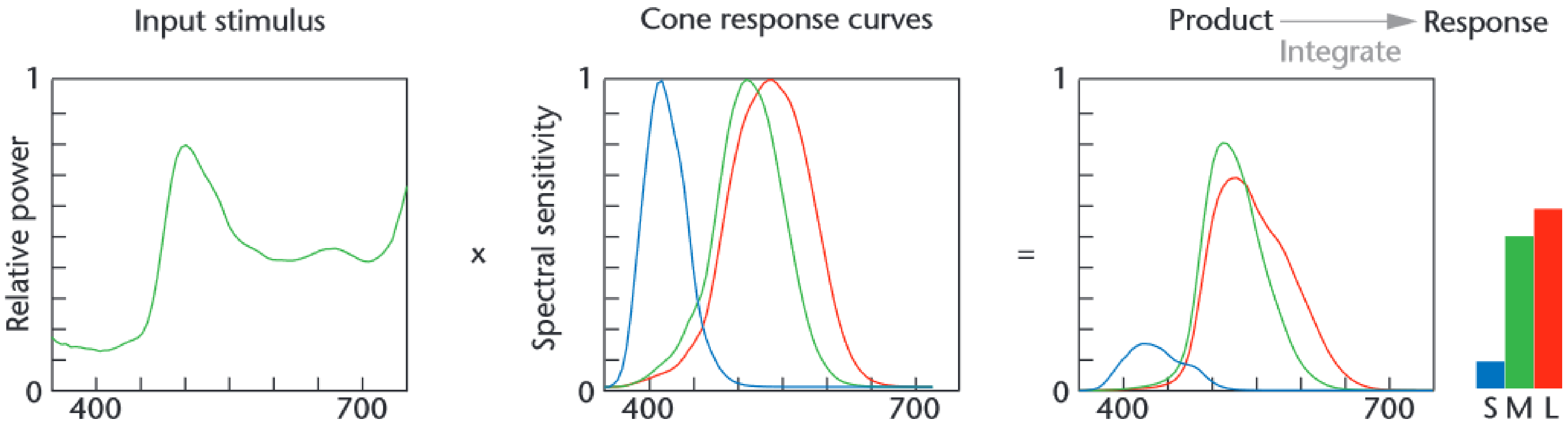
Digital Image Processing (CSE/ECE 478)
Lecture7: Color Image Processing

Vineet Gandhi

Center for Visual Information Technology (CVIT), IIIT Hyderabad

Color signal to the brain



Today's class

- Attributes of color
- Primary colors and color matching functions (link to perception)
- Lab color space (perceptually uniform color space)
- Other color spaces
- Pseudo color image processing
- Some modern applications

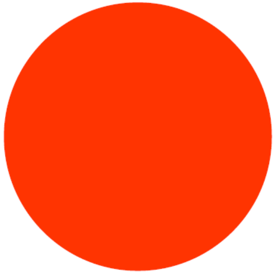
Color perception

- Fascinating and complicated phenomena
- Has kept scientist, psychologists, philosophers, and artists interested for years

- Why study color?
  - Object recognition and tracking
  - Constancy problem (Chromatic Adaptation)
  - Perceptual metric for differences (color management)
  - Image enhancement

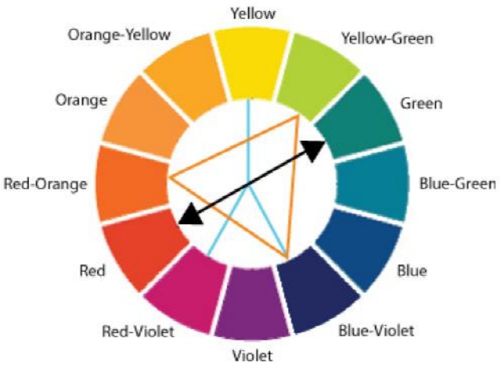
Related and unrelated colors

- When a color is observed in relation with another color, it is a related color
- When the color is seen isolated from other colors it is an unrelated color.



Attributes of color

- **Hue:** attribute of visual perception according to which we characterize an area as red, yellow, orange, green, blue or purple.



Achromatic color: perceived color devoid of hue.

Chromatic color: perceived color possessing a hue.

Attributes of color

- **Colorfulness:** attribute of visual perception according to which an area appears to exhibit more or less chromatic color.

Attributes of color

- **Brightness:** attribute of visual perception according to which an area appears to exhibit more or less light.

Decreasing brightness with depth
(example underwater photography)

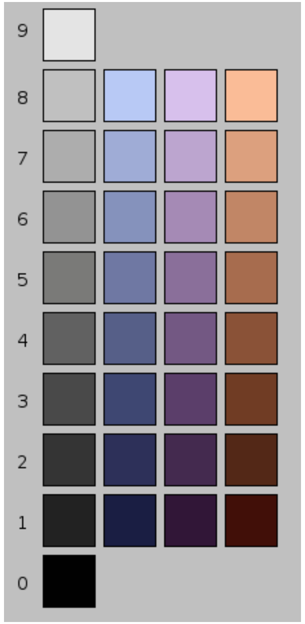
courtesy: wikipedia

Attributes of color

- **Saturation:** the colorfulness of an area judged in proportion to its brightness.

Attributes of color

- **Lightness:** the brightness of an area judged relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting.



courtesy: wikipedia

Attributes of color

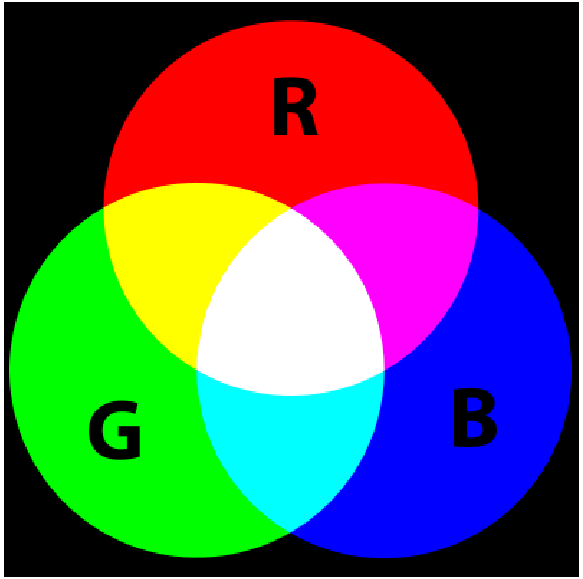
- **Chroma:** The colorfulness of an area judged in proportion relative to the brightness of a similarly illuminated area that appears to be white or highly transmitting.

- Lightness and chroma are defined for object colors and related colors. Then for these cases the three color attributes are: **lightness, hue and chroma.**
- For unrelated colors, light-source colors and aperture colors the three color attributes are: **brightness, hue and saturation**.

Attributes of color

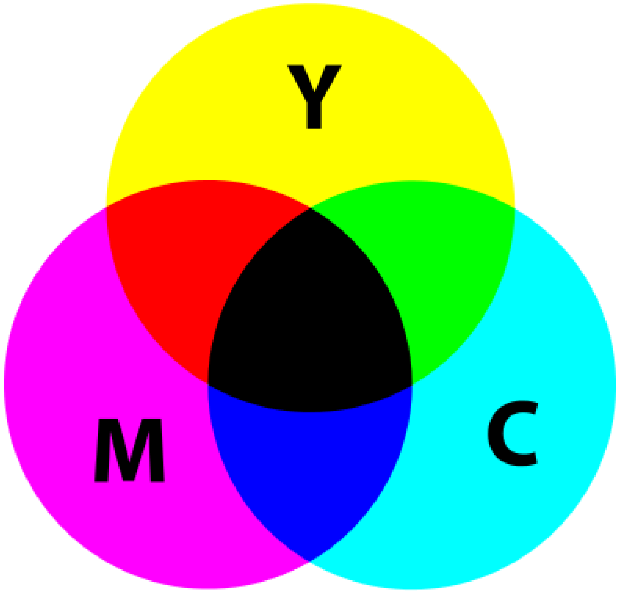
Primary Colors (color as three number)

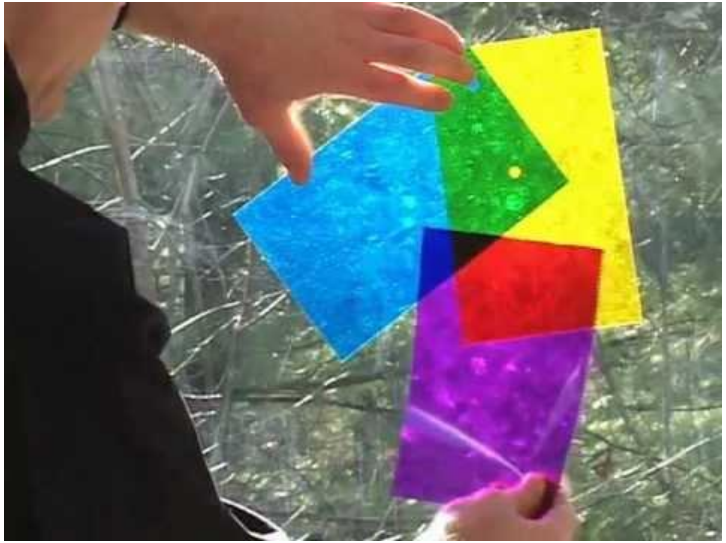
- Additive (CRT displays, projectors etc.)



Primary Colors

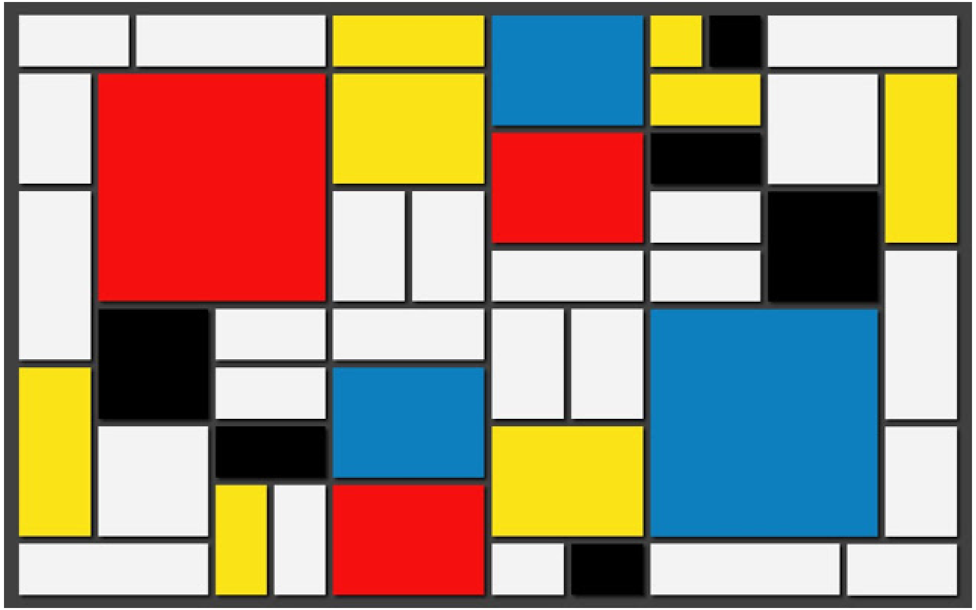
- Subtractive (mixing of pigments or dyes)





