CSI 4133 Computer Methods in Picture Processing and Analysis

Fall 2024

Pengcheng Xi, Ph.D.

Introduction to color

- Color definition
- Color in the human eye (absorption)
- Photoreceptor types

What is color?

- It is a **spectral power distribution** (inside the visible spectrum) of the light reflected or transmitted by an object
  - Many different spectral power distributions may form the same color
  - A pure color is a color composed of only one wavelength (the colors of the rainbow); also called **monochromatic** color
  - A color has a given **hue**, a given **saturation**, and a given **brightness**

Color spectrum

FIGURE 7.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lighting Division.)

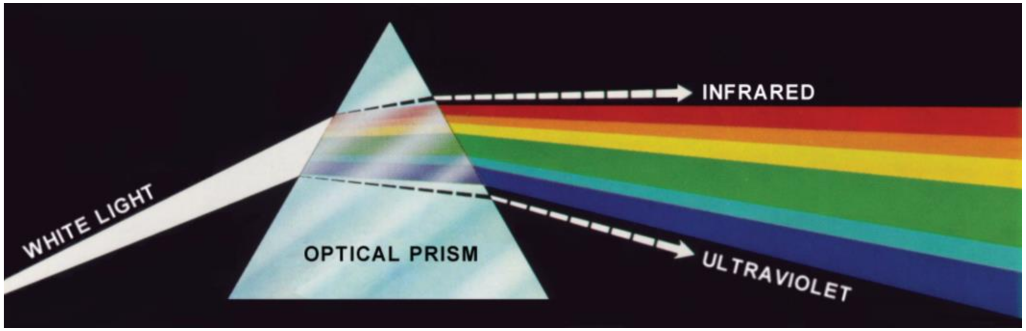
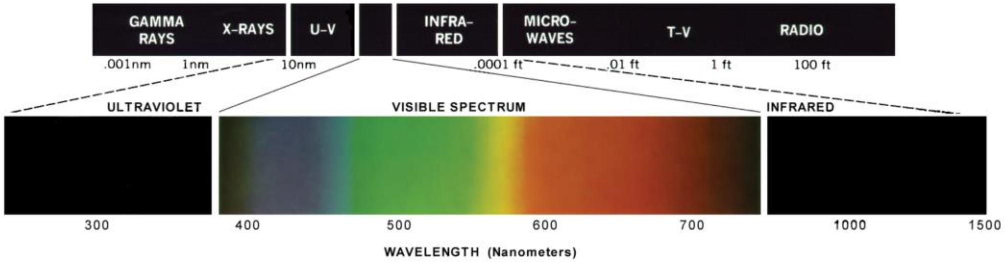


FIGURE 7.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lighting Division.)



www.imageprocessingbook.com

Color in the human eye (absorption)

