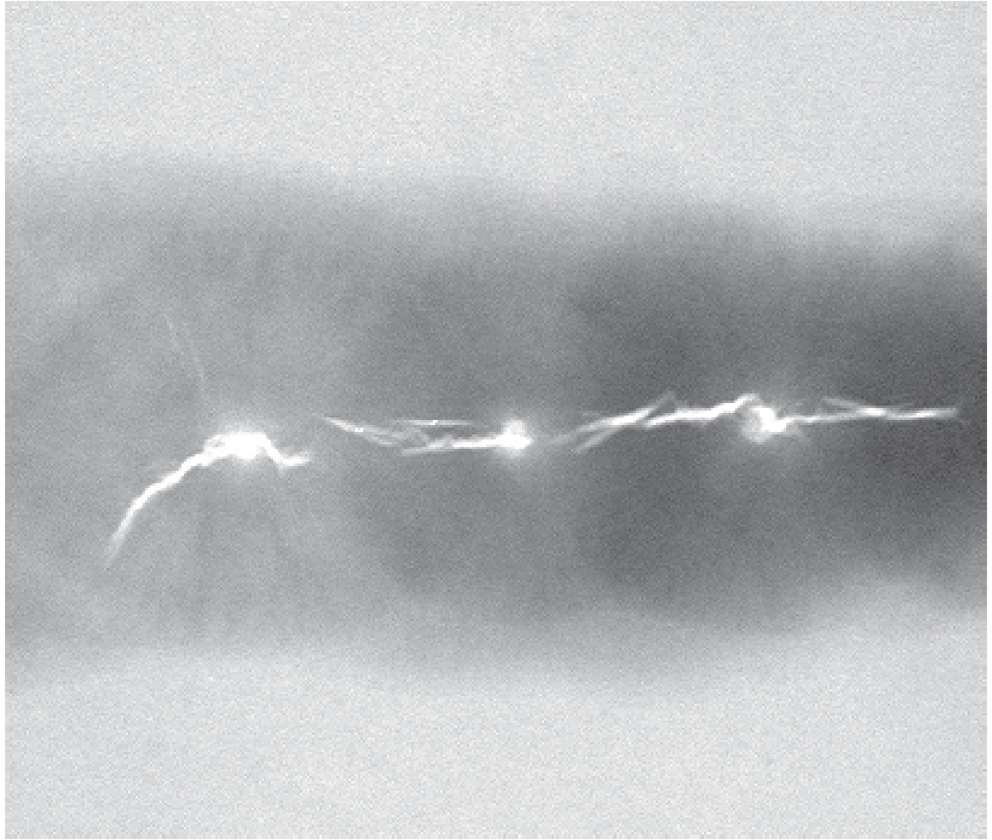
- ❑ Intensity Slicing
- ❑ Color coding

Intensity Slicing

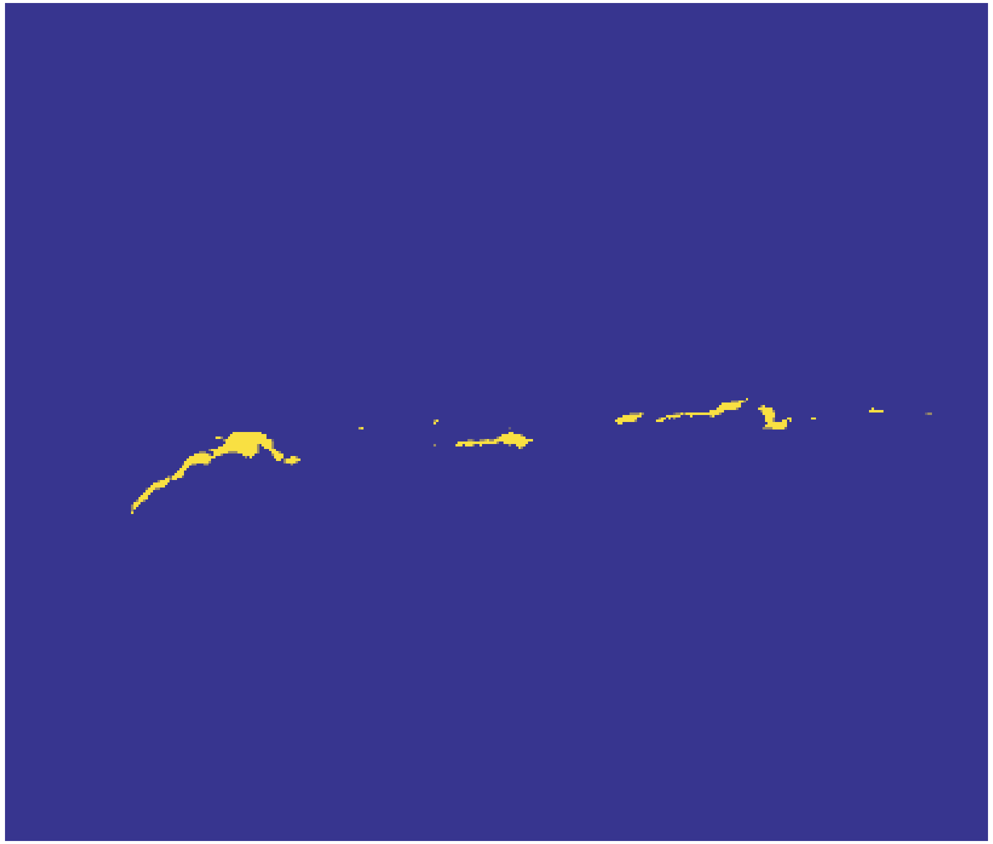




Intensity Slicing

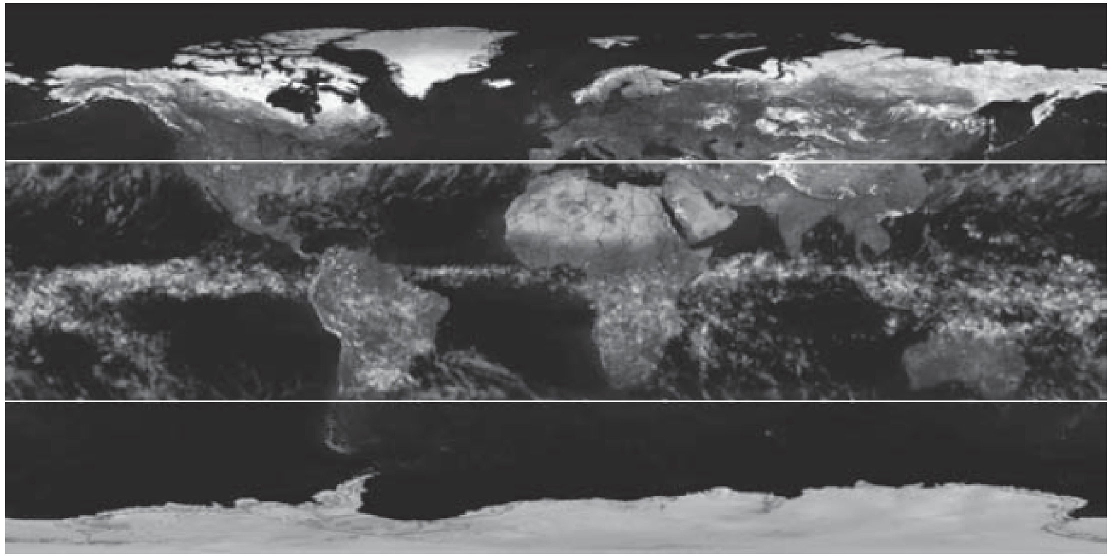


X-ray image of a weld

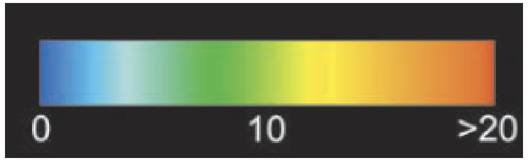