Primary Colors

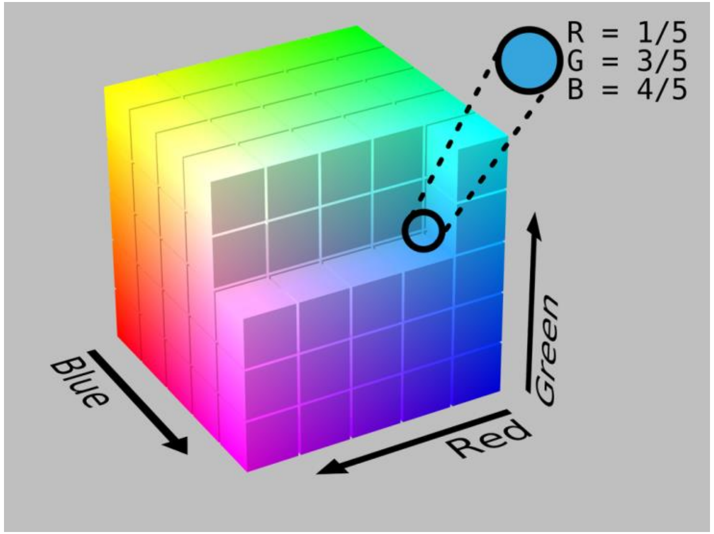
- Subtractive (artists, painters)



Painting of Piet Mondrian

RGB color space

- Primary colors
- Additive color model $f(x, y) = \alpha_1 R + \alpha_2 G + \alpha_3 B$
- Perceptually non uniform



Courtesy: wikipedia

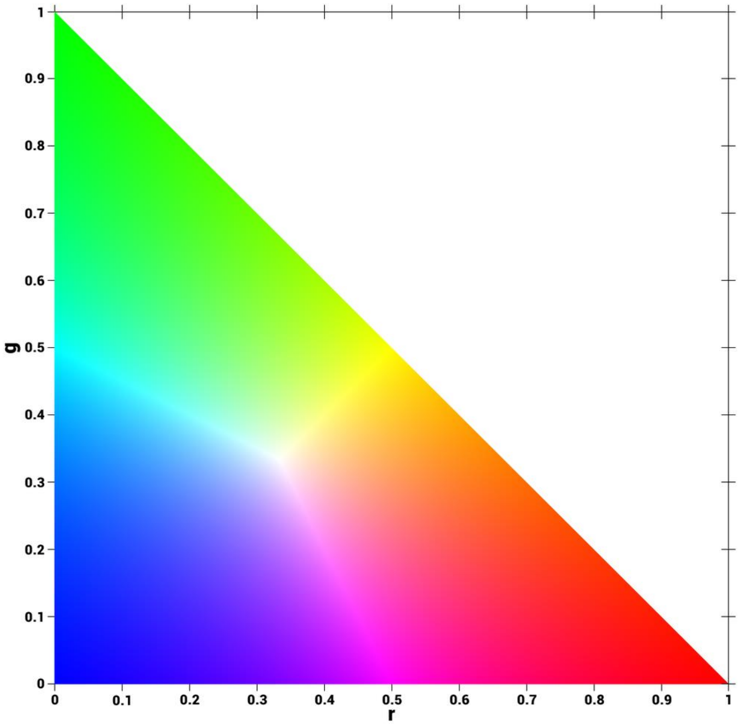
rg color space

$$r = \frac{R}{R+G+B}$$

$$g = \frac{G}{R+G+B}$$

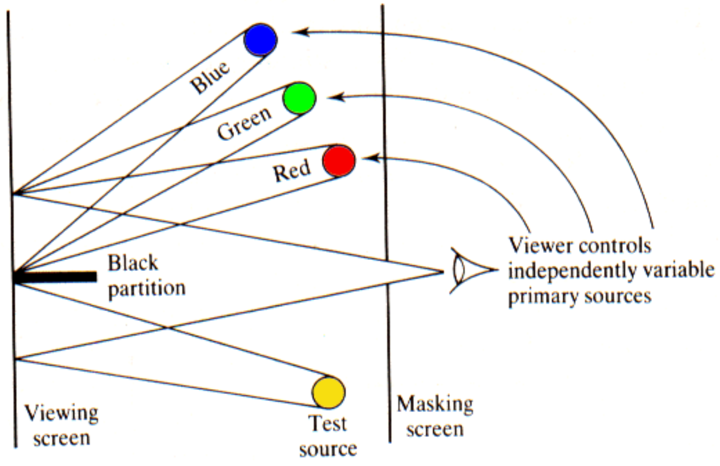
$$b = \frac{B}{R+G+B}$$

$$r + g + b = 1$$

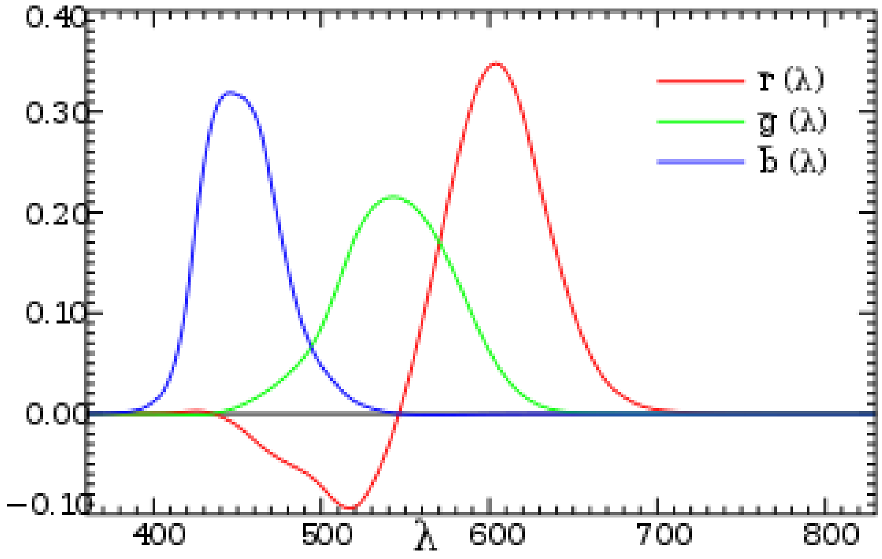


Color Matching Functions

- Primaries standardized by CIE In 1931(Red(R) - 700nm, Green(G) - 546.1nm, Blue(B) – 435.8)



$$f(\lambda) = r(\lambda) + g(\lambda) + b(\lambda)$$



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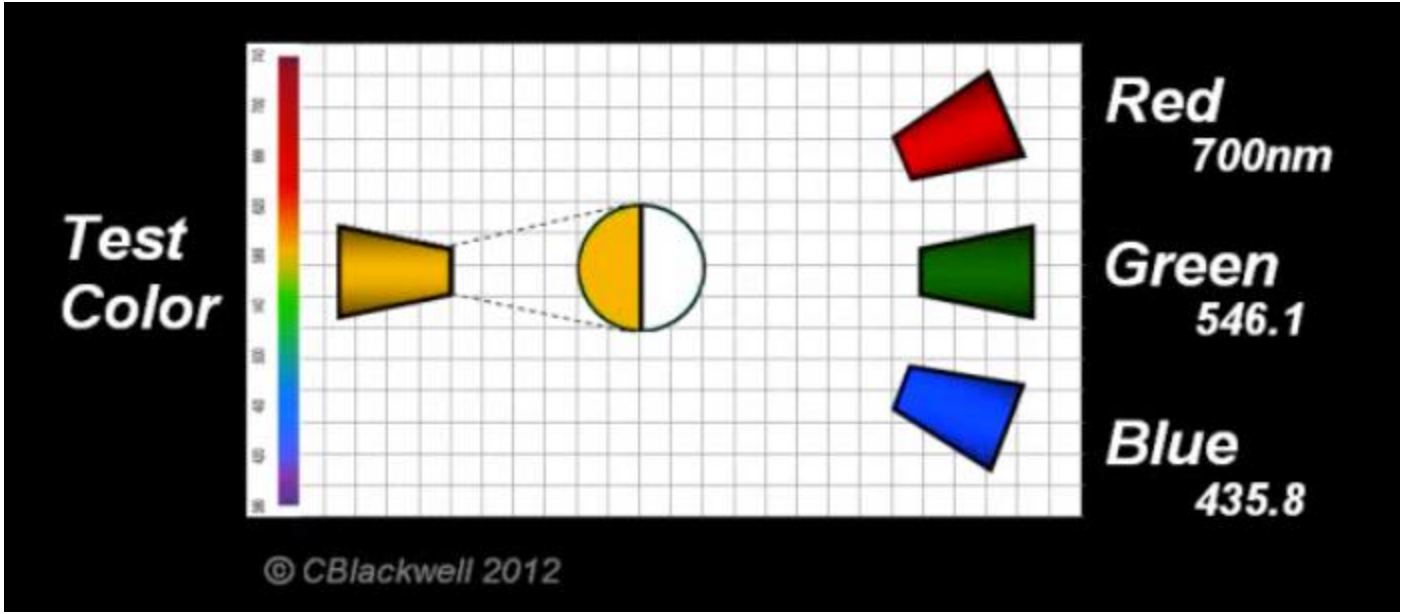

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Color Matching Functions

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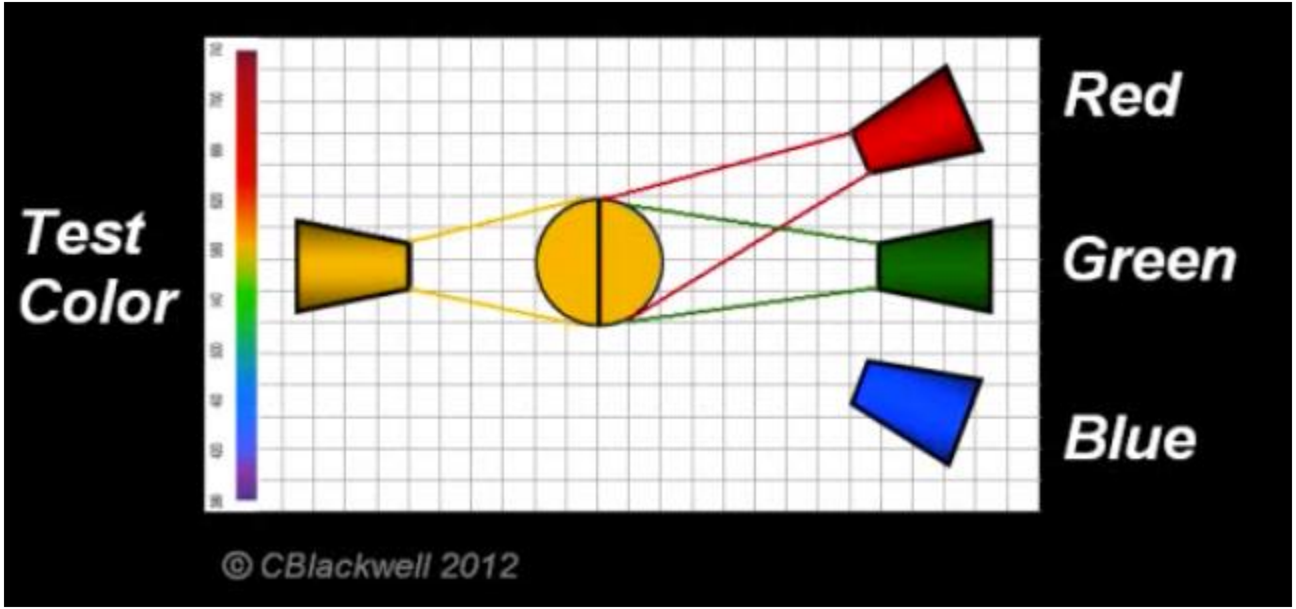

