Digital Image Processing (CSE/ECE 478)

Lecture 13 : Color Image Processing

Why study color?

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

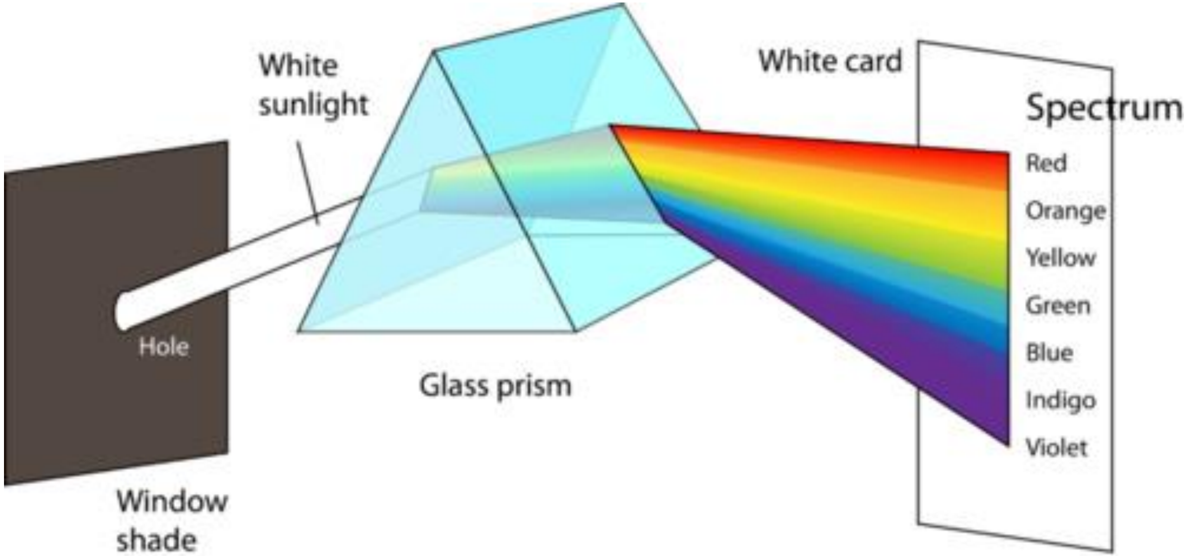
- In terms of digital image processing
  - Image enhancement and manipulation – aesthetics, restoration, reproducing detail.
  - Image analysis – color is information!

What is Color?

- Physical Phenomenon

- Physiopsychological Phenomenon

Color as a Physical Phenomenon



Color as a Physical Phenomenon

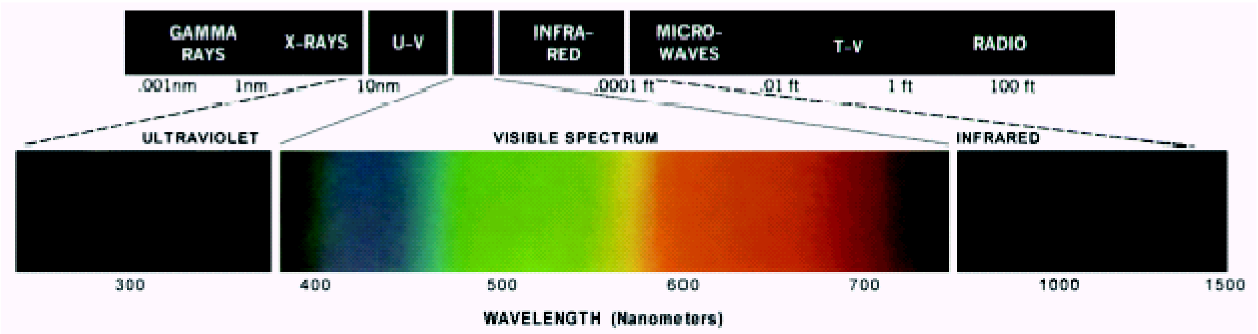


FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Physical Quantities

- Radiance: total amount of energy that flow from the light source, measured in watts (W)

- Luminance: amount of energy an observer *perceives* from a light source, measured in lumens (lm)
  - Far infrared light: high radiance, but 0 luminance

- Brightness: subjective descriptor that is hard to measure, similar to the achromatic notion of intensity

What is Color?

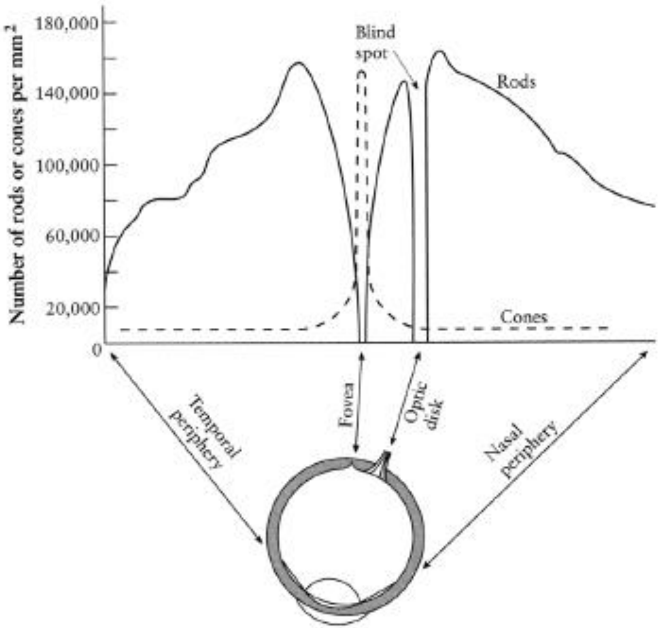
- Physical Phenomenon
- Physiopsychological Phenomenon

Physiopsychological Phenomenon

- The eye and brain turn an incoming emisson spectrum into a discrete set of values.

- The signal sent to our brain is interpreted as color.

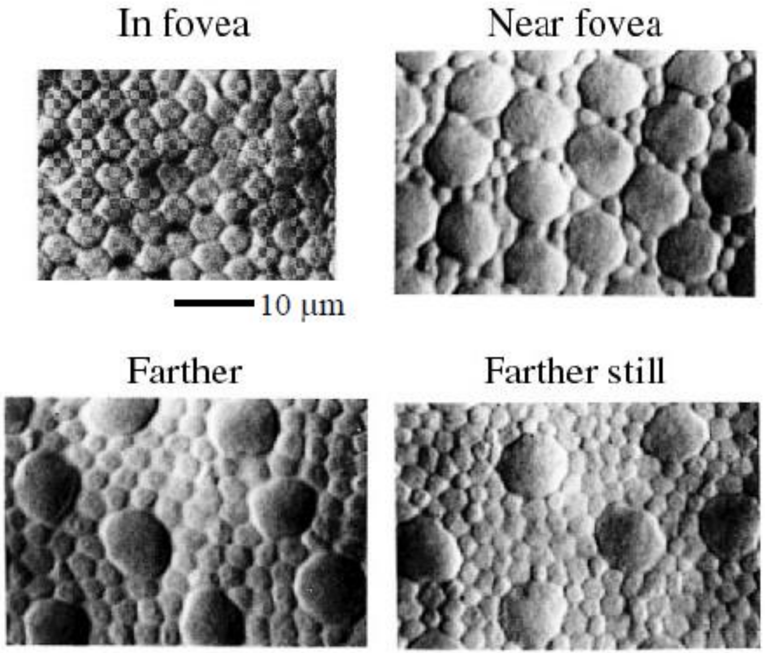
Biology of Vision



Density of photoreceptors on the retina (Glassner, 1.4)

- **Retina** - a layer of photosensitive cells covering 200° on the back of the eye.
  - **Cones** - responsible for color perception.
  - **Rods** - Limited to intensity (but 10x more sensitive).
- **Fovea** - Small region (1 or 2°) at the center of the visual axis containing the highest density of cones (and no rods).