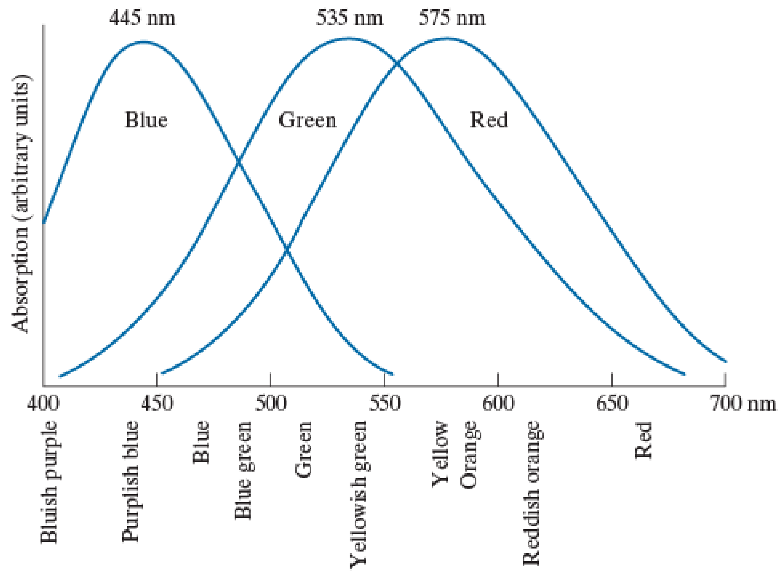
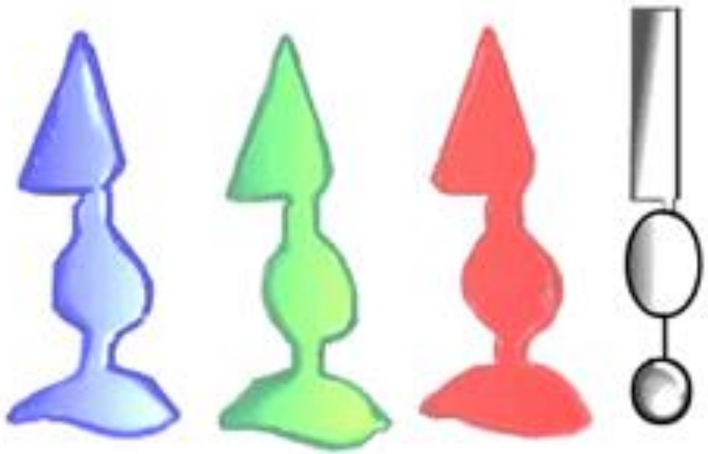
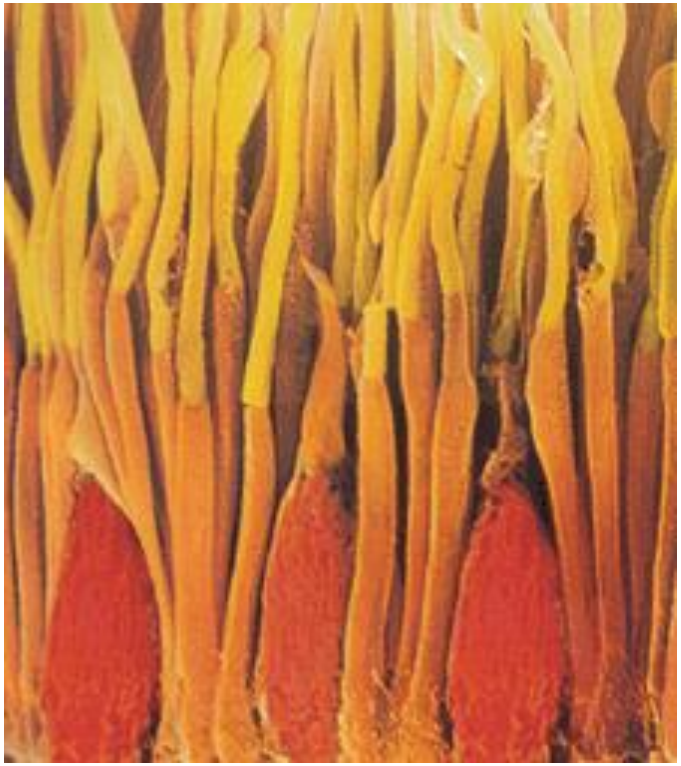


FIGURE 7.3 Absorption of light by the red, green, and blue cones in the human eye as a function of wavelength.