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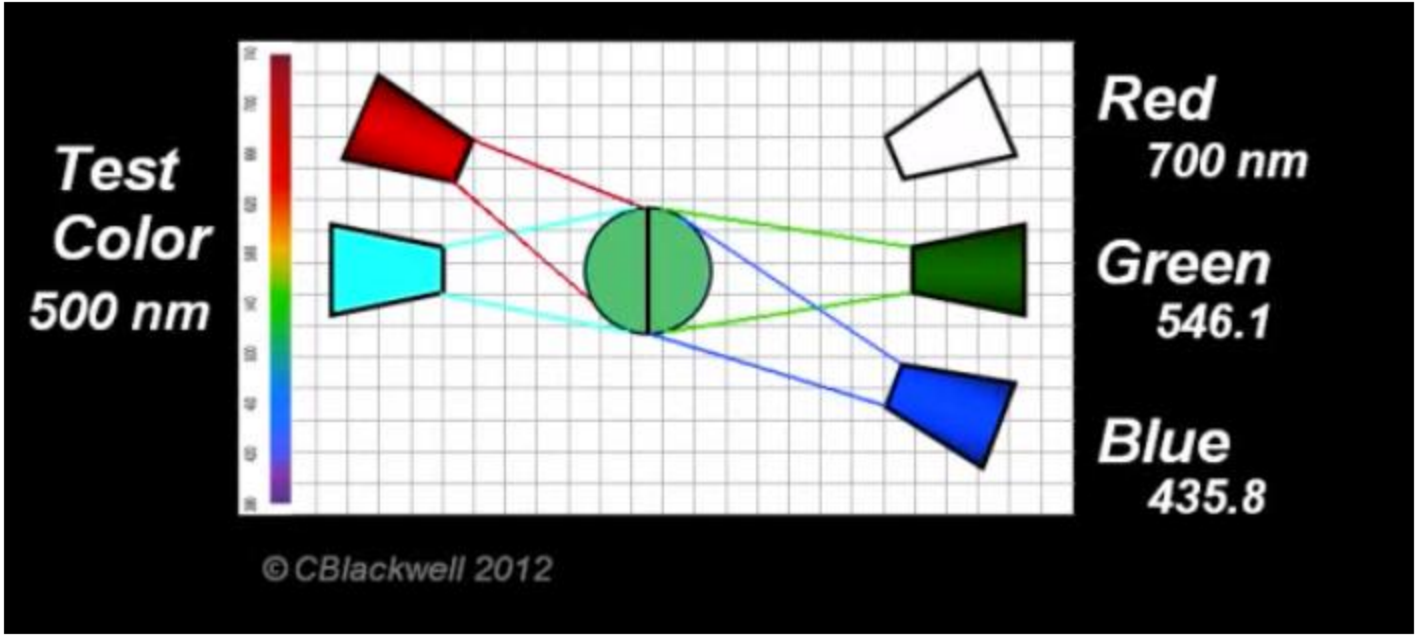

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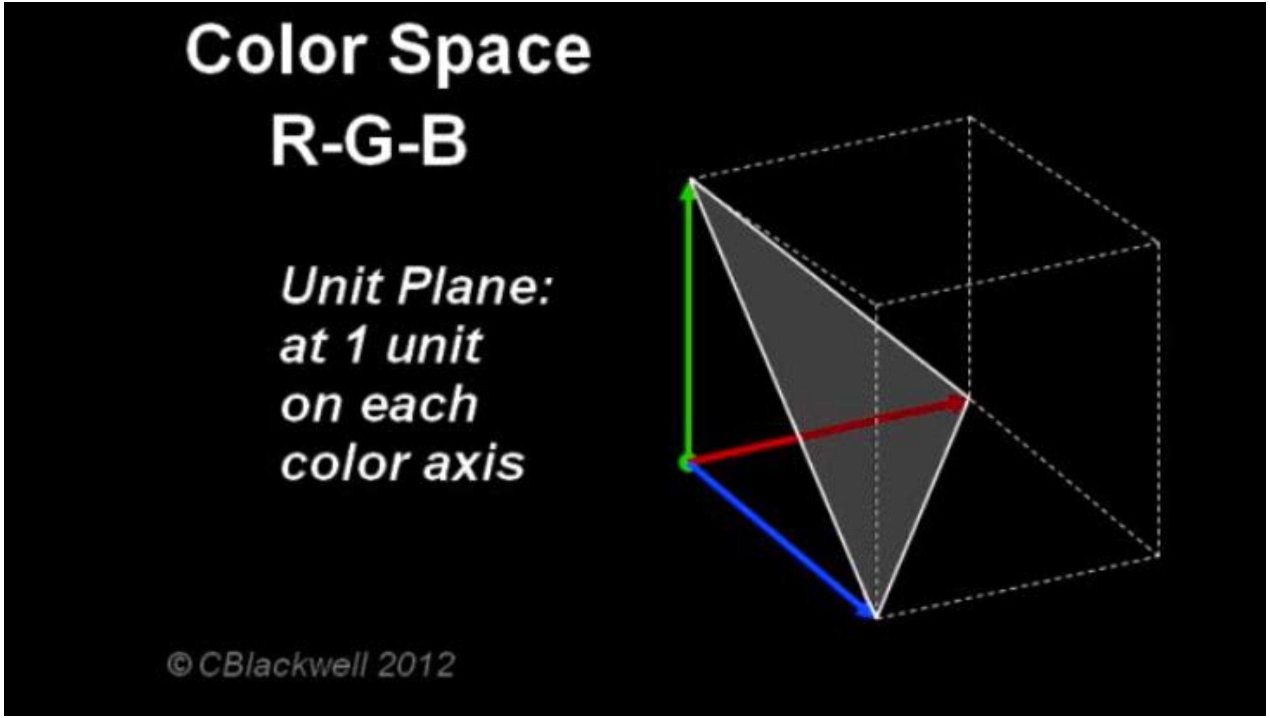

Color Matching Functions

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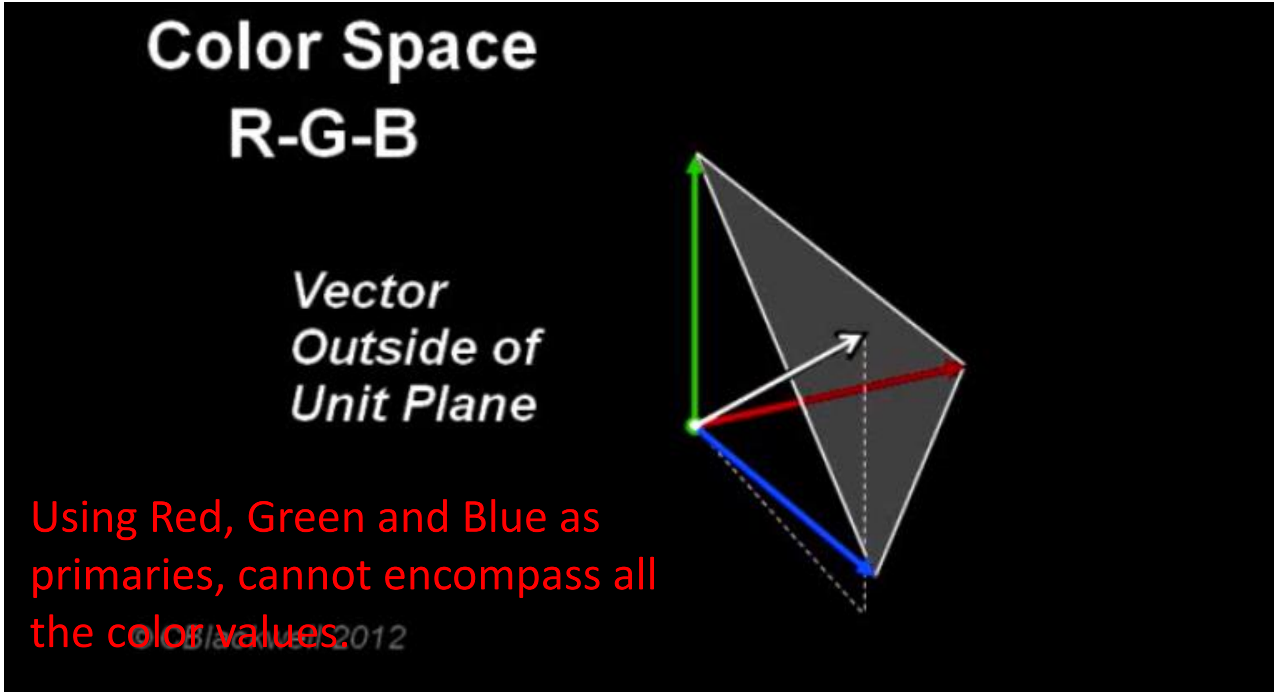
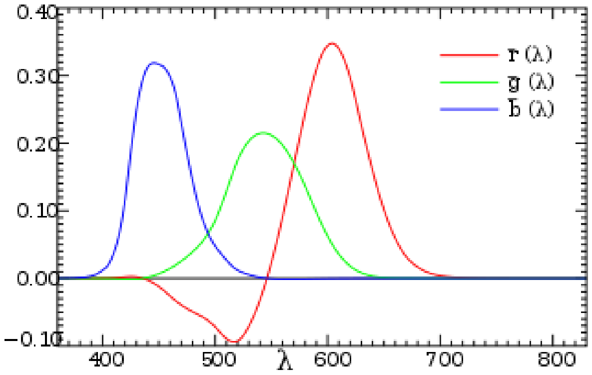


Using Red, Green and Blue as primaries, cannot encompass all the color values.

Color Matching Functions, negative values?

- For certain monochromatic lights it is impossible to obtain a match with the additive mixing of any amounts of the three primary stimuli. But it is possible to obtain a match in this way:



$$f(\lambda) + r(\lambda) = g(\lambda) + b(\lambda)$$

add primary light to the test source

which is equivalent to:

$$f(\lambda) = -r(\lambda) + \ g(\lambda) + b(\lambda)$$

XYZ color space

- The new system was created according to the following premises:
  - to **avoid negative values of** $r(\lambda), g(\lambda)\ and\ b(\lambda)$
  - one of the new color-matching functions **should directly express a photometric quantity** (the stimulus luminance).