Biology of Vision

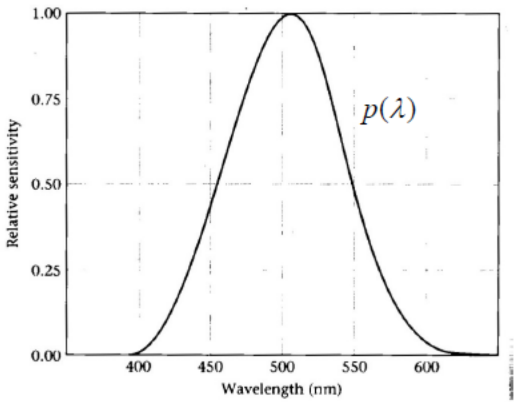


Photomicrographs at increasing distances from the fovea. The large cells are cones; the small ones are rods. (Glassner , 1.5 and Wandell, 3.4).

Biology of Vision

Photopigments are the chemicals in the rods and cones that react to light. Can respond to a single photon!

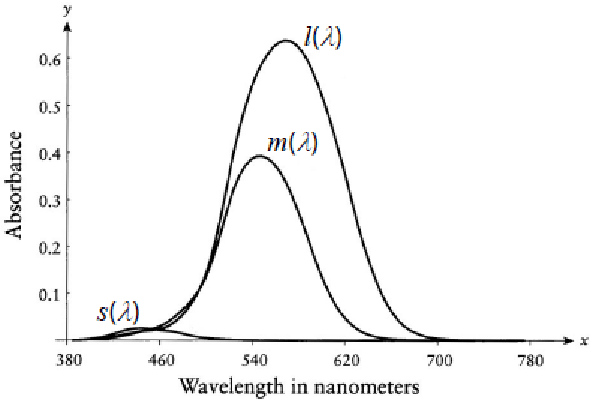
Rods contain **rhodopsin**, which has peak sensitivity at about 500nm.



Rod sensitivity (Wandell ,4.6)

Rods are active under low light levels, i.e., they are responsible for **scotopic** vision.

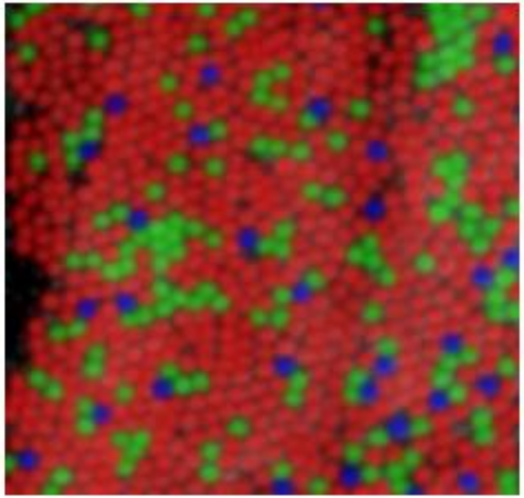
Cones come in three varieties: L, M, and S.

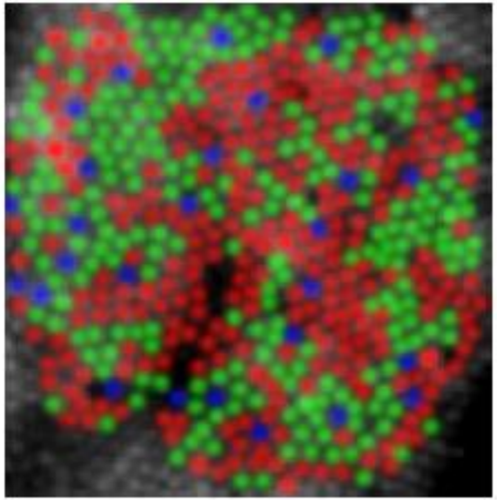


Cone photopigment absorption (Glassner, 1.1)

Cones are active under high light levels, i.e., they are responsible for **photopic** vision.

Cone distribution

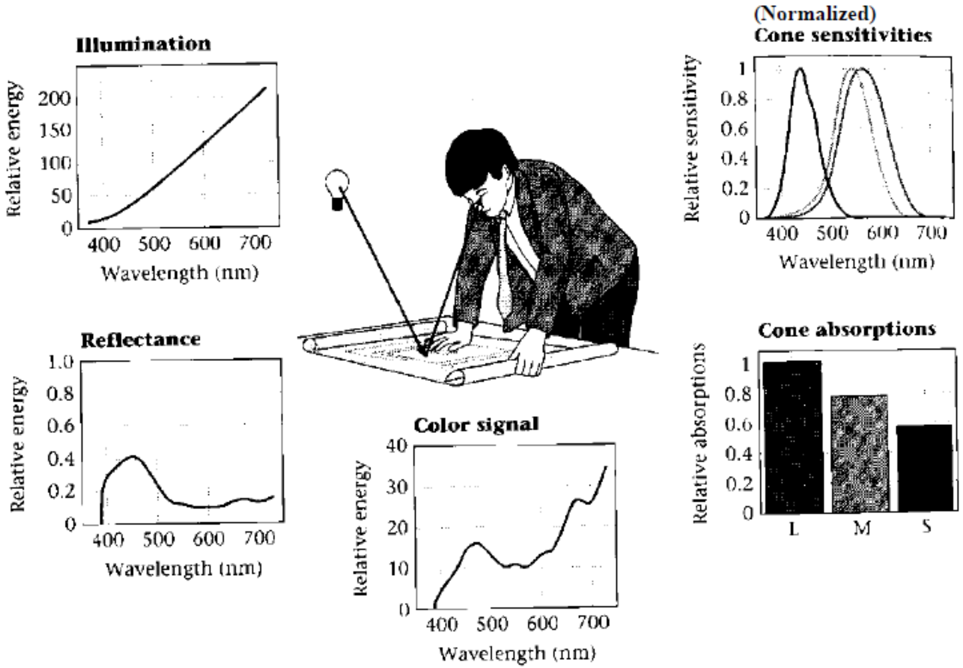




Here are images of near-fovea regions for two different human subjects, with colors to indicate the L (red), M (green) and S (blue) cones:

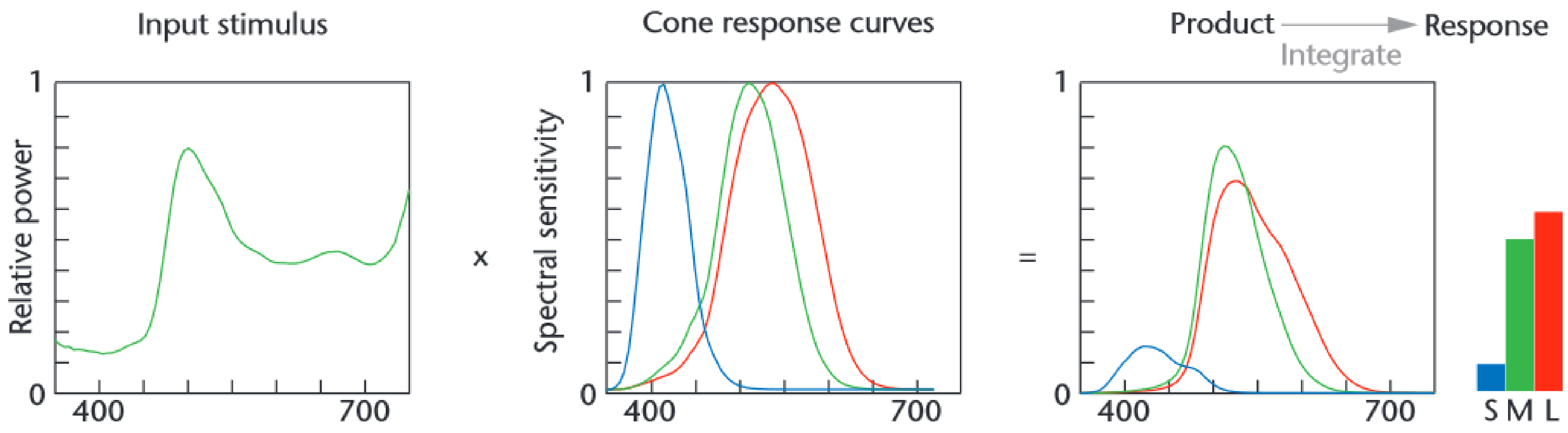
Remarkably, both subjects have normal color vision!