Result of color coding

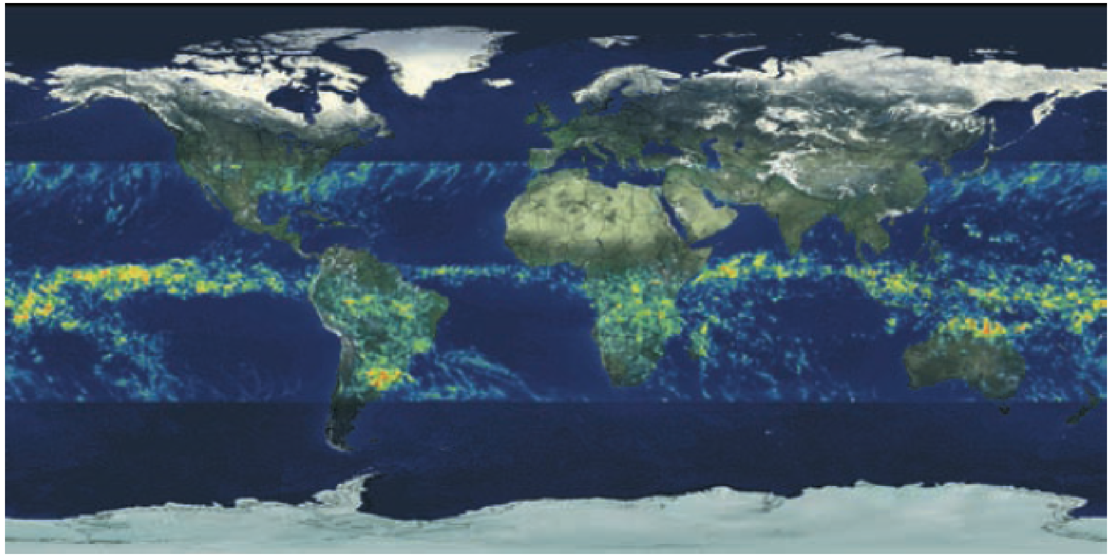
Intensity Slicing

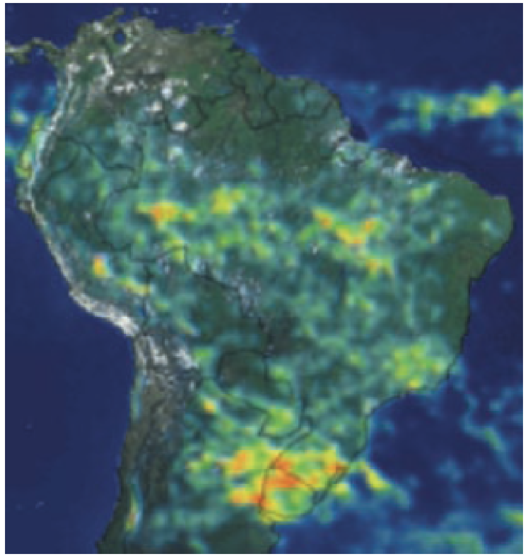


(a) Grayscale image in which intensity (in the horizontal band shown) corresponds to average monthly rainfall.