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 2.7989 & 1.7517 & 1.1302 \\ 1.0000 & 4.5907 & 0.0601 \\ 0.0000 & 0.0565 & 5.5943 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

XYZ color space

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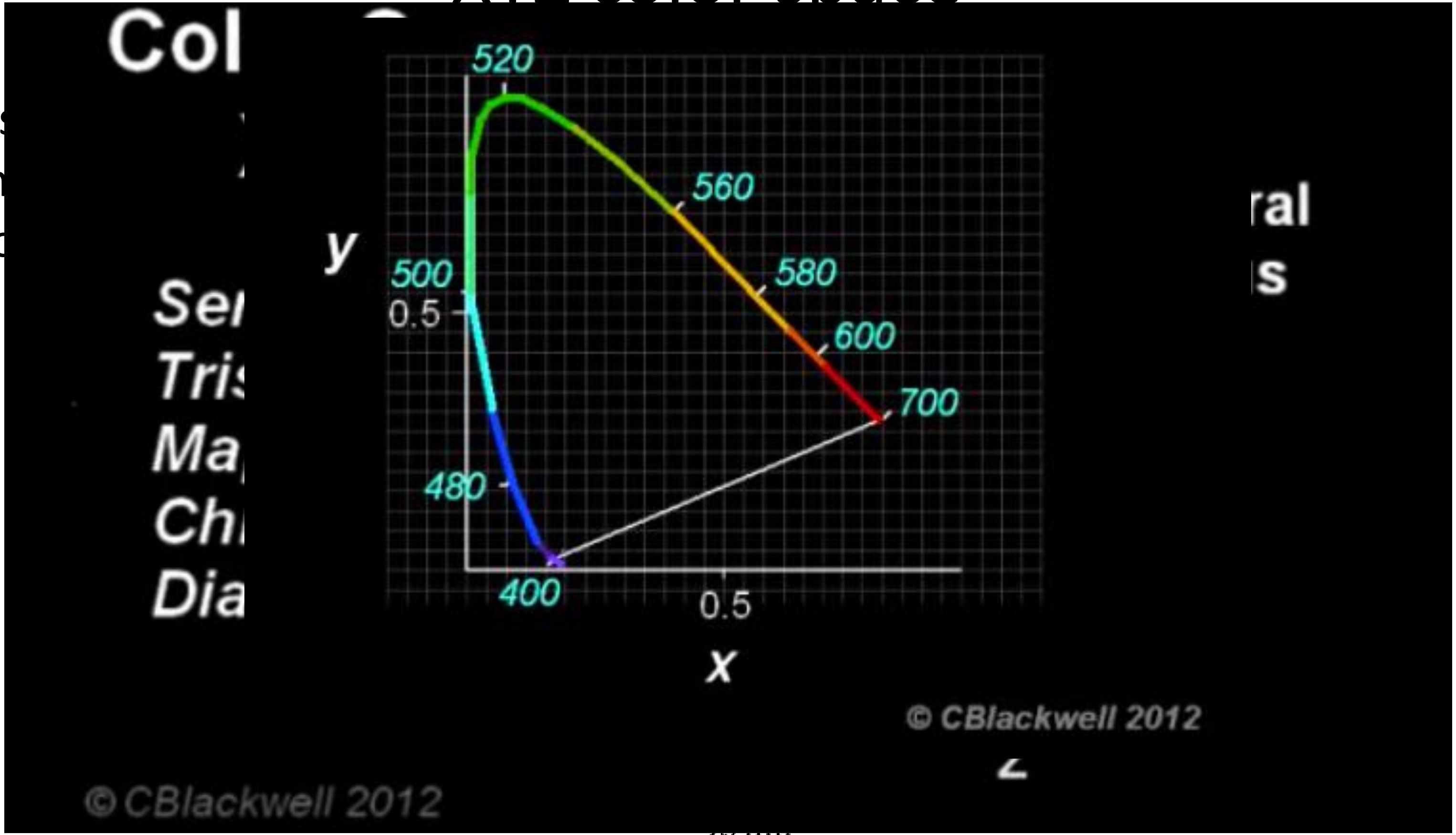
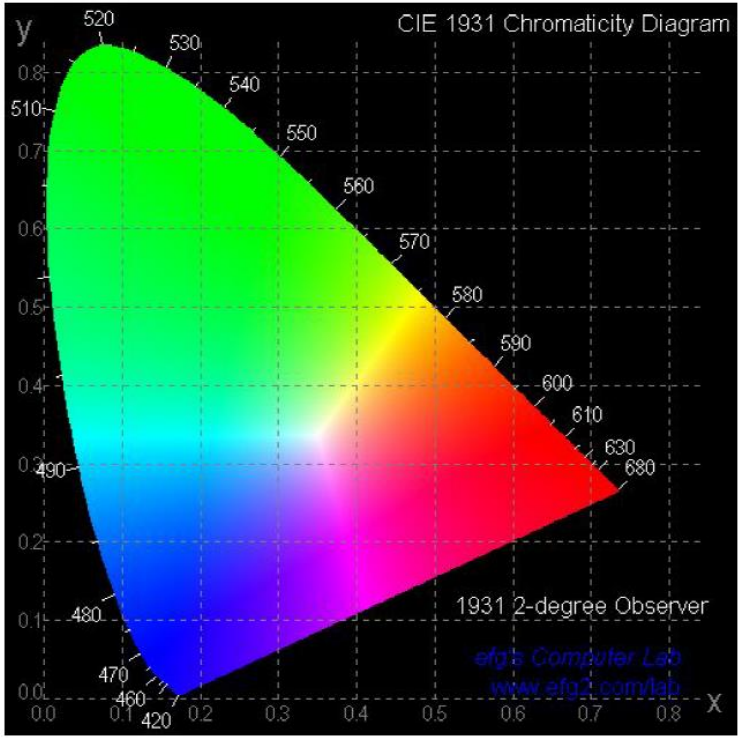


CIE 1931 (x,y) chromaticity diagram



- Chromaticity coordinates:

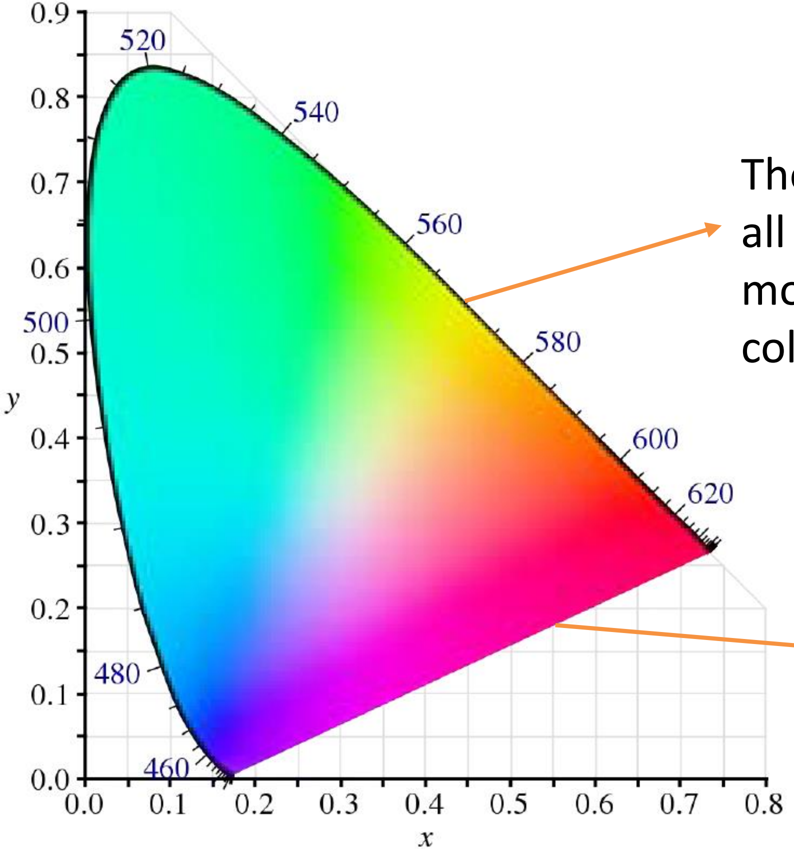
$$x = \frac{X}{X+Y+Z}$$

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

- x and y are chromaticity coordinates, Y is relative luminance
- Chromaticity coordinates discard the absolute intensity of a given color sample and just represent its pure color
- This figure shows the (x,y) value for every color value perceivable by most humans

CIE 1931 (x,y) chromaticity diagram

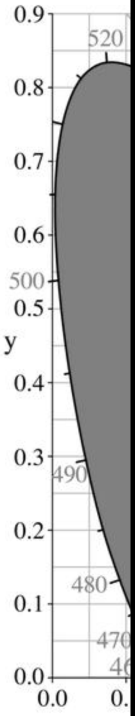
A convenient representation for color values, when we want to tease apart luminance and chromaticity, is therefore Yxy (luminance plus the two most distinctive chrominance components)

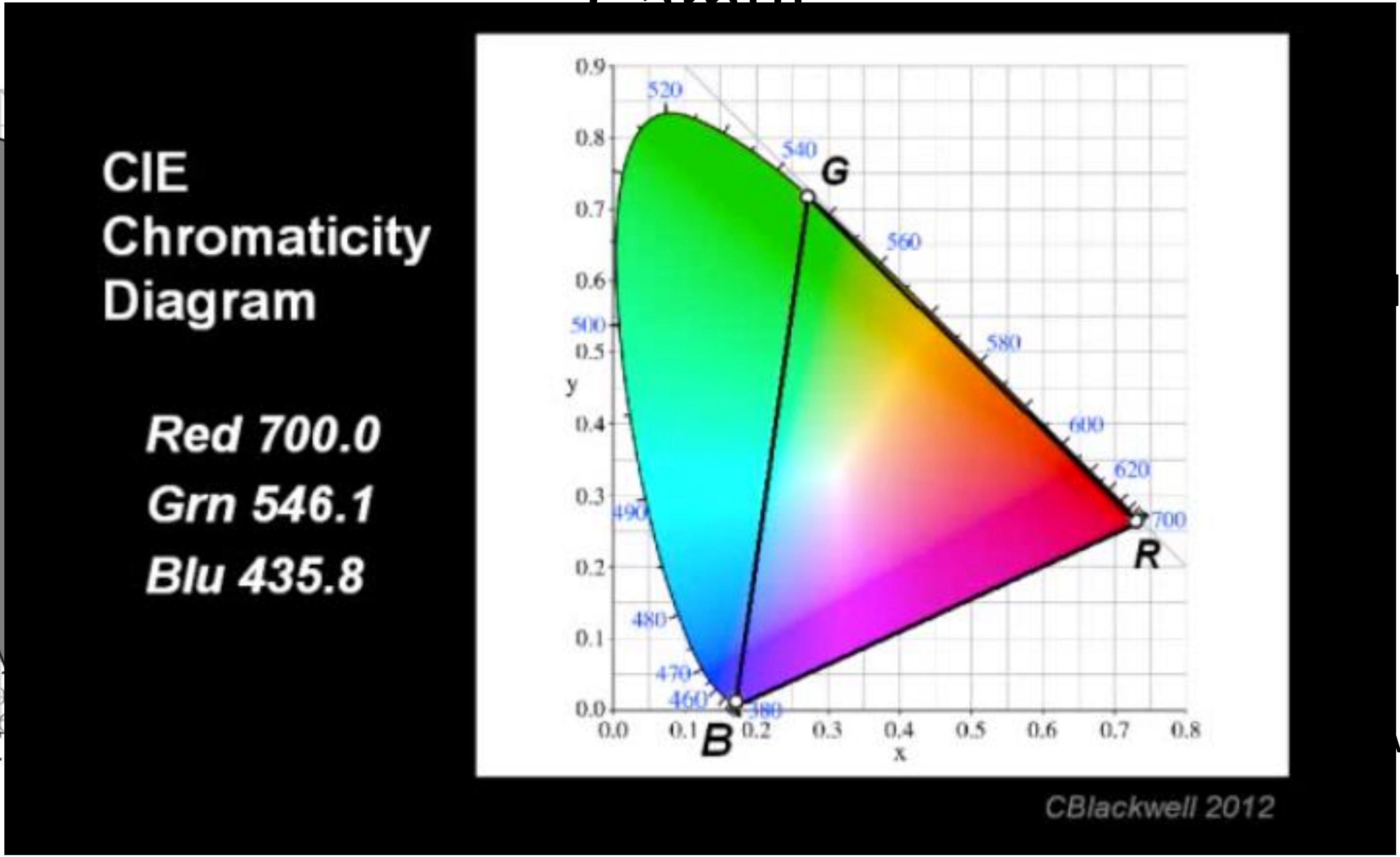


The rim represents all of the pure monochromatic colors

Purple Line

Gamut





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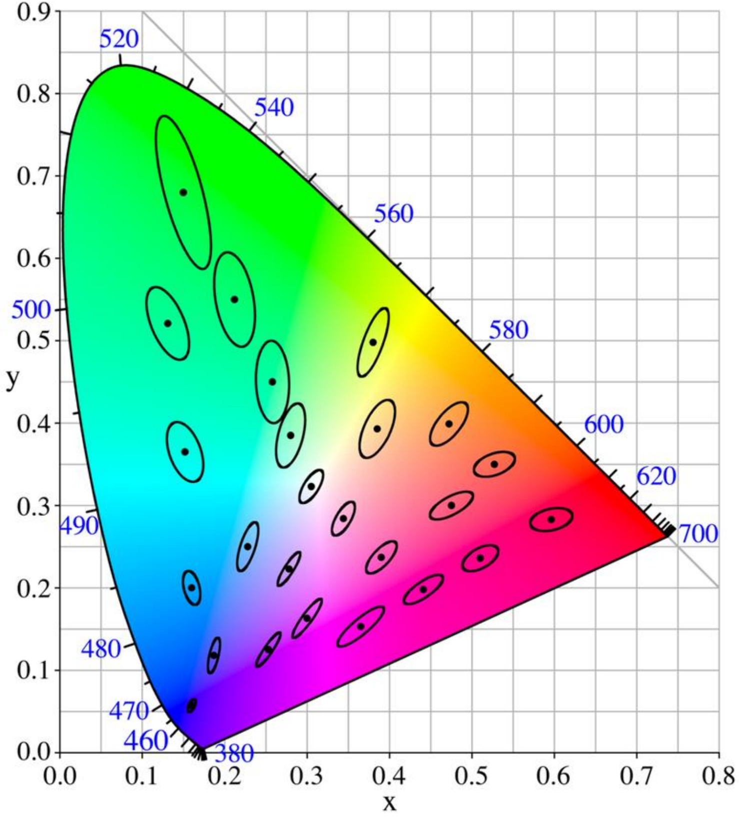
courtesy: wikipedia