Light source vs. reflected light



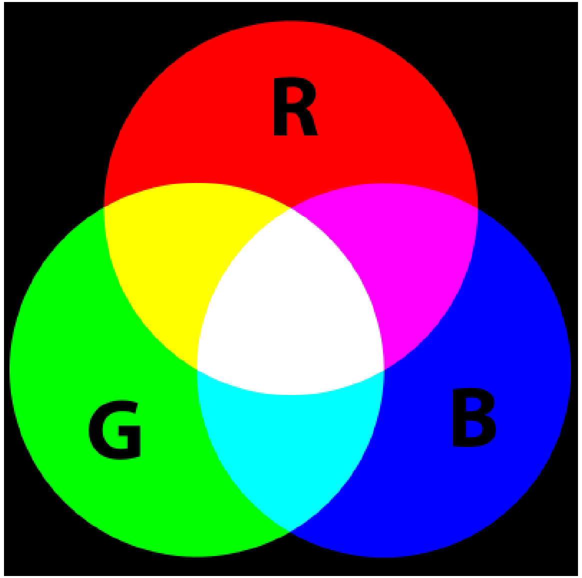
How light and reflectance become cone responses (Wandell, 9.2)

Color signal to the brain



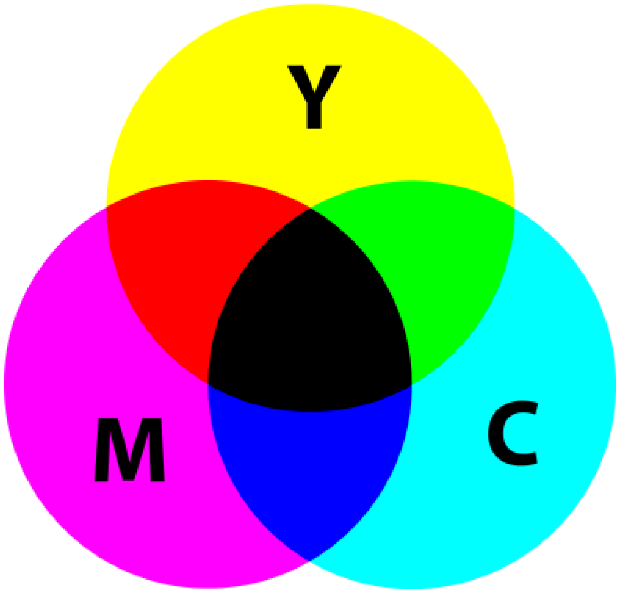
Primary Colors (color as three numbers)

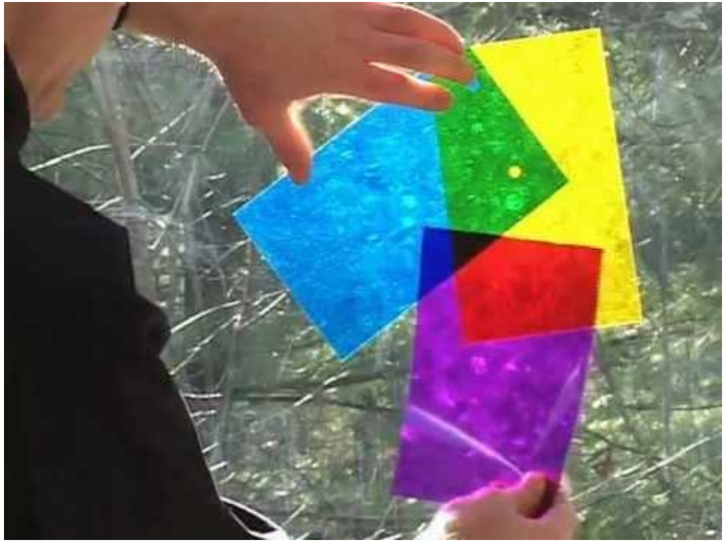
- Additive (CRT displays, projectors etc.)



Primary Colors

- Subtractive (mixing of pigments or dyes)