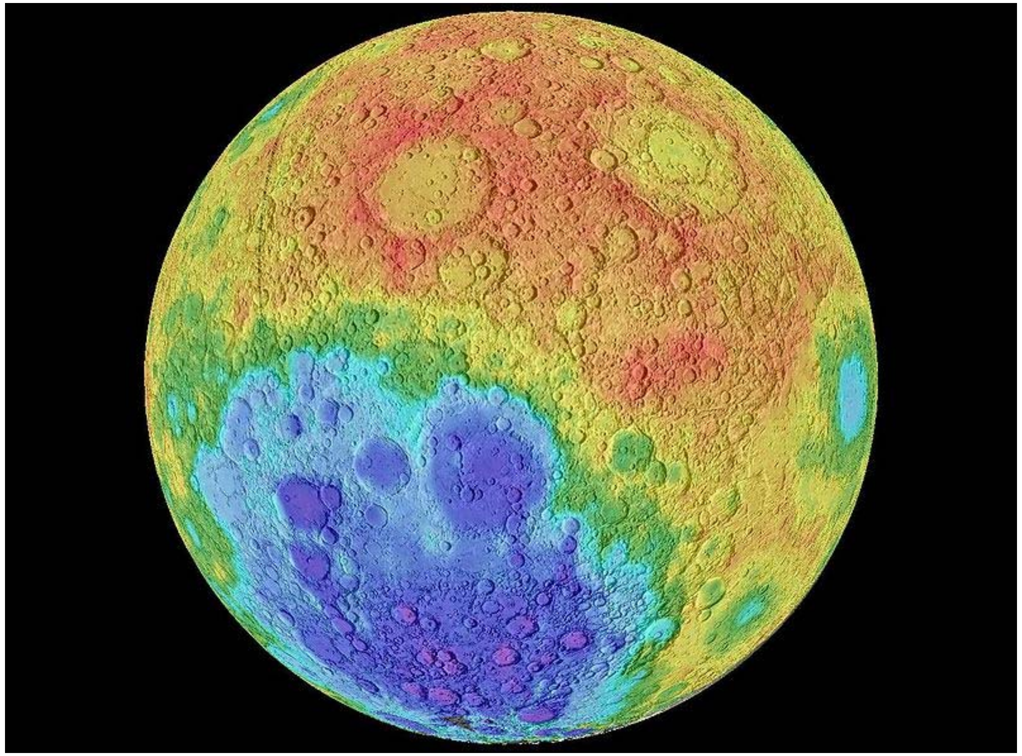
(b) Colors assigned to intensity values.

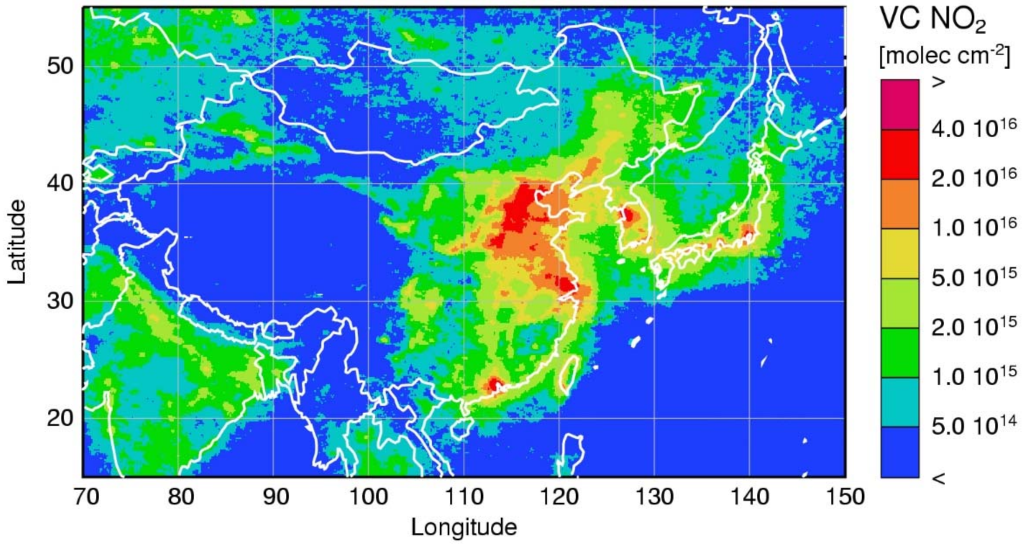


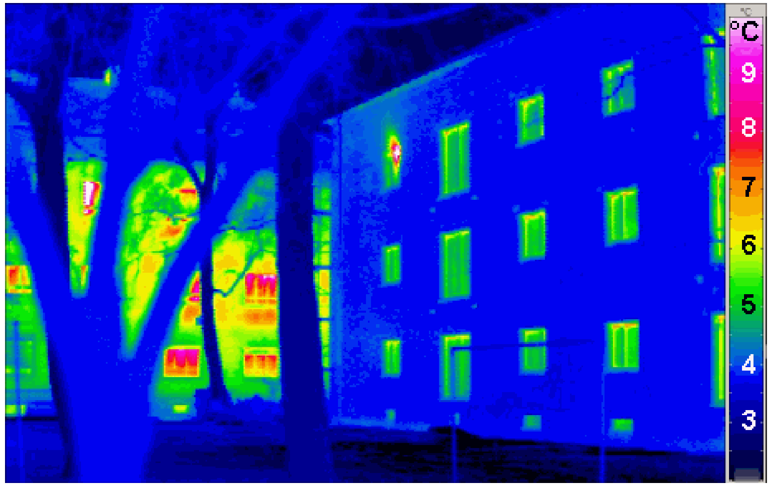


(c) Color-coded image.