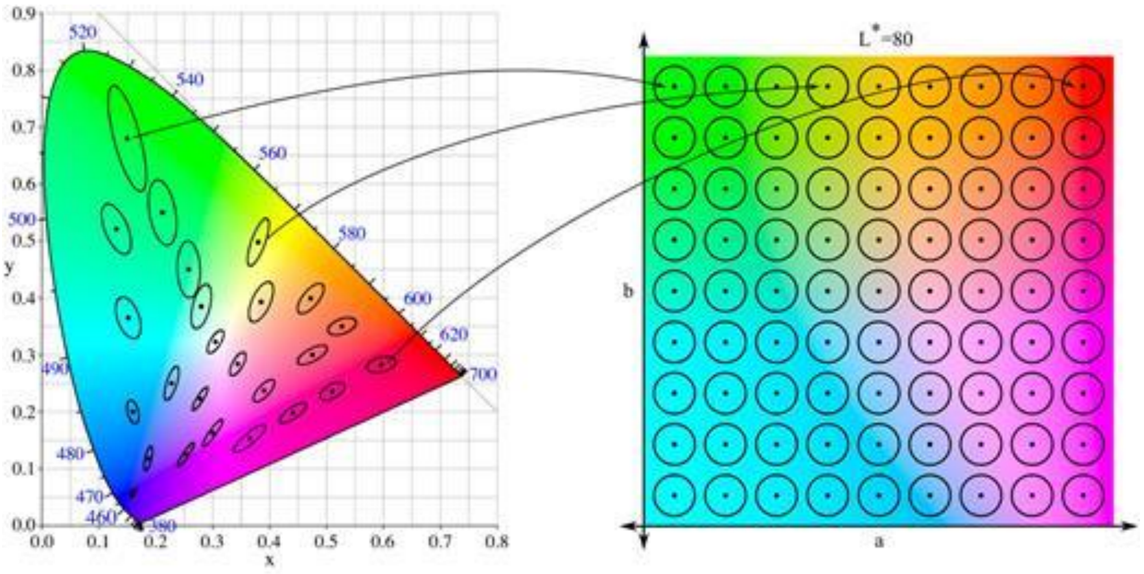
McAdam Ellipses



- **MacAdam ellipses** refer to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse
- The contour of the ellipse represents the just noticeable differences of chromaticity

courtesy: wikipedia

CIE Lab color space



CIE 1931

CIELAB (CIE 1976 L*,a*,b*)

Ideal scenario

CIE Lab color space

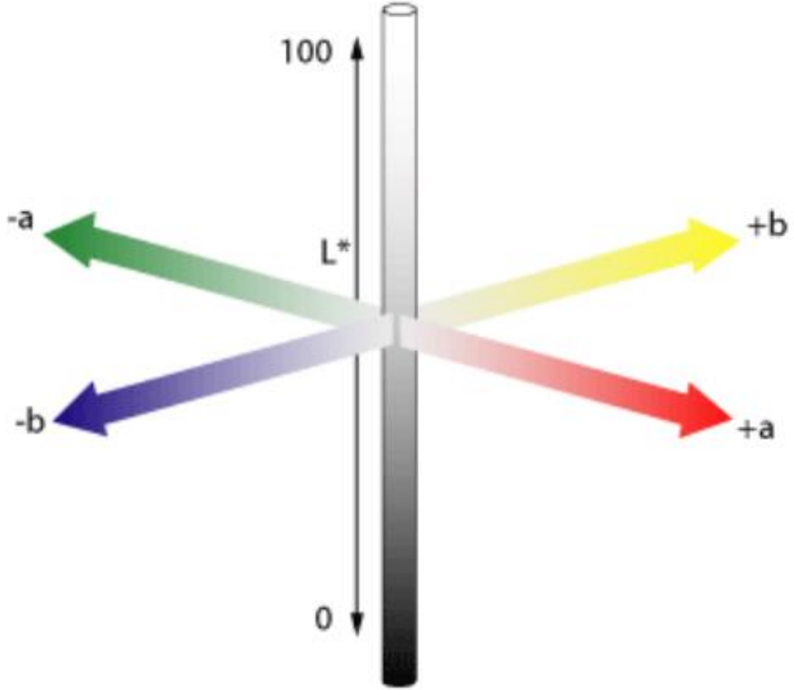
$$L^\star = 116 f(Y/Y_n) - 16$$
$$a^\star = 500\left[f(X/X_n) - f(Y/Y_n)\right]$$
$$b^\star = 200\left[f(Y/Y_n) - f(Z/Z_n)\right]$$

$$f(t) = \begin{cases} t^{1/3} & \text{if } t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{4}{29} & \text{otherwise} \end{cases}$$

(X_n, Y_n, Z_n) is the measured white point.

- Differences in luminance or chrominance are more perceptually uniform
- The contour of the ellipse tends to be more closer to circles

CIE Lab color space



Color difference (in Lab space)

Using (L_1^*, a_1^*, b_1^*) and (L_2^*, a_2^*, b_2^*), two colors in Lab space

$$\Delta E_{ab}^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

$\Delta E_{ab}^* \approx 2.3$, corresponds to a JND (just noticeable distance)

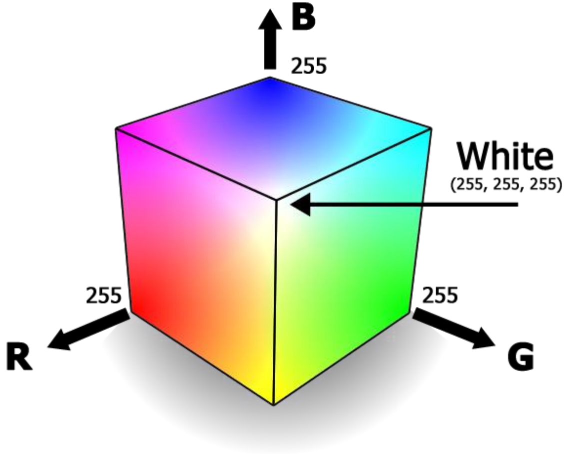
Other color spaces

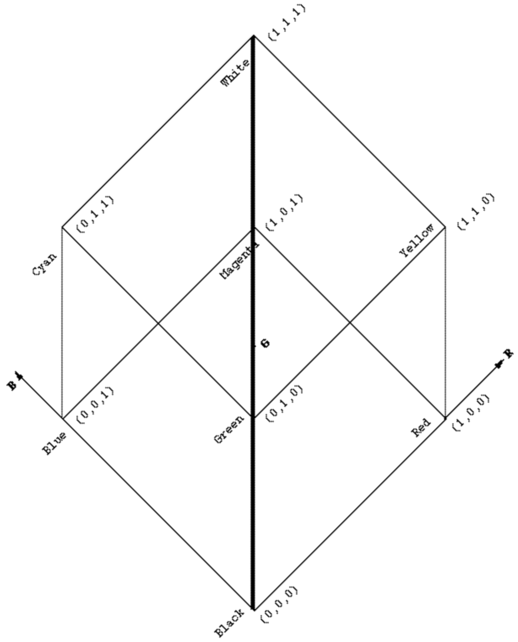
- RGB system based on the idea that human eye is strongly perceptive to red, green and blue primaries (CMY, Lab are extension of RGB)
- How would you define color of an automobile?

We will now study some color spaces, directly inspired from color attributes

HSI color space

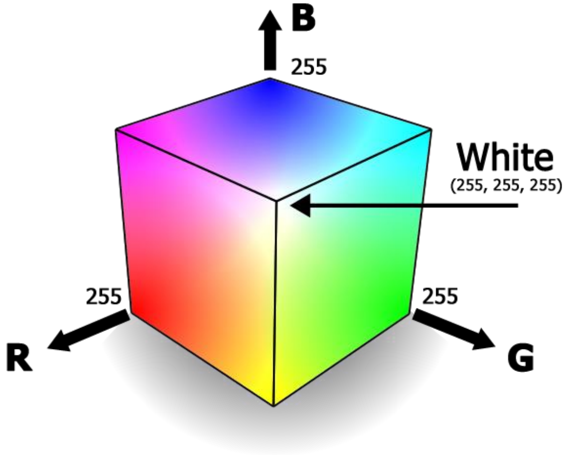
- Intensity (the diagonal axis)

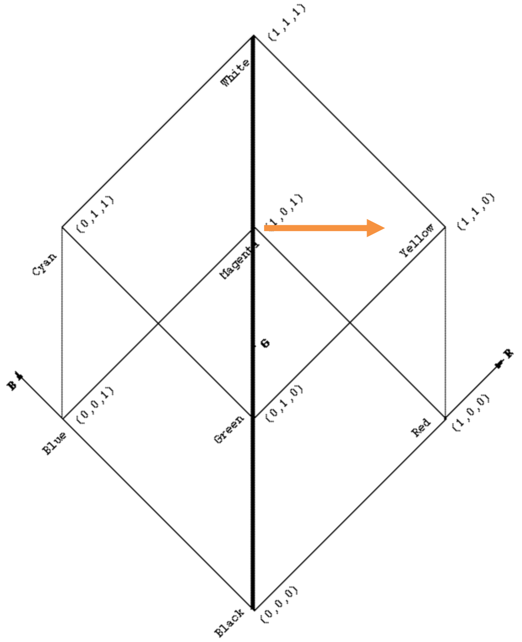




HSI color space

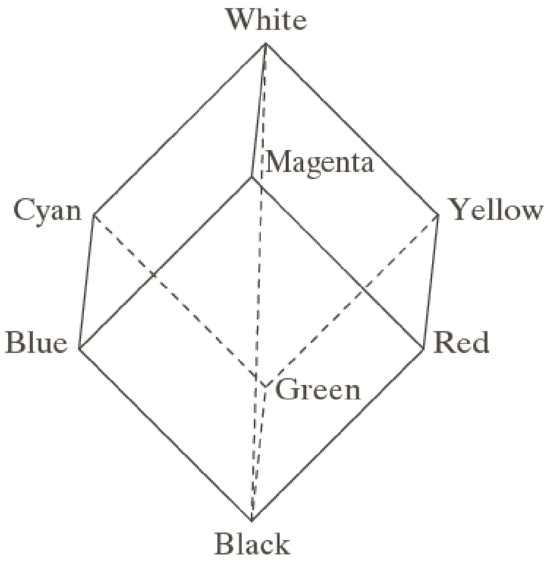
- Saturation (distance from diagonal axis)