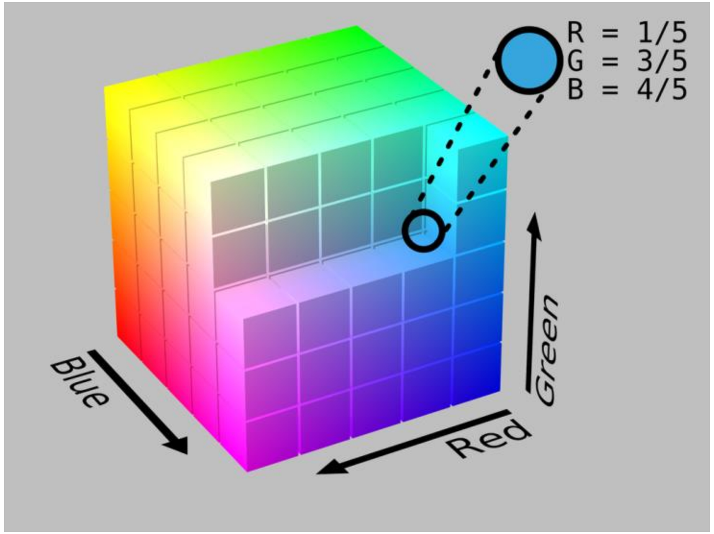


Color Models

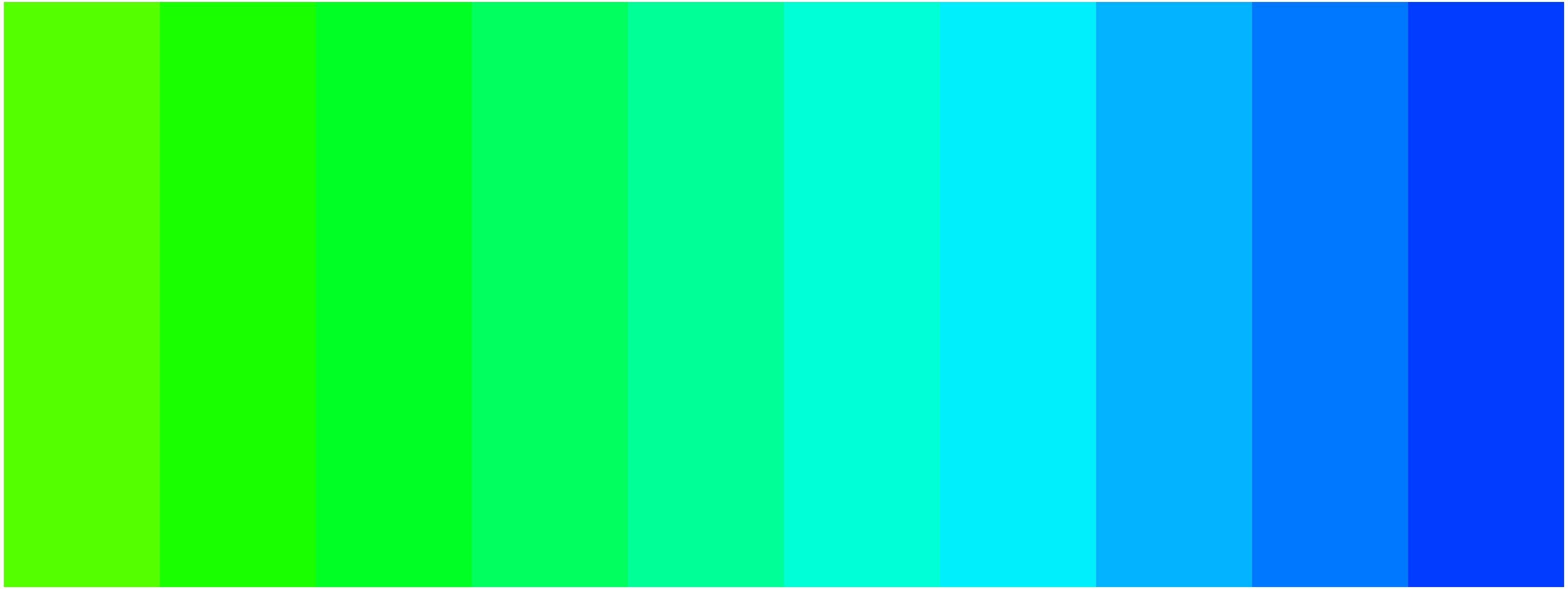
- RGB
- CIE XYZ
- HSI / HSY
- CIE LAB

RGB color space

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

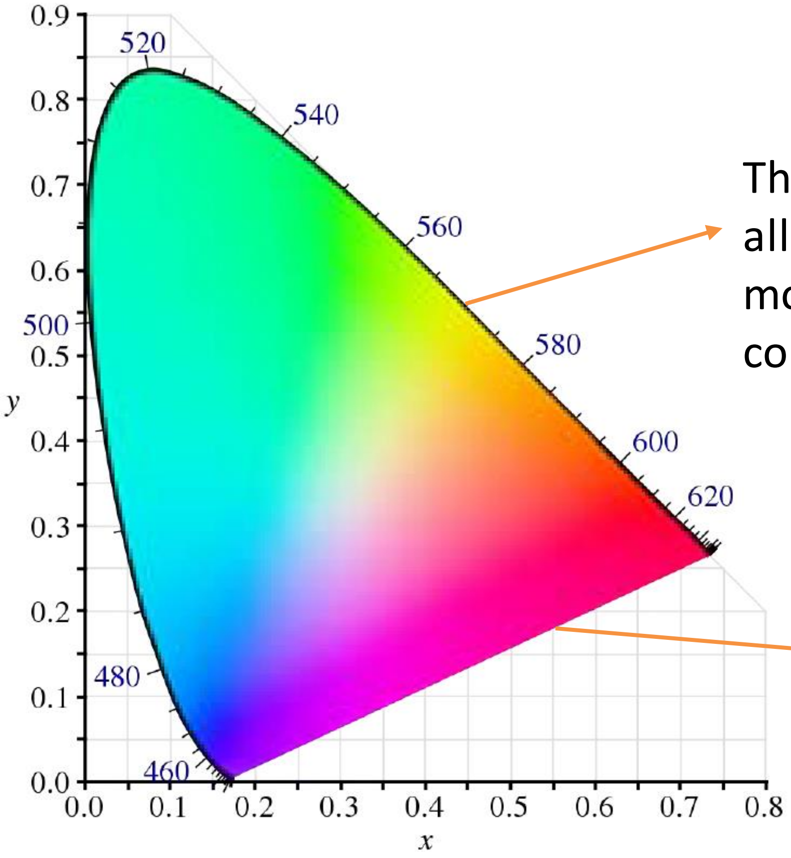


Courtesy: wikipedia



CIE 1931 (x,y) chromaticity diagram

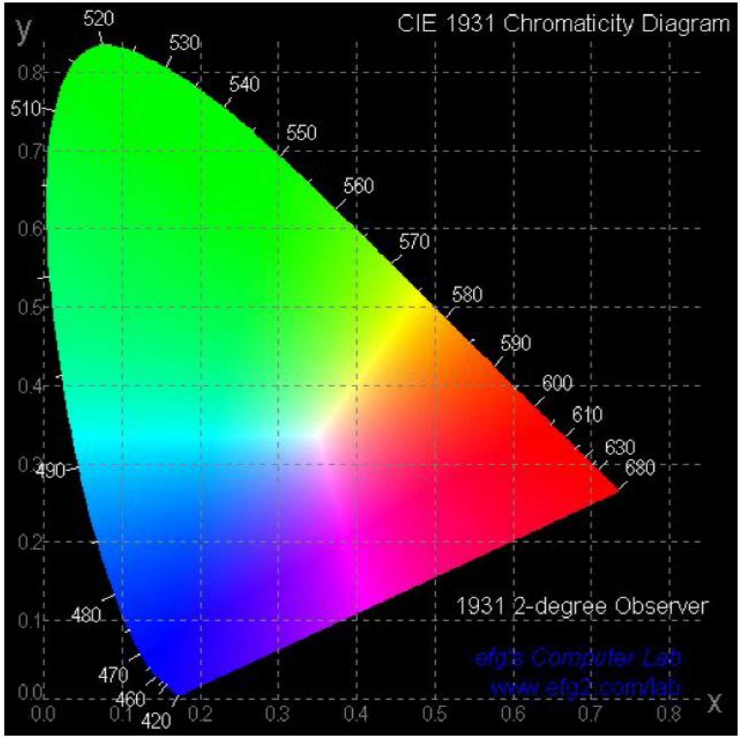
A convenient representation for color values, when we want to tease apart luminance and chromaticity, is therefore Yxy (luminance plus the two most distinctive chrominance components)



The rim represents all of the pure monochromatic colors

Purple Line

CIE 1931 (x,y) chromaticity diagram



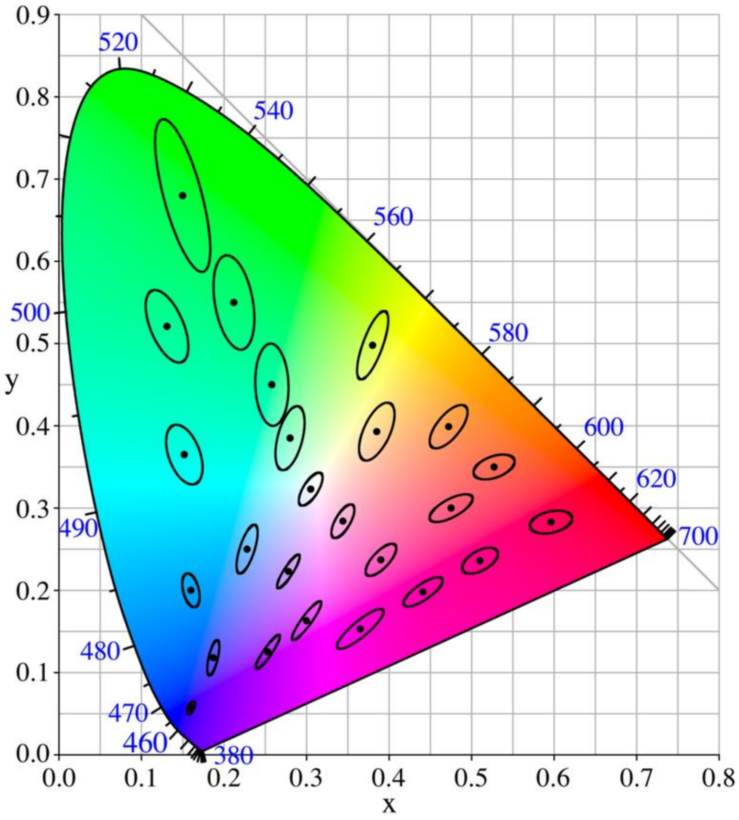
- Chromaticity coordinates:

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

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

- 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

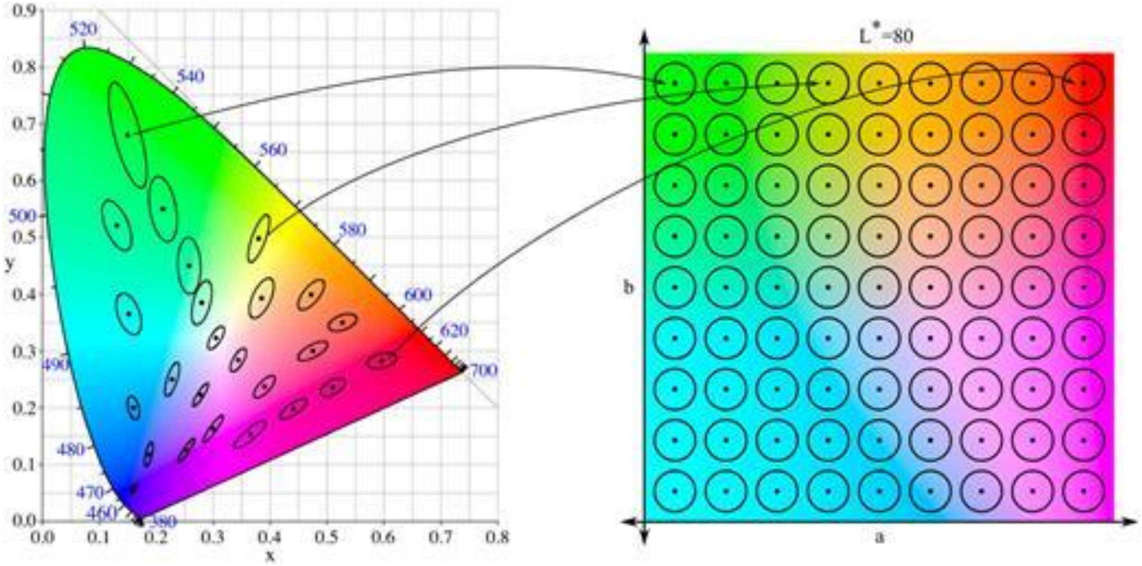
McAdam Ellipses



- **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

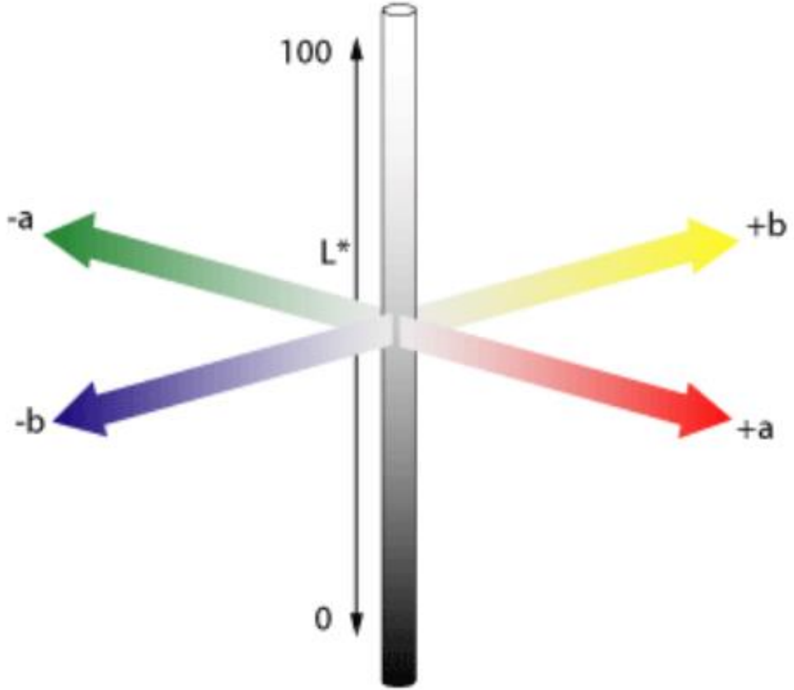


CIE 1931

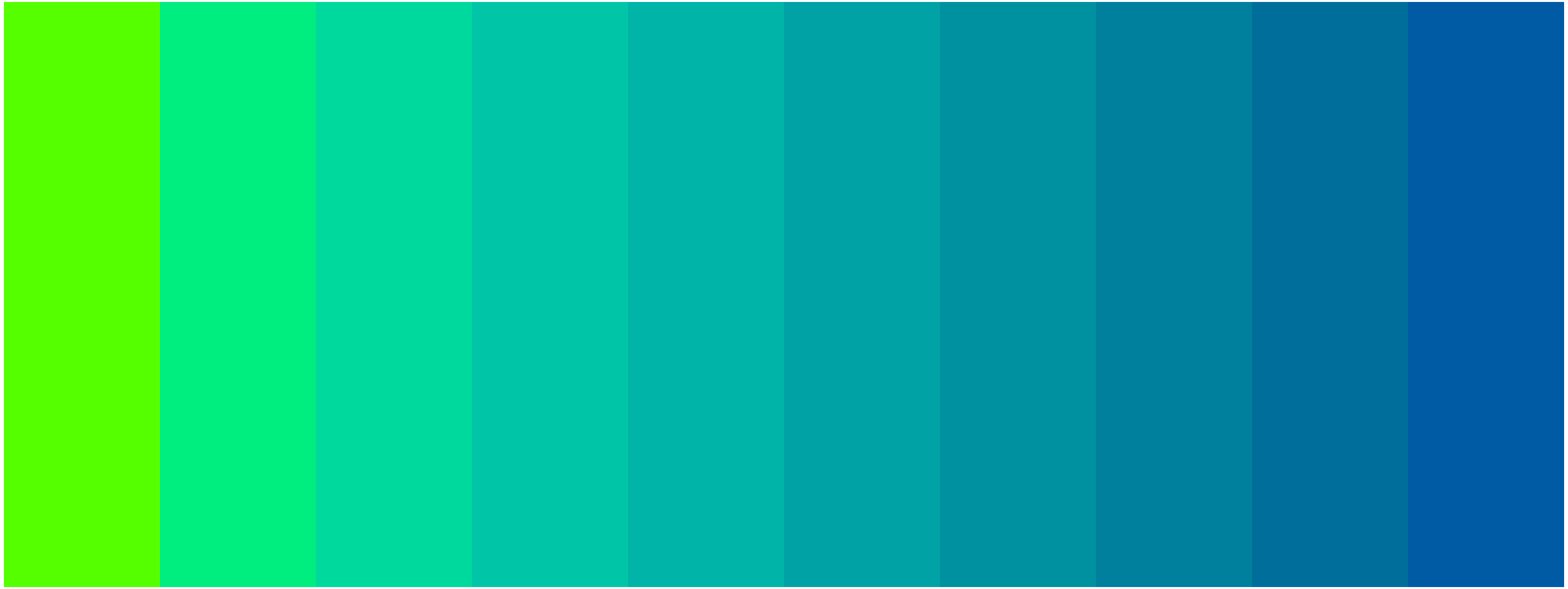
CIELAB (CIE 1976 L*,a*,b*)

Ideal scenario

CIE Lab color space

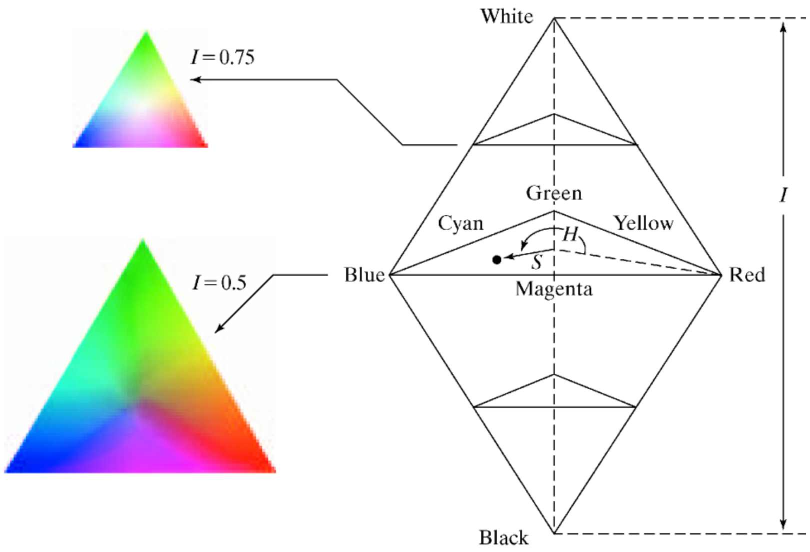


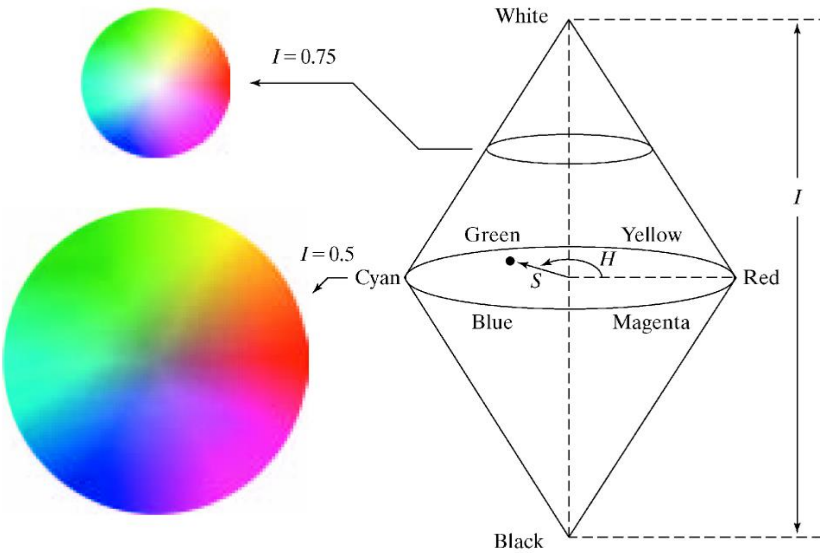
Perceptually Uniform Color Spaces



https://matplotlib.org/3.1.1/tutorials/colors/colormaps.html

HSI color space





color space

- What color space do you think might have been used in re-coloring of Mughal-e-Azam (1960)?