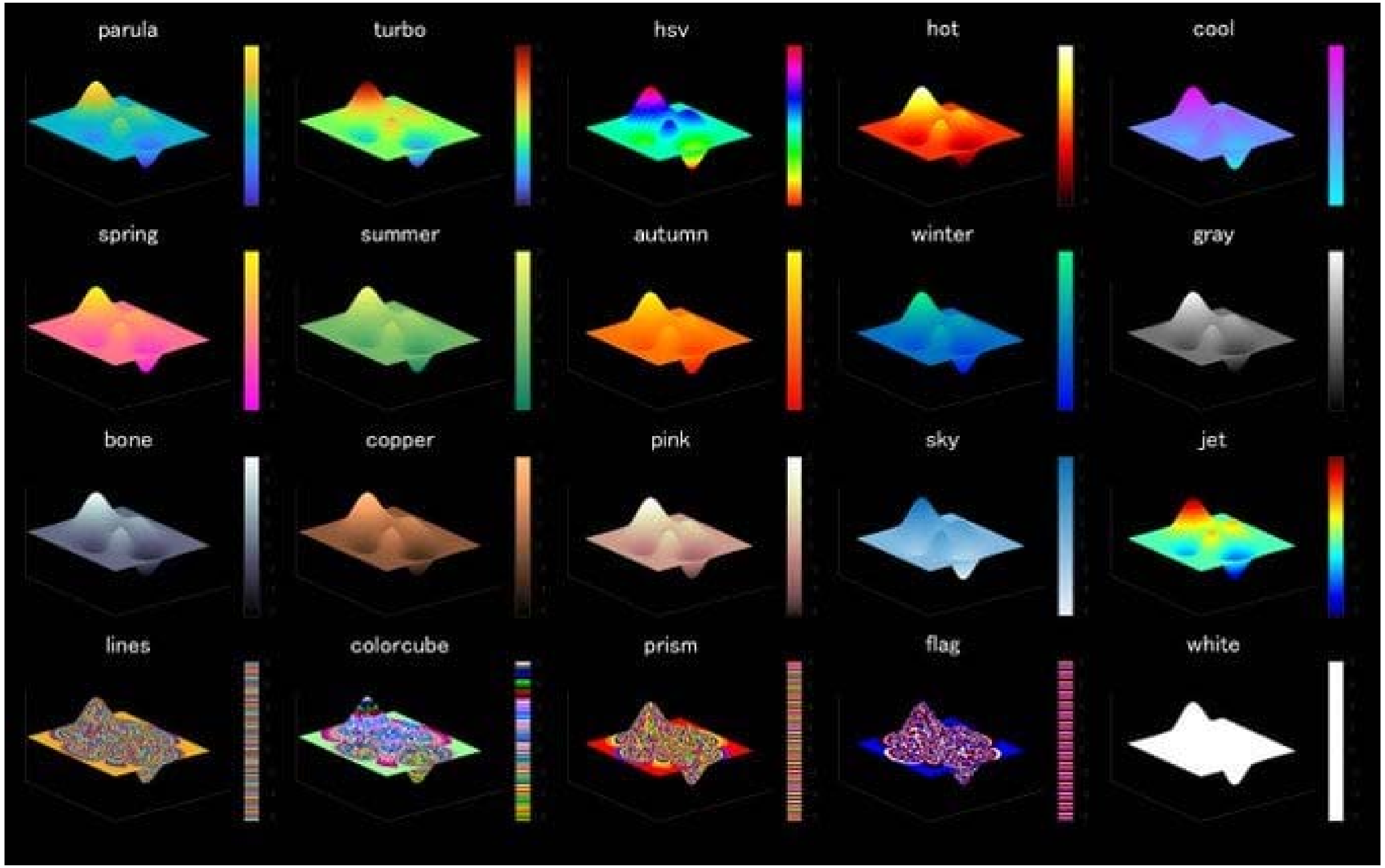
Intensity Slicing







Intensity Slicing

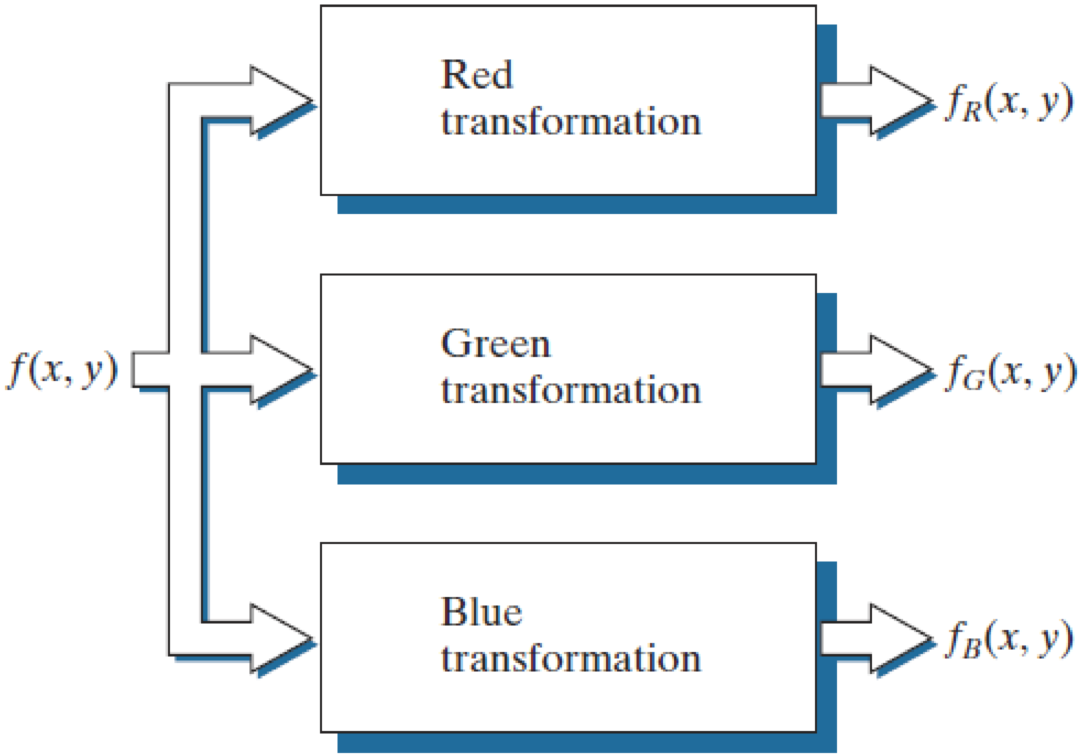


Matlab colormaps and colorbars

Gray Level to Color Transformation

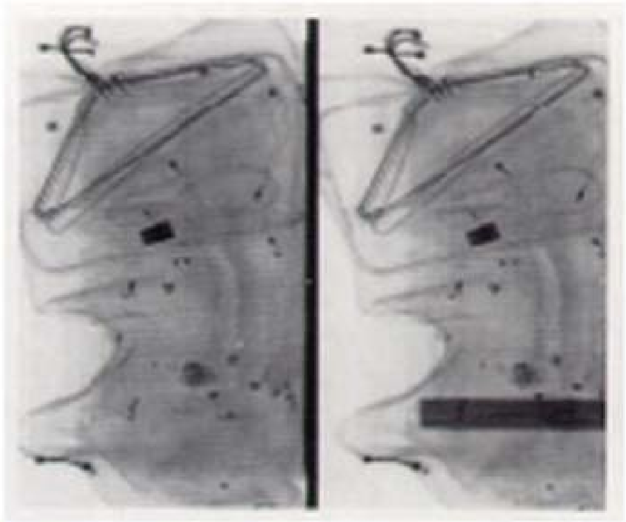
Important

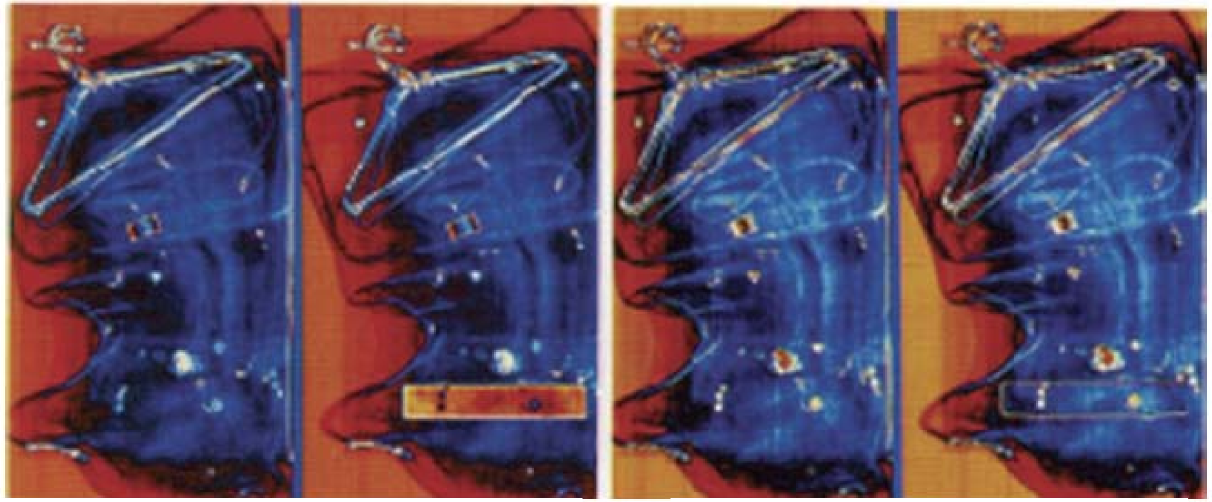