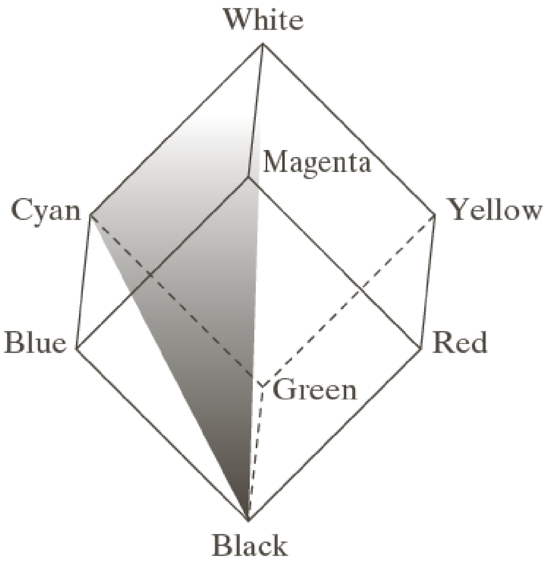




HSI color space

- Hue

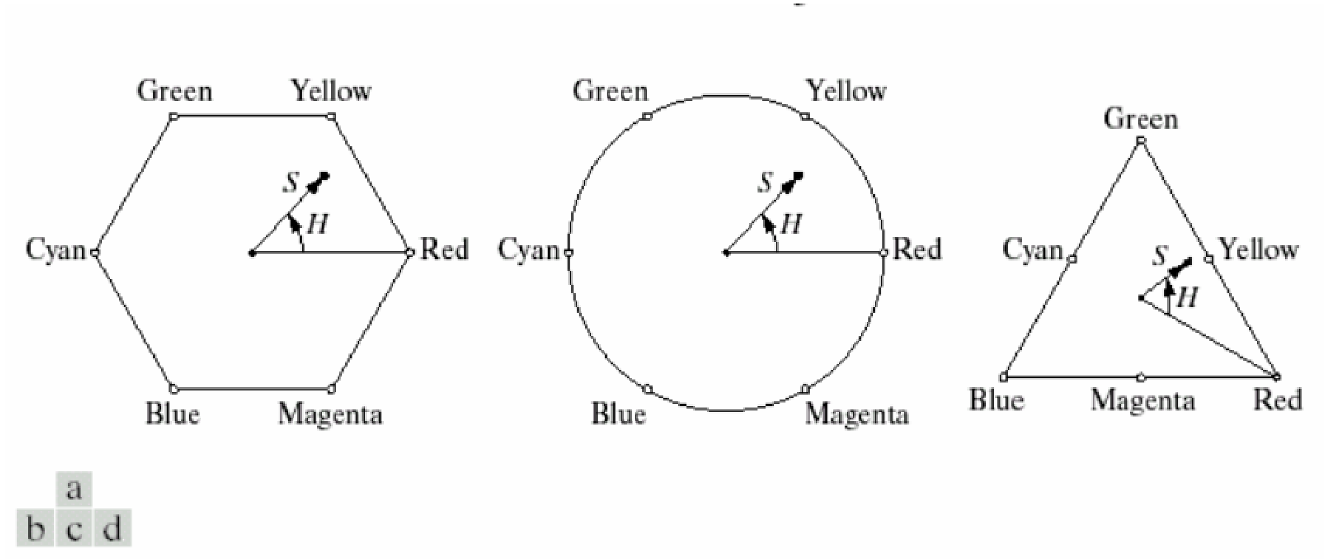




Hue, Saturation and Intensity can be obtained from RGB cube

HSI color space

- Hue



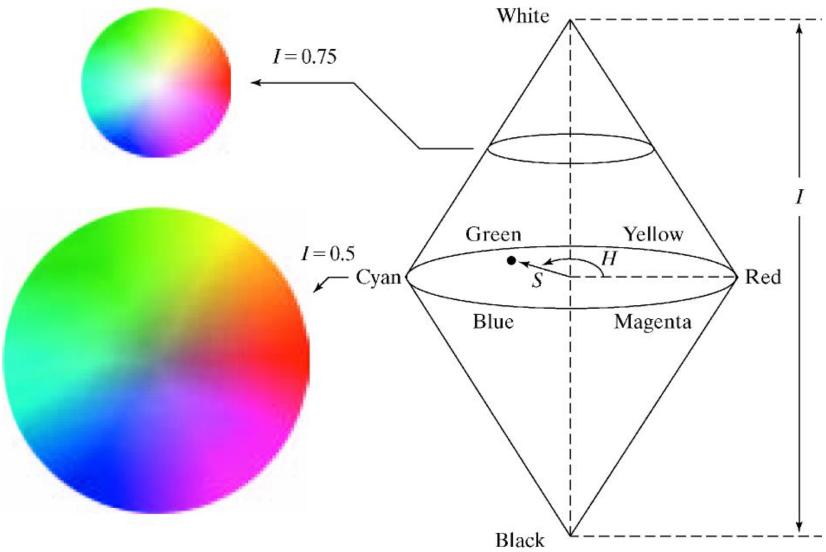
Courtesy: Gonzalez and woods

HSI color space

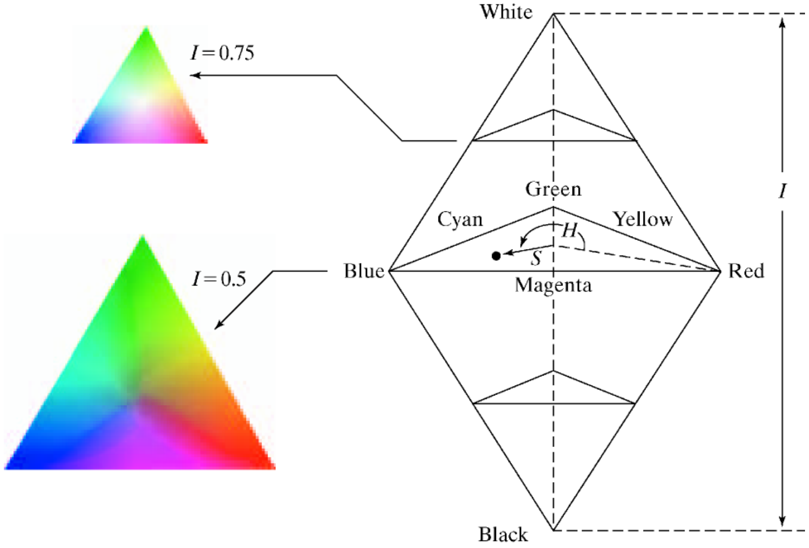
$$I = \frac{1}{3}(R + G + B)$$

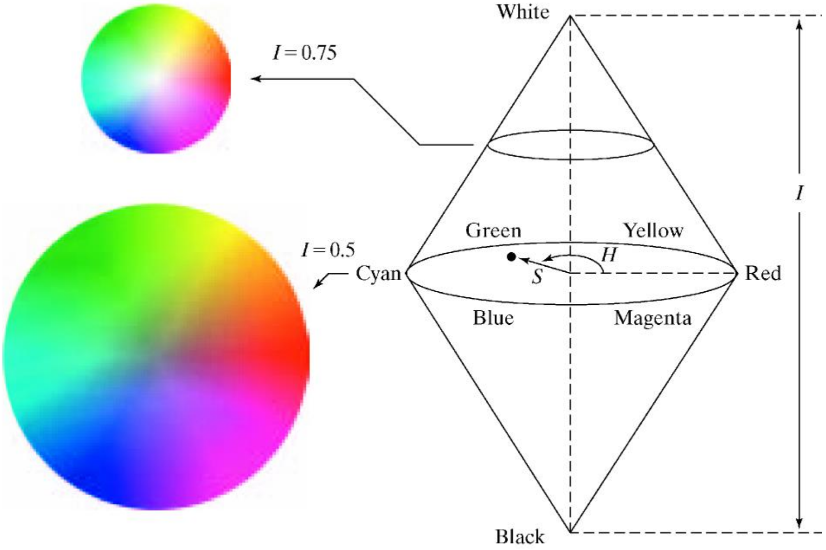
$$H = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{1/2}} \right\}$$

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



HSI color space





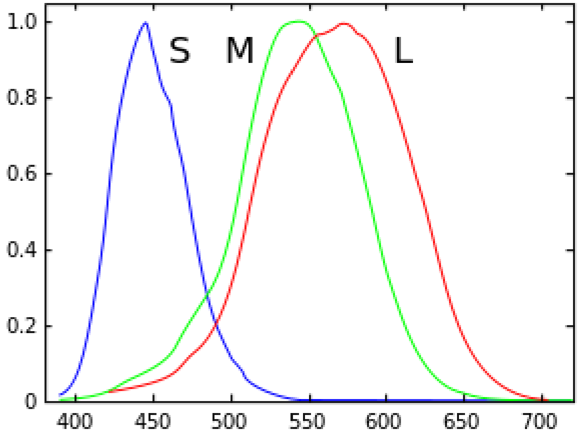
HSI color space

- What color space, do you think might have been used in re-coloring of Mughal-e-Azam?

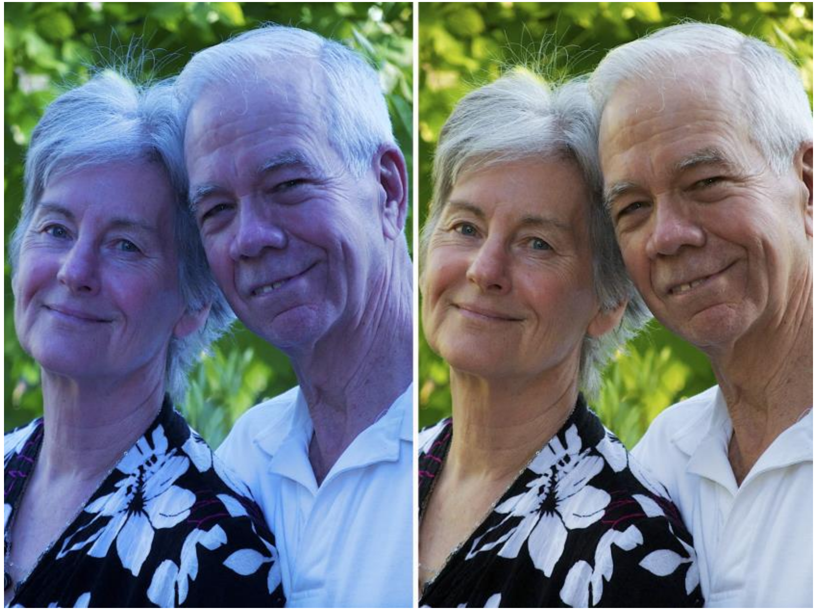
LMS color space

- It is common to use the LMS color space when performing chromatic adaptation (estimating the appearance of a sample under a different illuminant)
- It's also useful in the study of color blindness, when one or more cone types are defective.