The colourisation team spent 18 months developing software for colouring the frames, called "Effects Plus", which was designed to accept only those colours whose hue would match the shade of grey present in the original film. This ensured that the colours added were as close to the real colour as possible;[113] the authenticity of the colouring was later verified when a costume used in the film was retrieved from a warehouse, and its colours were found to closely match those in the film. Every shot was finally hand-corrected to perfect the look.[116] The actual colourisation process took a further 10 months to complete.[113] The exact cost of the colourisation is disputed, with a wide variety of estimates ranging from ₹20 million (US$290,000)[117] to ₹50 million,[46][118] or ₹100 million.[76]

https://en.wikipedia.org/wiki/Mughal-e-Azam

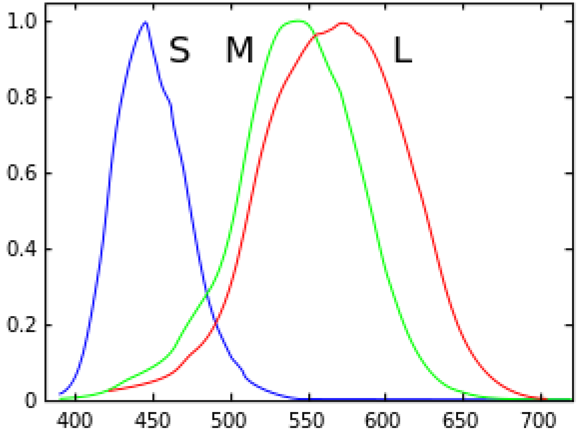
Mayabazar (1957), colorized (2007)

The Film Heritage Foundation announced in March 2015 that they would be restoring *Mayabazar*, along with a few other Indian films from 1931 to 1965, as a part of their restoration projects carried out in India and abroad in accordance with international parameters. **The foundation opposed digital colourisation, stating that they "believe in the original repair as the way the master or the creator had seen it"**

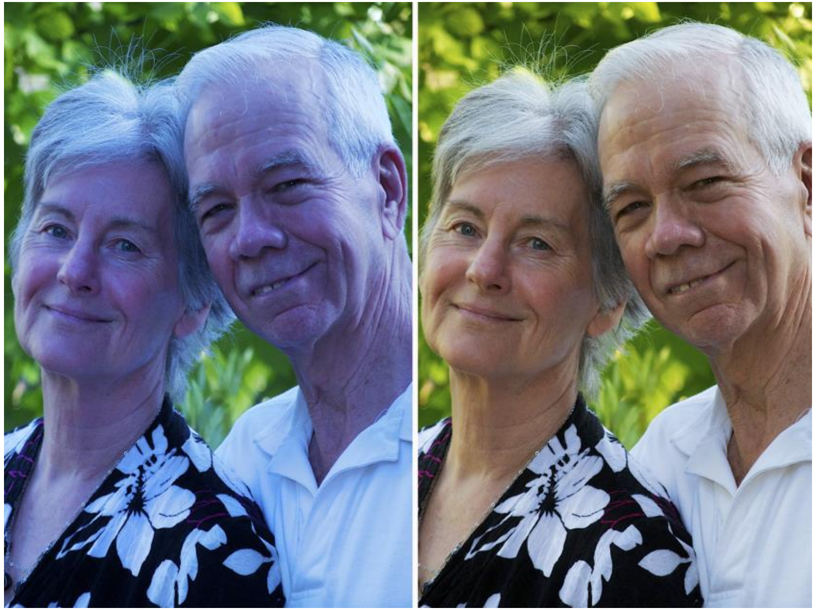
LMS color space

- 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

White Balancing

```
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);
```

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

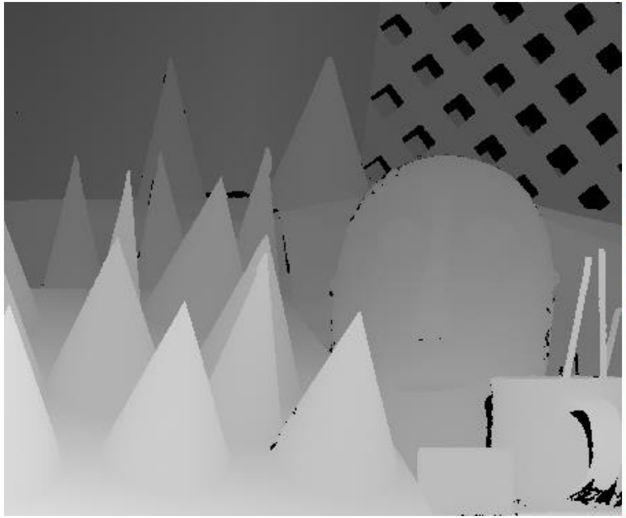
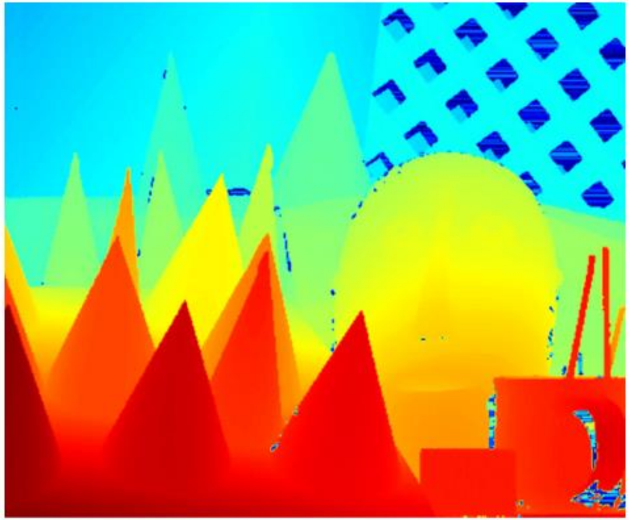
Camera Flash