Photoreceptor types



Scanning electron micrograph of the rods and cones of the primate retina

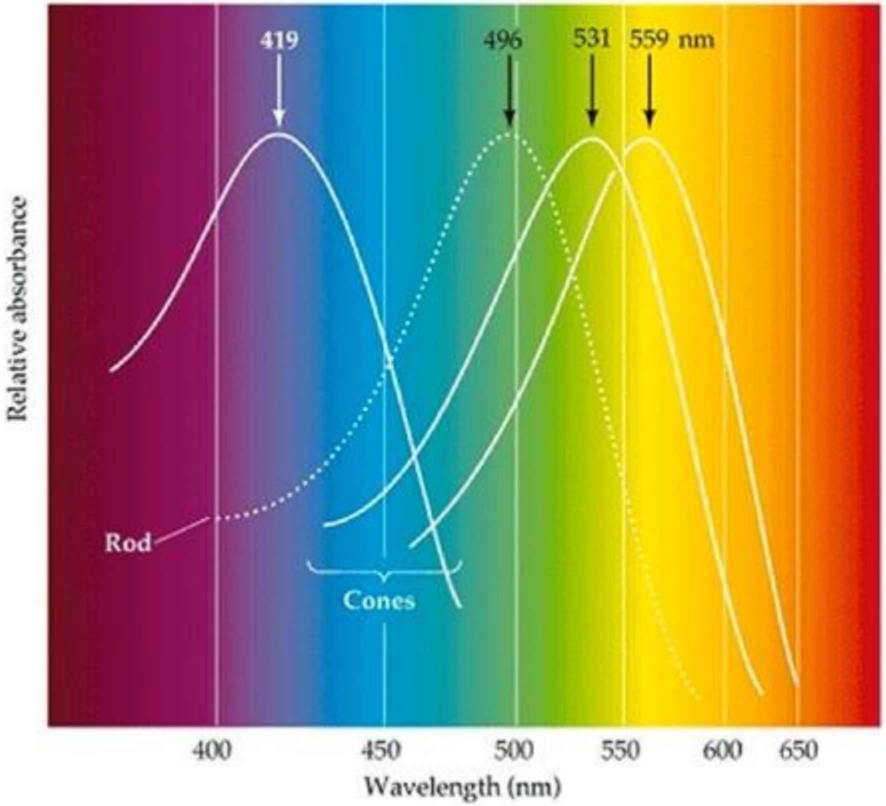


http://webvision.med.utah.edu/book/part-ii-anatomy-and-physiology-of-the-retina/photoreceptors/

Cone cell

- 3 types of cones (color perception):
  - Red absorbing cones
    - Those that absorb best at the relatively long wavelengths peaking at 565 nm
  - Green absorbing cones
    - With a peak absorption at 535 nm
  - Blue absorbing cones
    - With a peak absorption at 440 nm
- Wavelength of maximum cone sensitivity:
  - 560 nm (orange)

Light spectra (absorbance for rod and cones)



http://webvision.med.utah.edu/book/part-ii-anatomy-and-physiology-of-the-retina/photoreceptors/

Learning resources on color

- Color vision 3: color map by Craig Blackwell

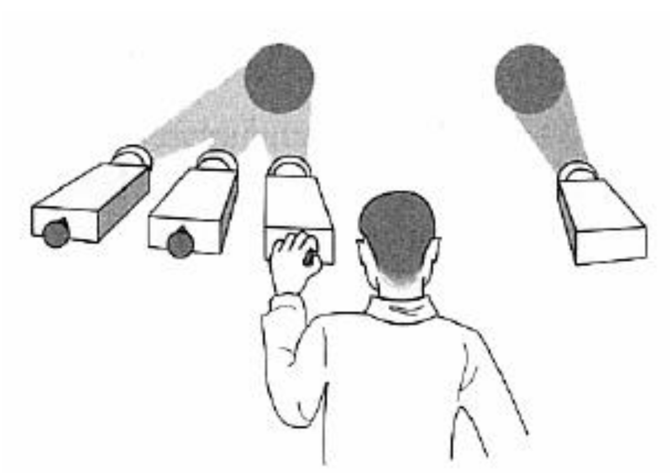
https://www.youtube.com/watch?v=KDiTxWcD3ZE

Color representation

- Tri-stimulus values
- Color matching
- Metamerism
- Gamut

Tri-stimulus values

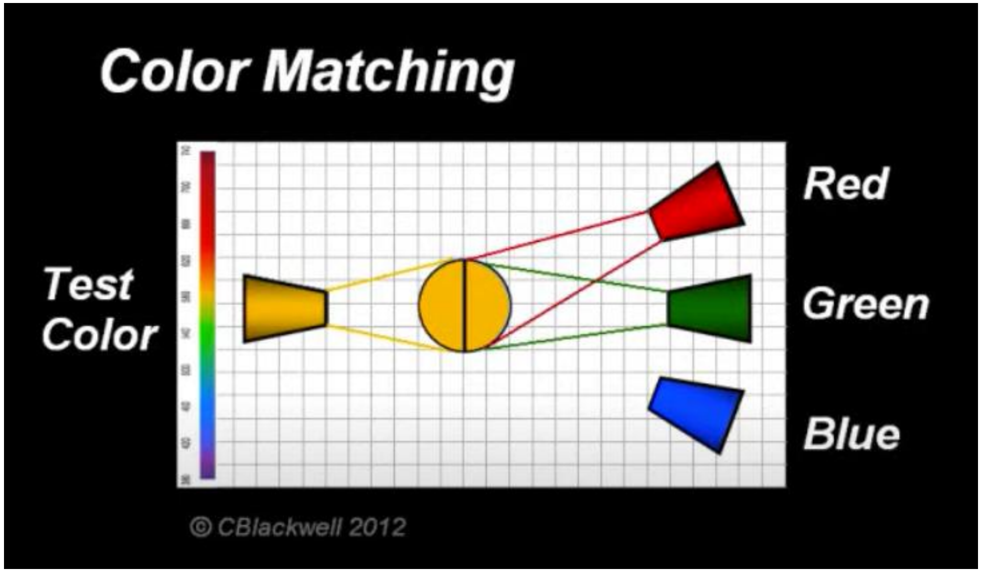
- The amount of red, green, and blue needed to form any particular color
- To reproduce a given color $c(\lambda)$