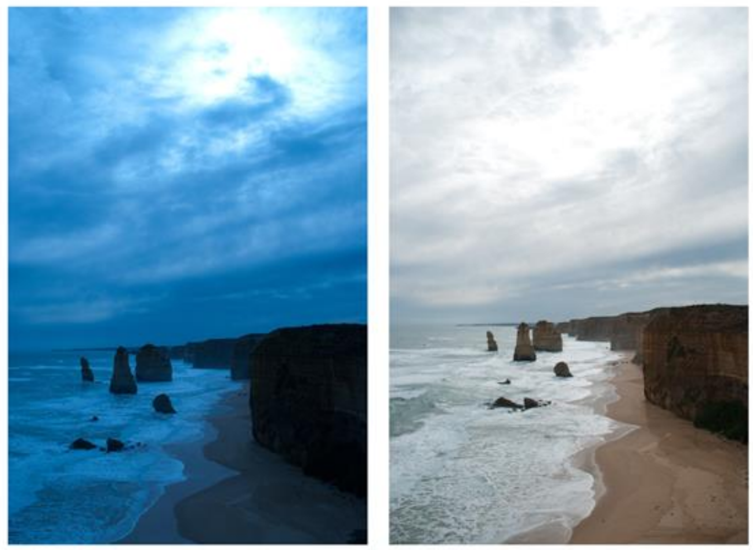
$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



White Balancing



Courtesy: wahlmanphotography.com



Courtesy: wallcreations.com.au

White Balancing

White Balancing

- Simply scaling RGB values

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 255/R'_w & 0 & 0 \\ 0 & 255/G'_w & 0 \\ 0 & 0 & 255/B'_w \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

White Balancing

White Balancing

White Balancing (code)

```
im = double(imread('lighthouse.jpg'));

RGBw = [246 169 87];

im1(:,:,1) = im(:,:,1)*255/RGBw(1);
im1(:,:,2) = im(:,:,2)*255/RGBw(2);
im1(:,:,3) = im(:,:,3)*255/RGBw(3);
```

White Balancing

Von Kries Method

- Scaling operation is performed in LMS space

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 1/L'_w & 0 & 0 \\ 0 & 1/M'_w & 0 \\ 0 & 0 & 1/S'_w \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix}$$

Von Kries Method

White Balancing

Incandescent lighting

Fluorescent lighting

Sunlight

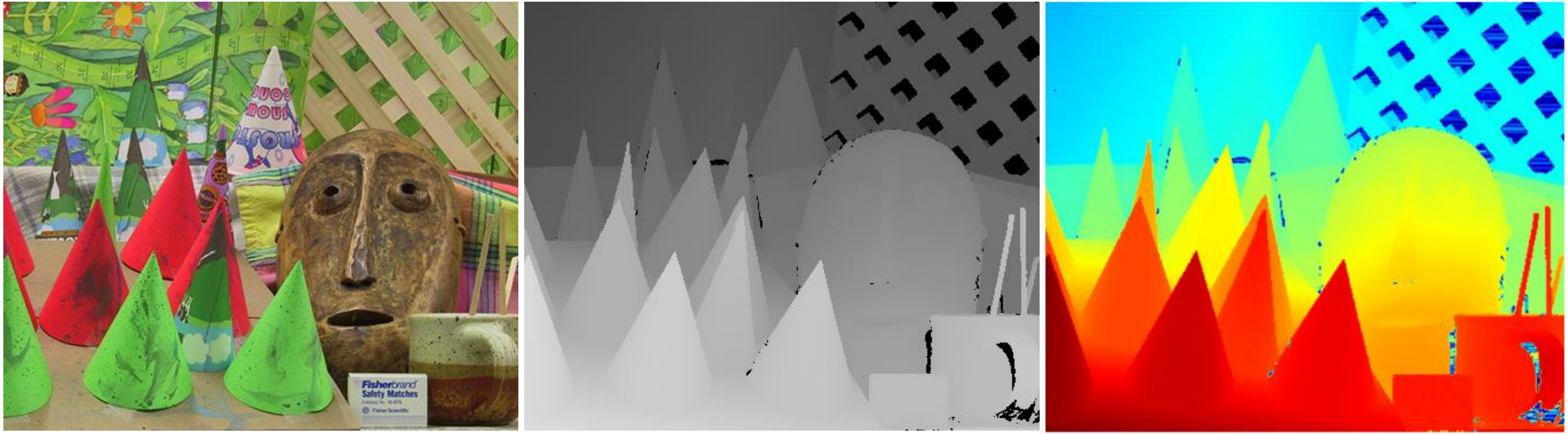
Camera Flash

Cloudy

Shadow

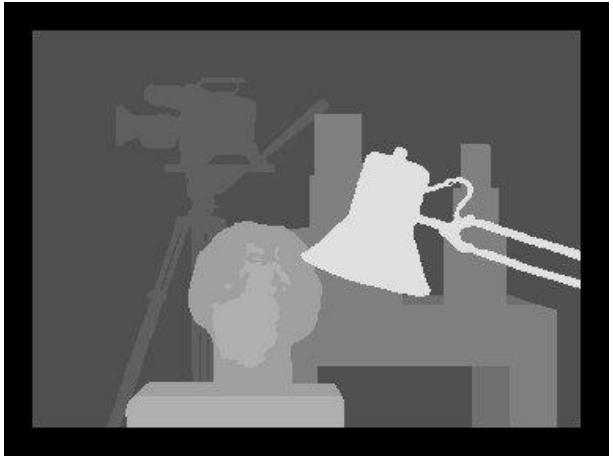
courtesy: seventhgrove.com

Pseudo color Image Processing



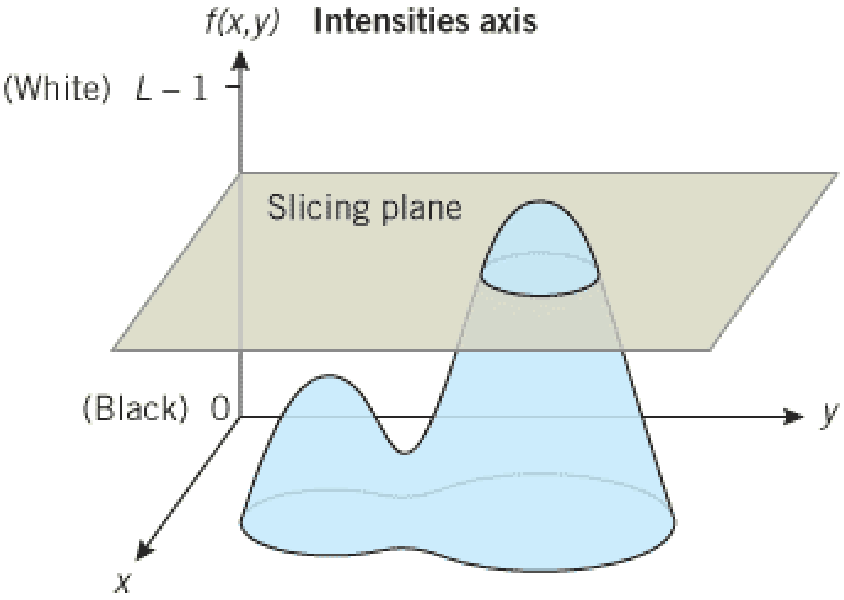
courtesy: middlebury dataset

Pseudo color Image Processing



courtesy: middlebury dataset

Pseudo color Image Processing (Intensity Slicing)

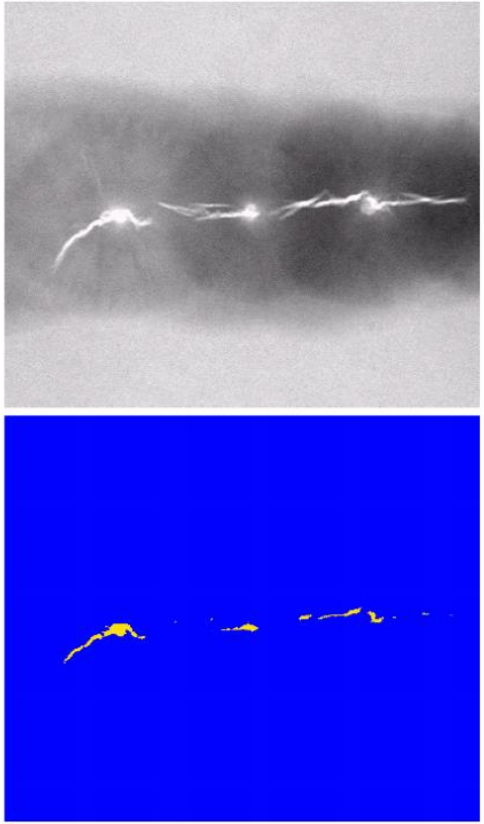


courtesy: Gonzalez and Woods

Pseudo color Image Processing (Intensity Slicing)

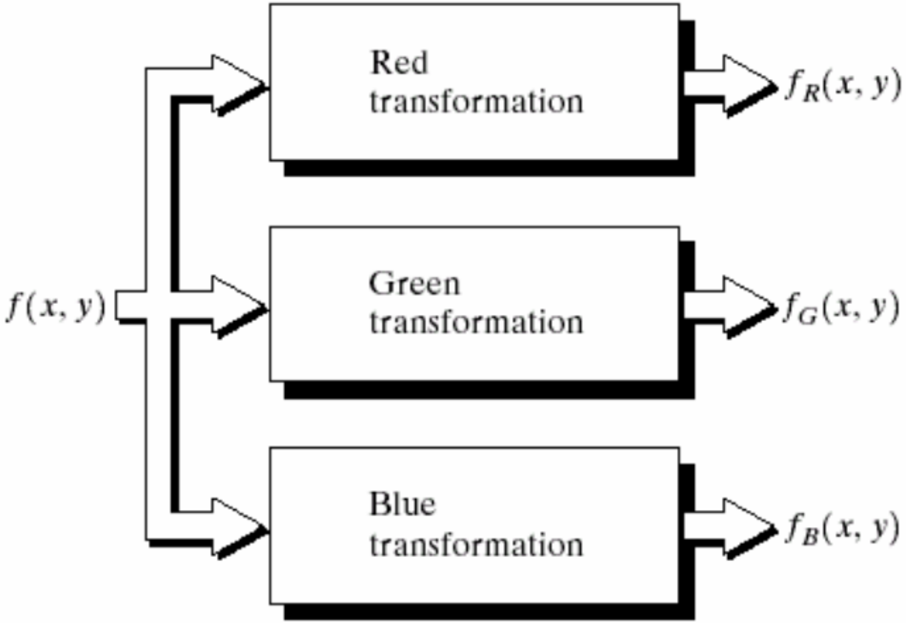
a
b

FIGURE 6.21 (a) Monochrome X-ray image of a weld. (b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)