Cloudy

Shadow

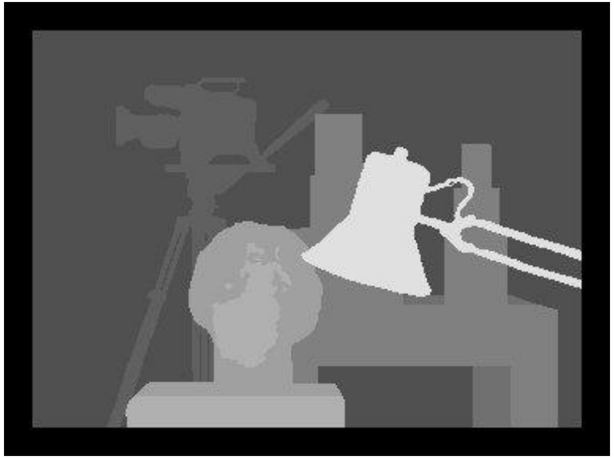
courtesy: seventhgrove.com

Pseudo color Image Processing

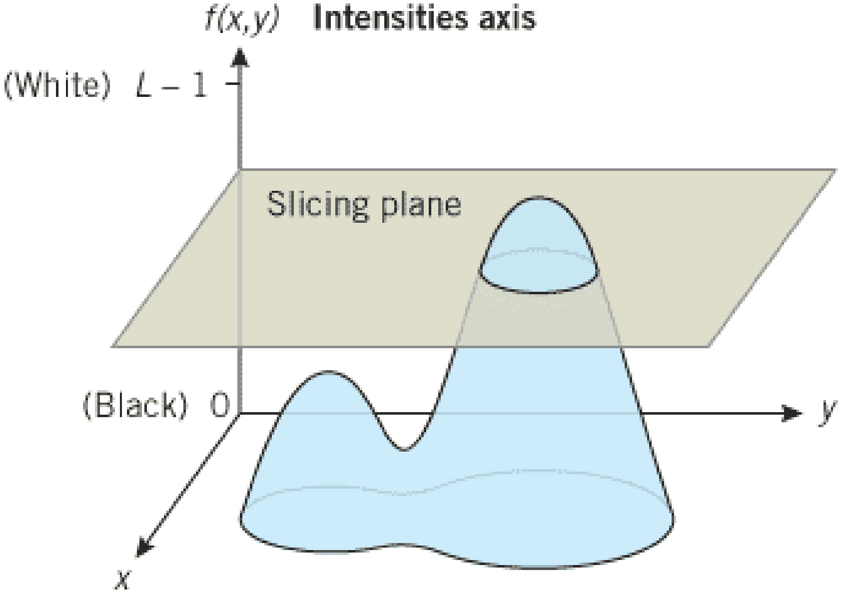
courtesy: middlebury dataset

Pseudo color Image Processing



courtesy: middlebury dataset

Pseudo color Image Processing (Intensity Slicing)

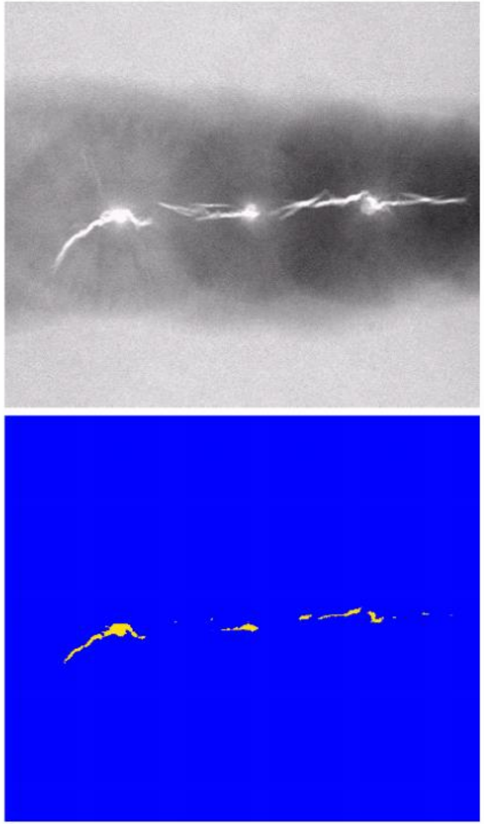


courtesy: Gonzalez and Woods

Pseudo color Image Processing (Intensity Slicing)

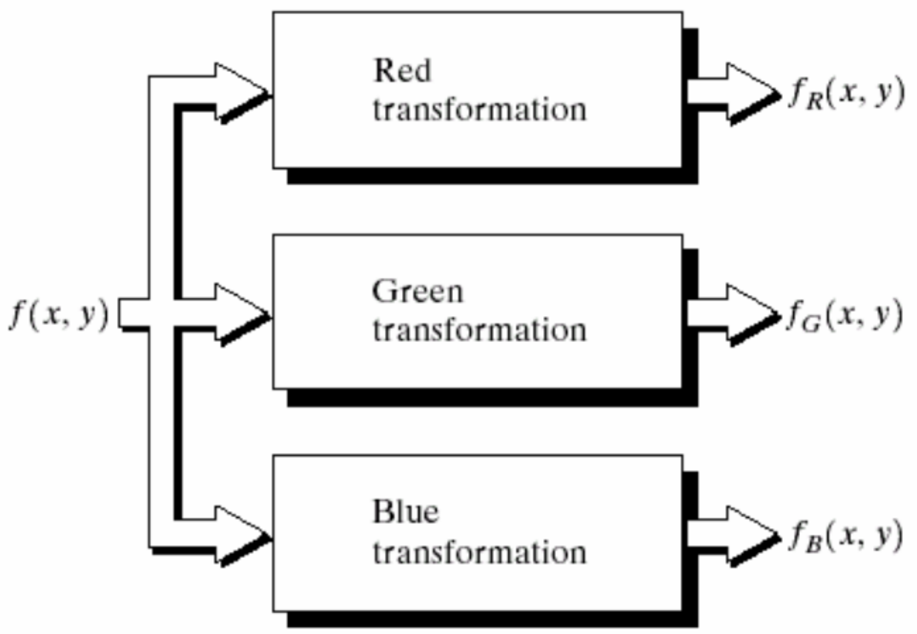
a
b

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



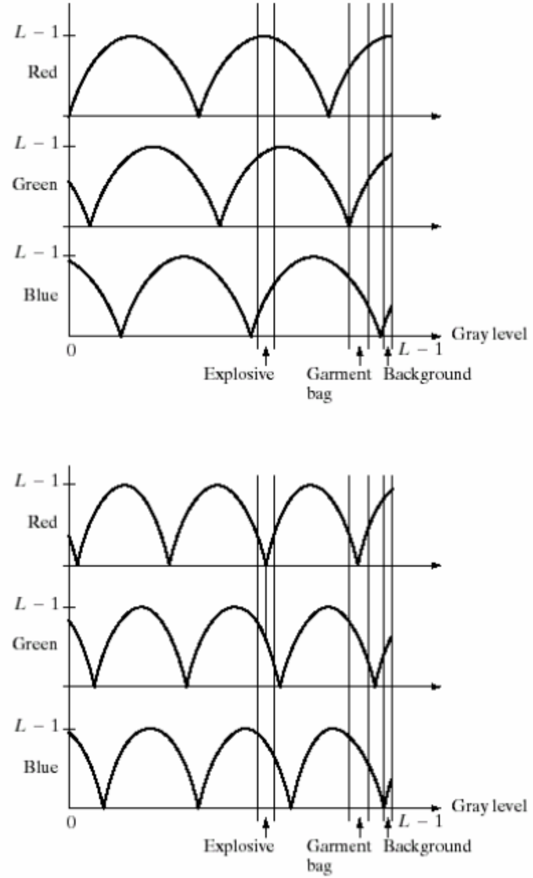
courtesy: Gonzalez and Woods

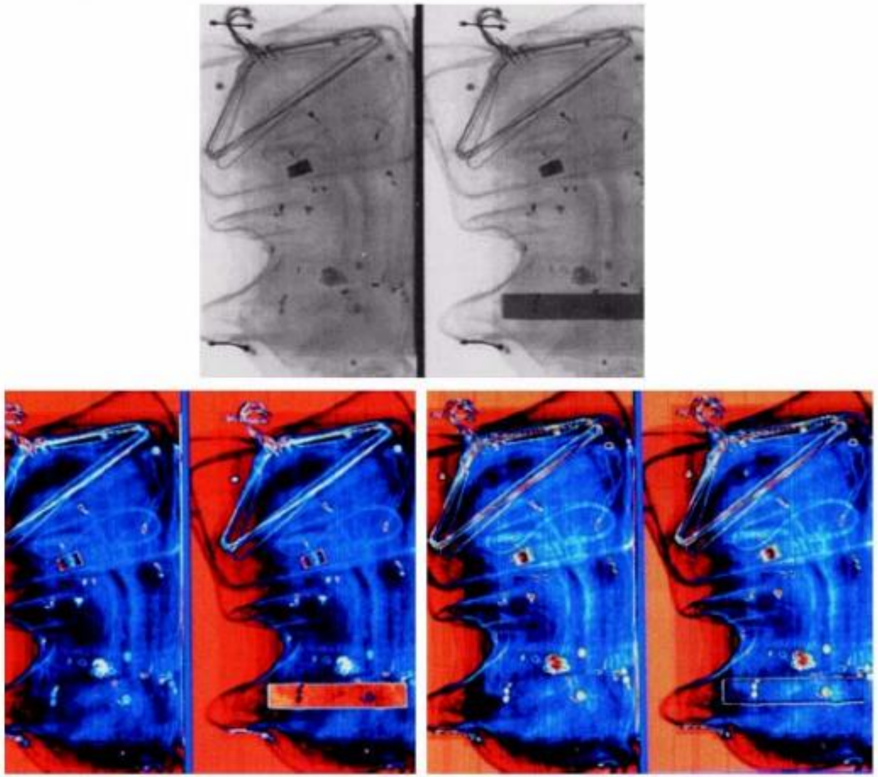
Pseudo color Image Processing (Transformations)