- Functional block diagram for pseudocolor image processing.
- Images f_R, f_G, and f_B are fed into the corresponding red, green, and blue inputs of an RGB color monitor.



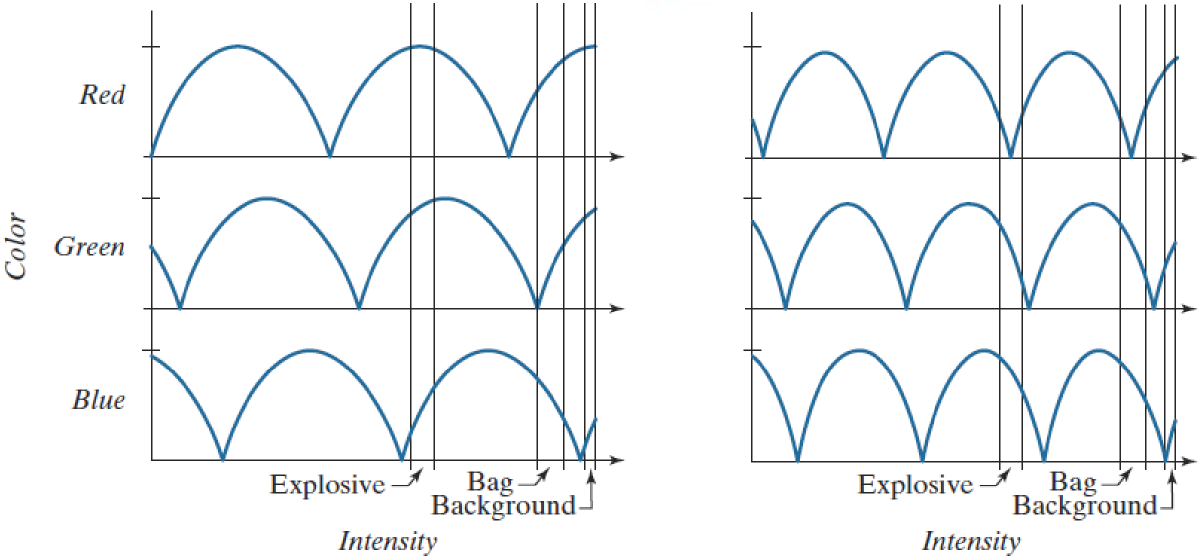
Note: These are transformations on the gray level values of an image and not functions of position.