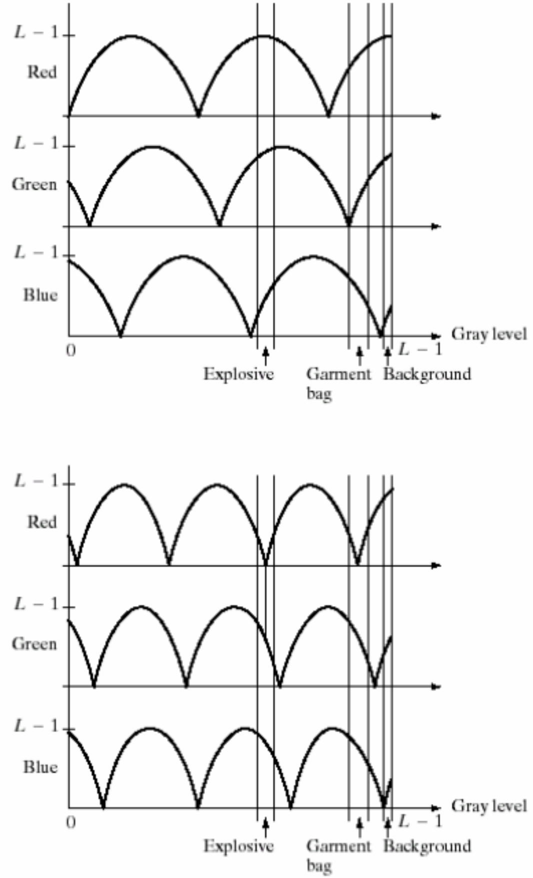
courtesy: Gonzalez and Woods

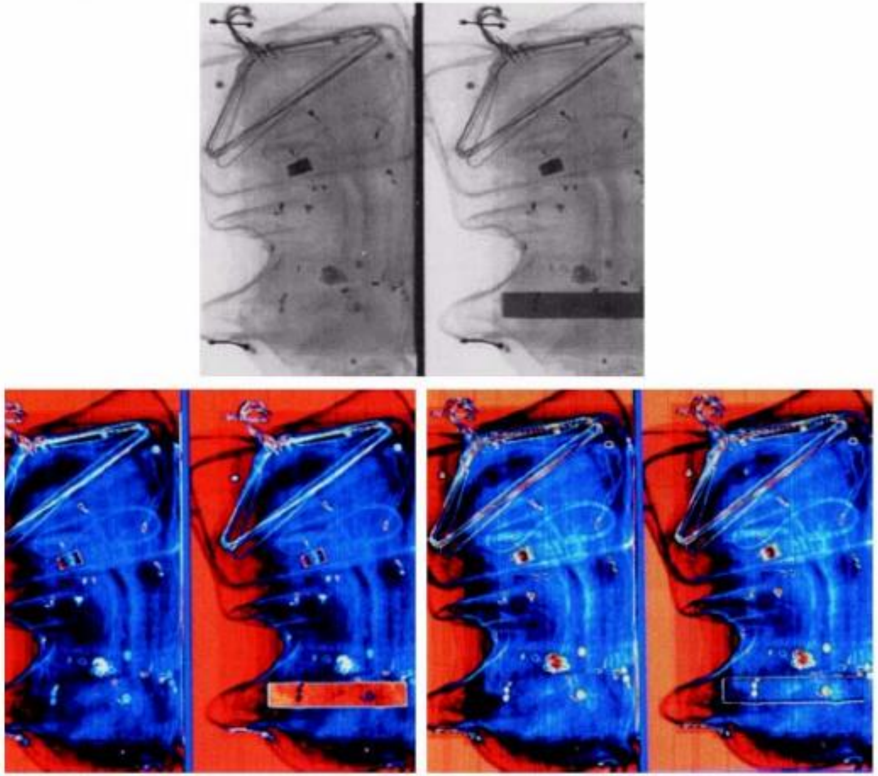
Pseudo color Image Processing (Transformations)



courtesy: Gonzalez and Woods

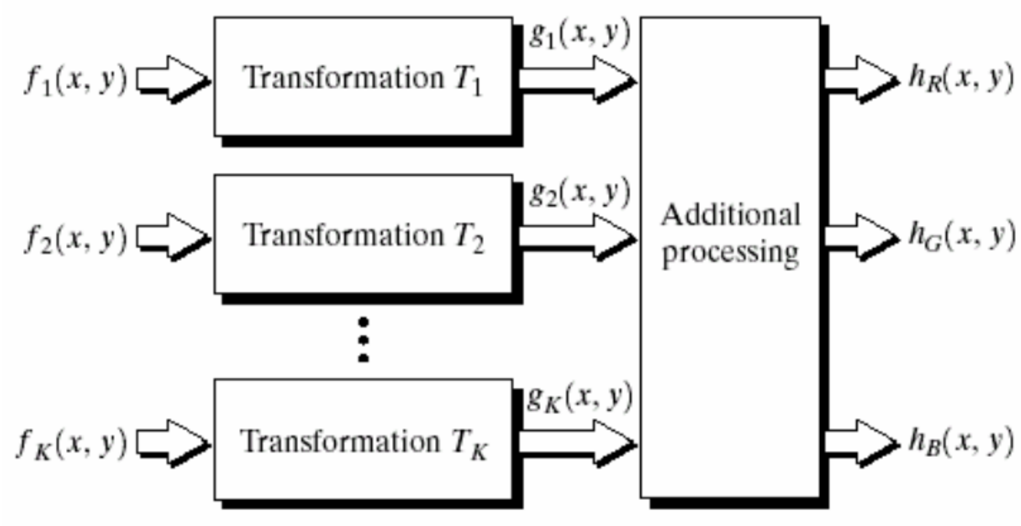
Pseudo color Image Processing (Transformations)





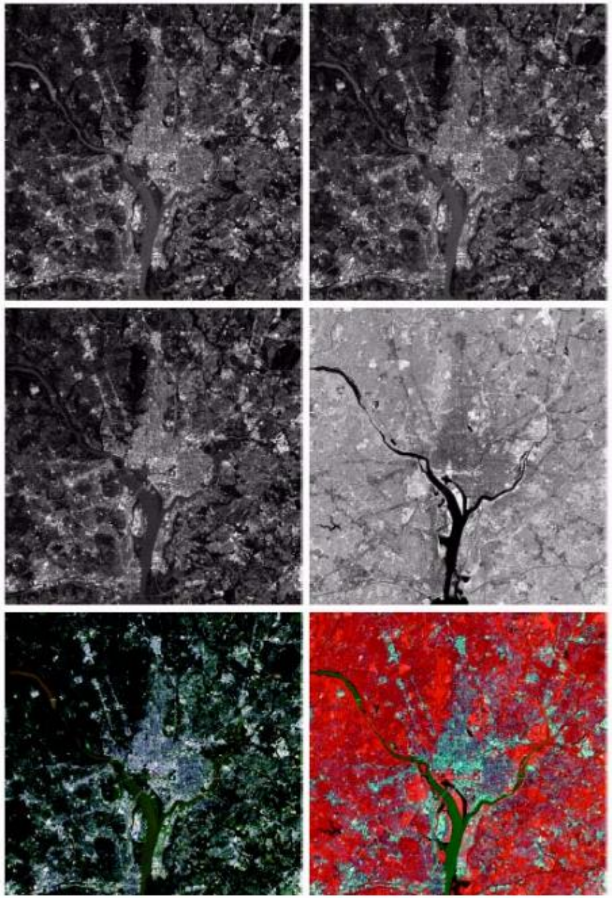
courtesy: Gonzalez and Woods

Pseudo color Image Processing (Multi Spectral)



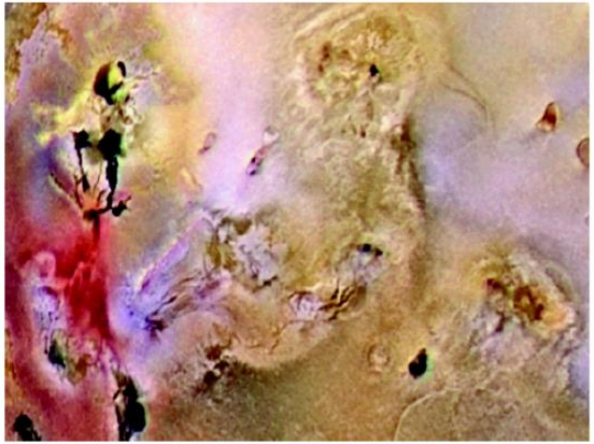
courtesy: Gonzalez and Woods

Pseudo color Image Processing (Multi Spectral)



courtesy: Gonzalez and Woods

Pseudo color Image Processing (Multi Spectral)



courtesy: Gonzalez and Woods

RGBA space

- A (alpha) for transparency (important in image editing)

$$I_{out} = \alpha I_{foreground} + (1 - \alpha) I_{background}$$

Trending applications: Image enhancement in RGB

Example: Vintage effect

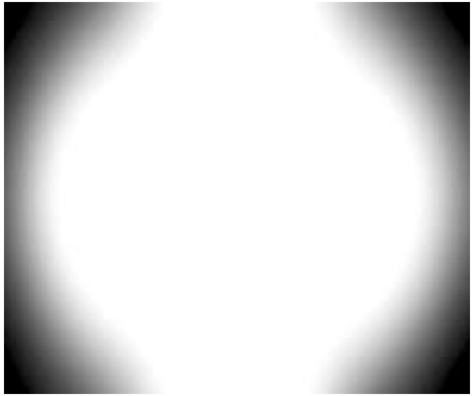
Example: Vintage effect

```
im = double(imread('bike.jpg'));

% Extract each colour plane
R = im(:,:,1); % Red
G = im(:,:,2); % Green
B = im(:,:,3); % Blue

% Create sepia tones for each channel
%(these number can be edited to create different styles)
outR= (R * .293) + (G *.769) + (B * .210);
outG = (R * .249) + (G *.686) + (B * .188);
outB = (R * .172) + (G *.534) + (B * .151);
```

Example: Vintage effect

```
texture = imread(texture_path);
texture = imresize(texture,[size(out,1) size(out,2)]);
texture = double(rgb2gray(texture))/255;

out1(:,:,1) = double(out(:,:,1)).*double(texture);
out1(:,:,2) = double(out(:,:,2)).*double(texture);
out1(:,:,3) = double(out(:,:,3)).*double(texture);
```

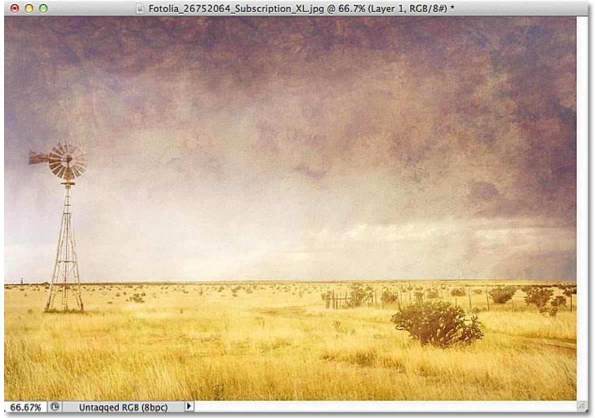
$\times$



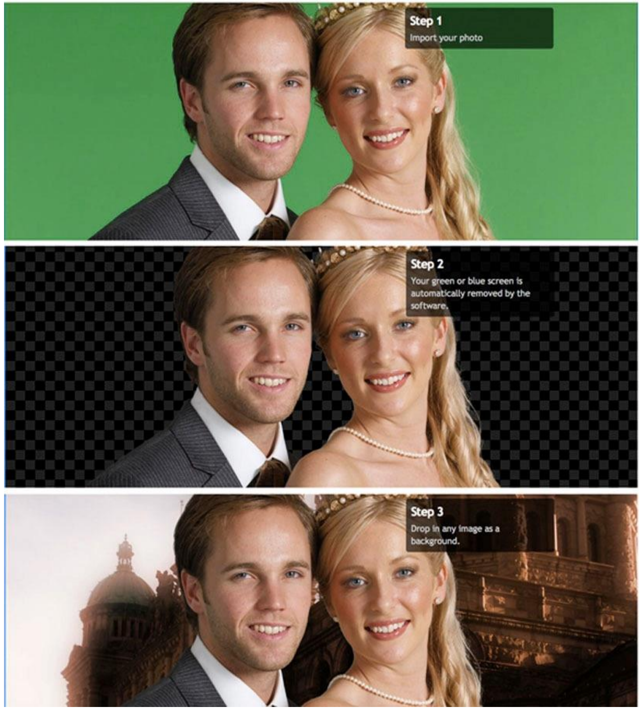
$=$

Other such image effects

1. Change the transformation matrix, to suit the desired color tones
2. Choose or design different textures and blend them with original image
3. Repeat 1 and 2 in innovative ways



Chroma Keying



courtesy: Gonzalez and Woods

References

- “Colorimetry”, Ohta and Robertson, John Wiley and Sons Ltd