courtesy: Gonzalez and Woods

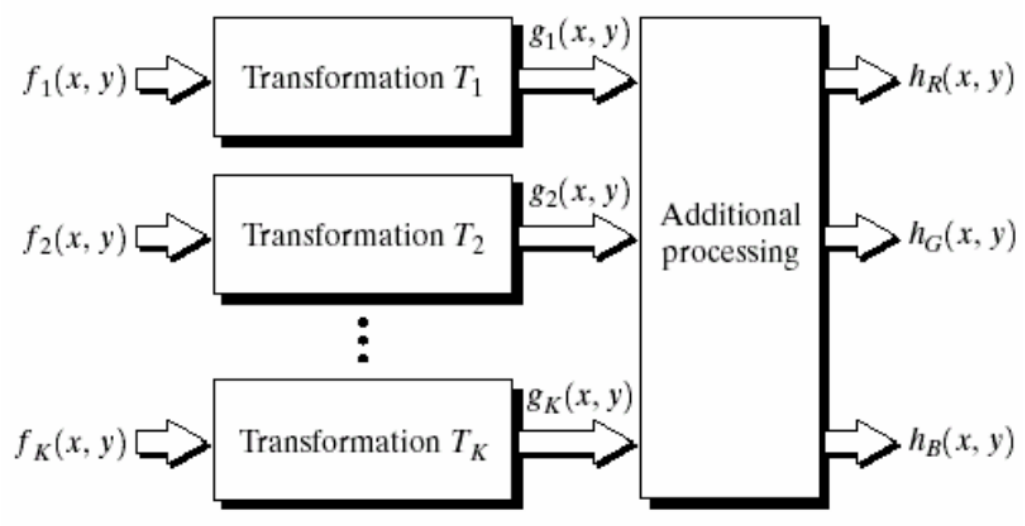
Pseudo color Image Processing (Transformations)





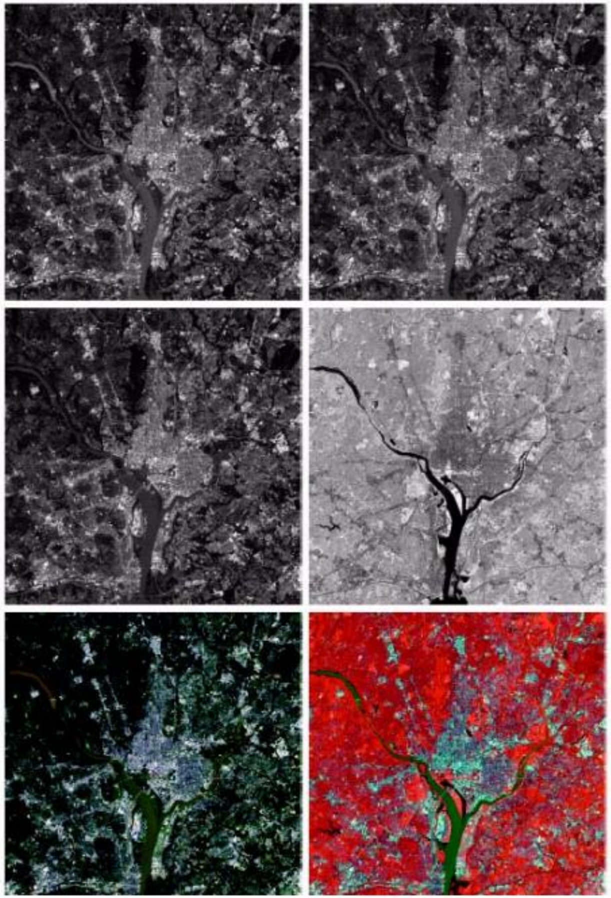
courtesy: Gonzalez and Woods

Pseudo color Image Processing (Multi Spectral)



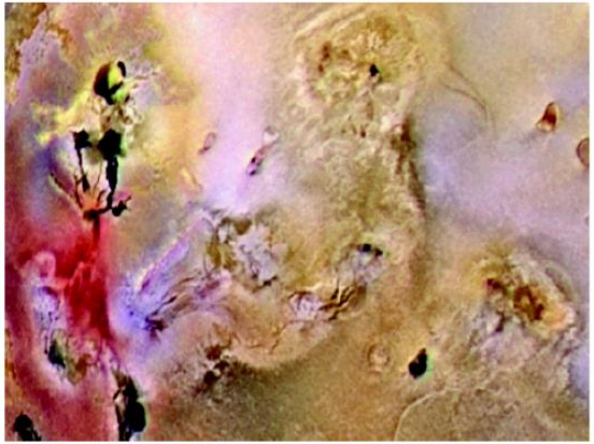
courtesy: Gonzalez and Woods

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

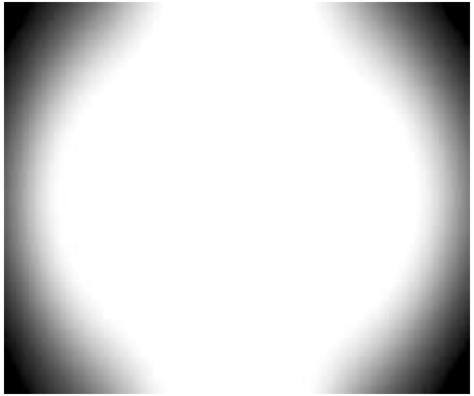
Example: Vintage effect

```
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: Vignetting 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);
```

×



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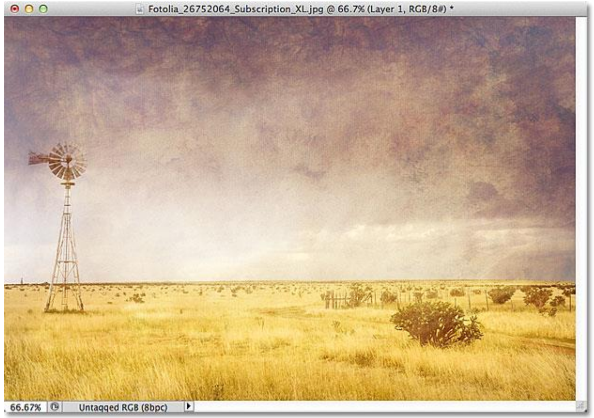
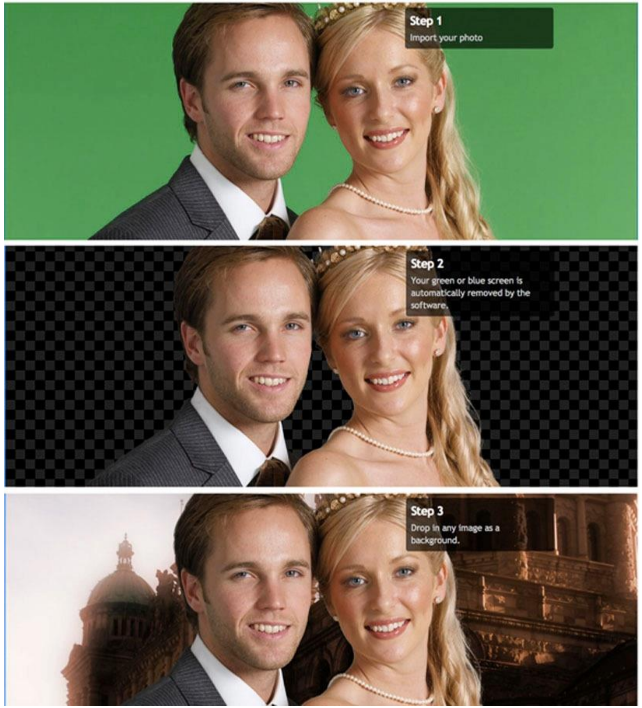
Other such image effects

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