Gray Level to Color Transformation



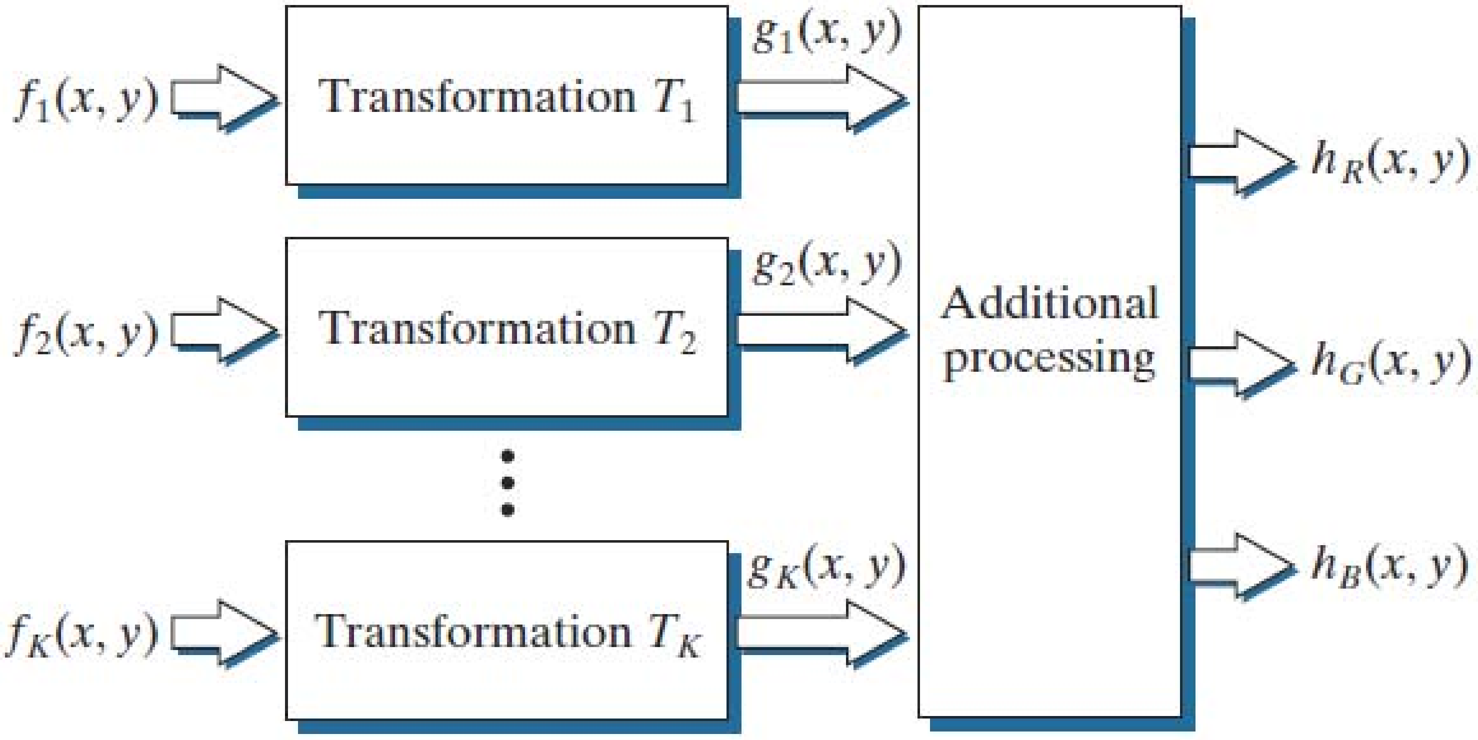


Transformation functions used

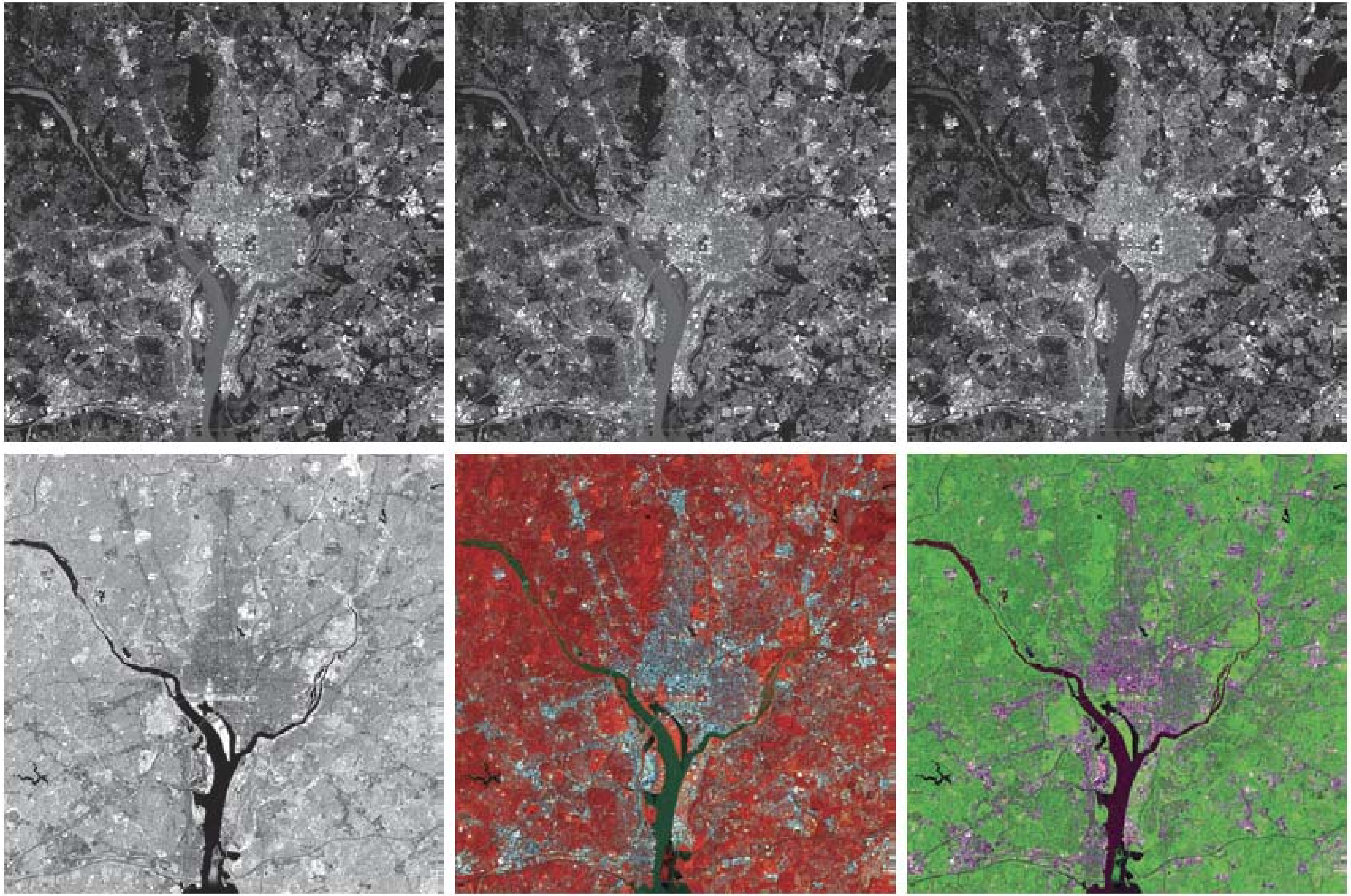


Gray Level to Color Transformation

A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.



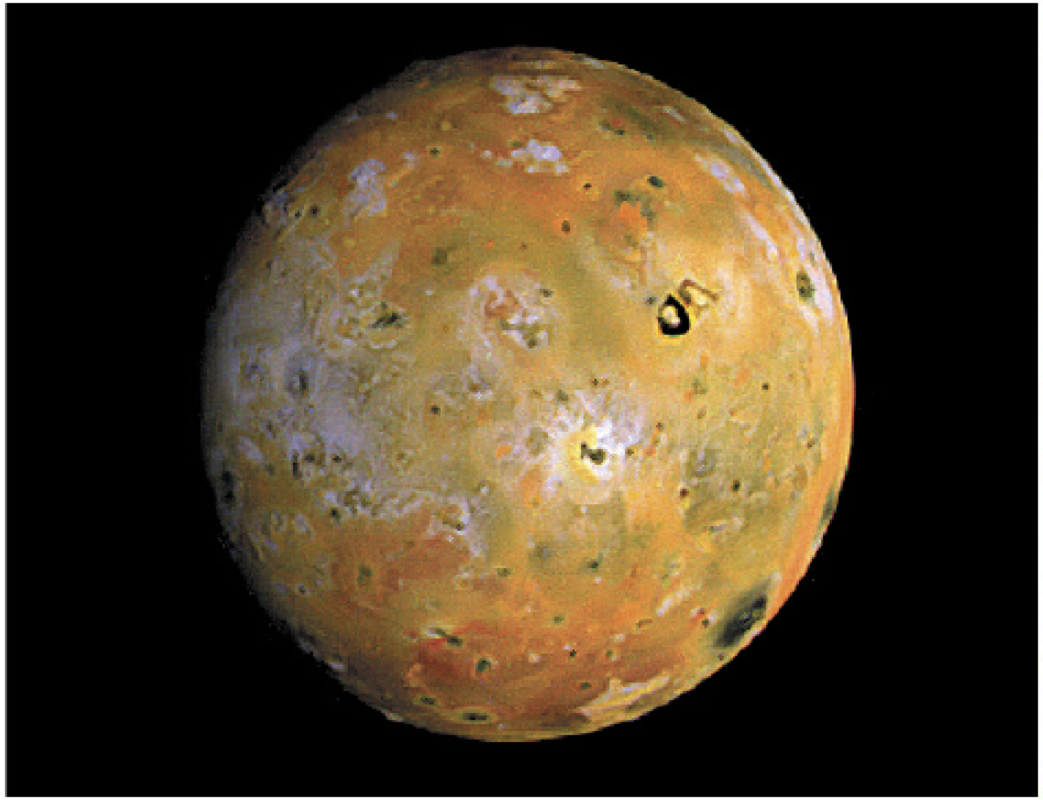
Gray Level to Color Transformation



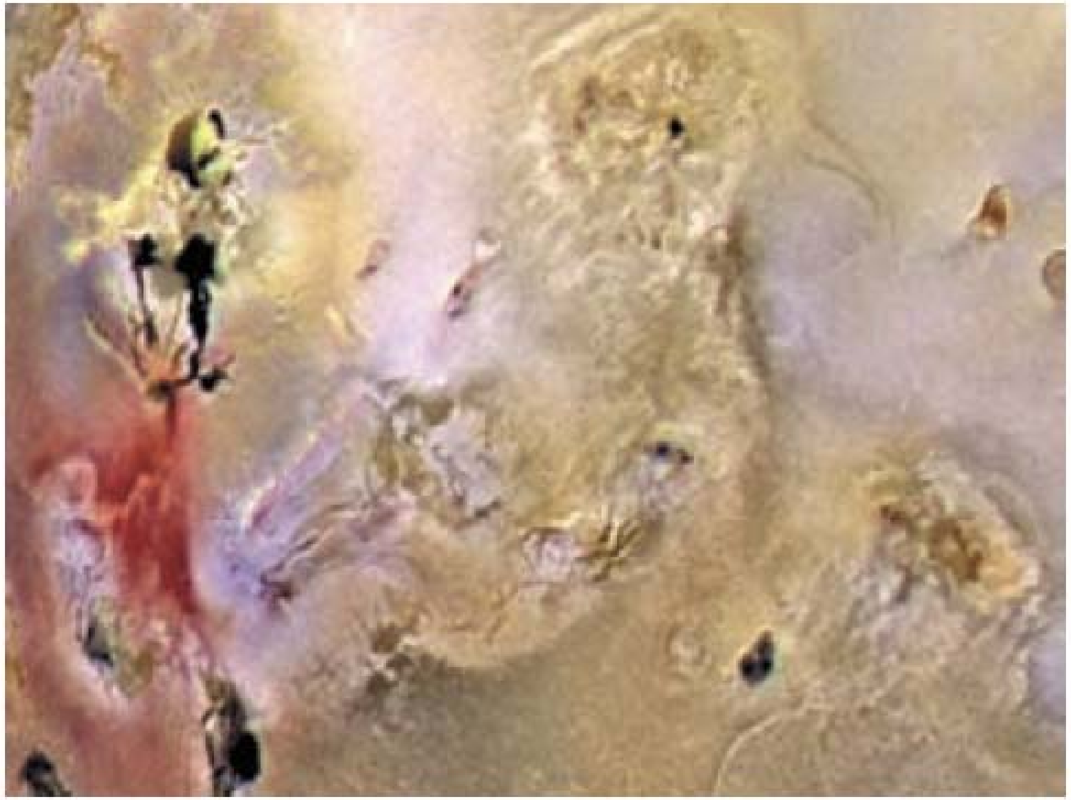
a b c
d e f

(a)–(d) Red (R), green (G), blue (B), and near-infrared (IR) components of a LANDSAT multispectral image of the Washington, D.C. area. (e) RGB color composite image obtained using the IR, G, and B component images. (f) RGB color composite image obtained using the R, IR, and B component images.

Gray Level to Color Transformation

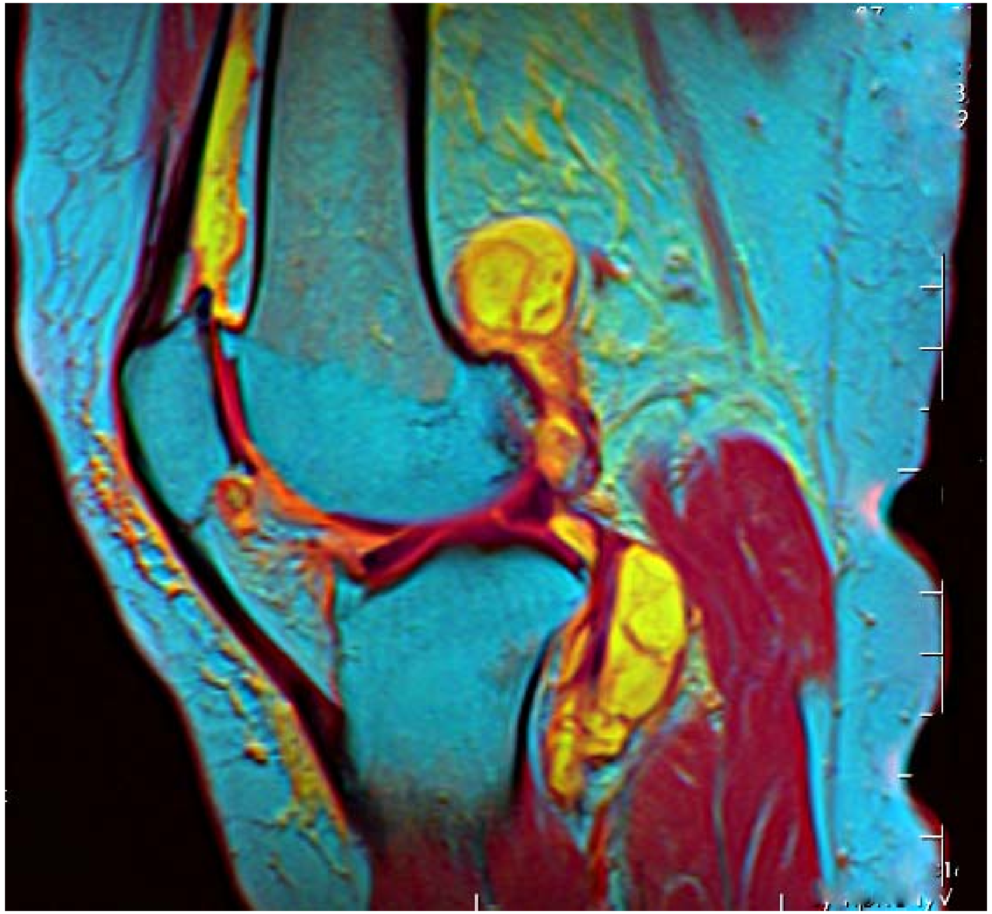


Pseudocolor rendition of Jupiter Moon Io.



A close-up.

Gray Level to Color Transformation



Summary

- In this lecture we have learnt:
  - Color fundamentals
  - Color models
  - Pseudo color processing
    - Intensity slicing
    - Gray level to color transform