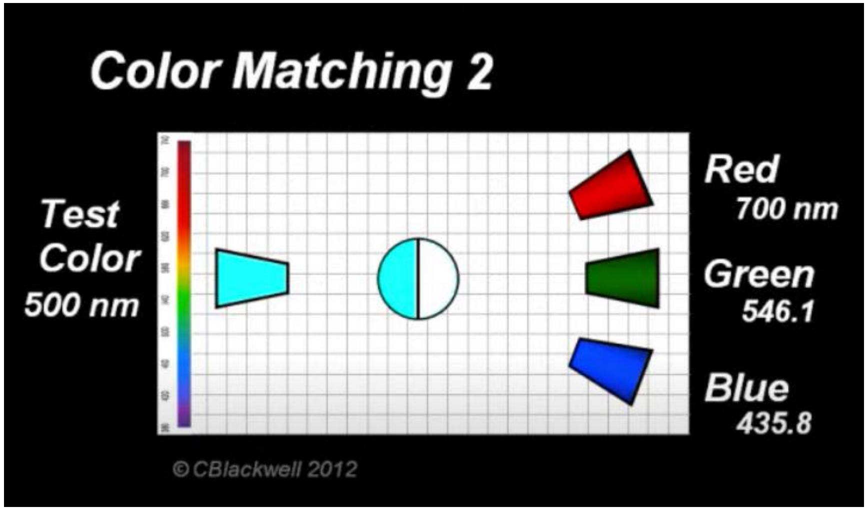


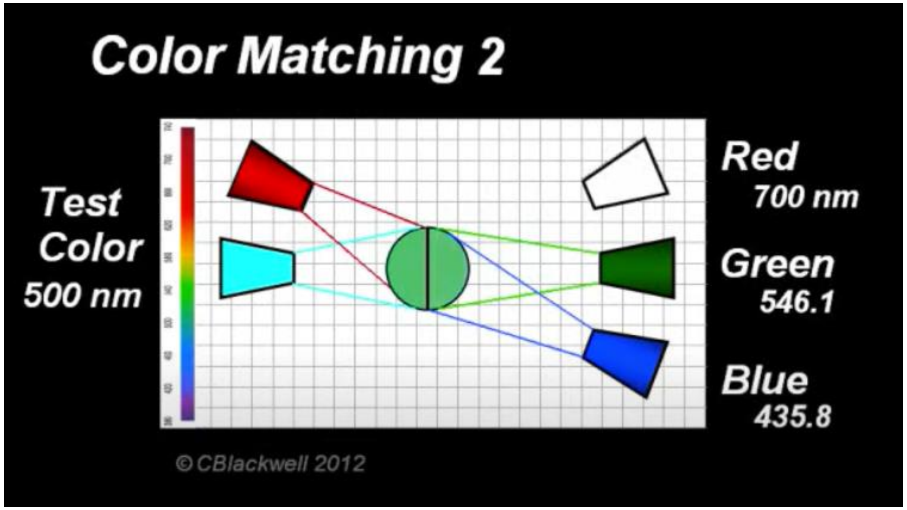
$$R = \int c(\lambda) r(\lambda) d\lambda$$

$$G = \int c(\lambda) g(\lambda) d\lambda$$

$$B = \int c(\lambda) b(\lambda) d\lambda$$

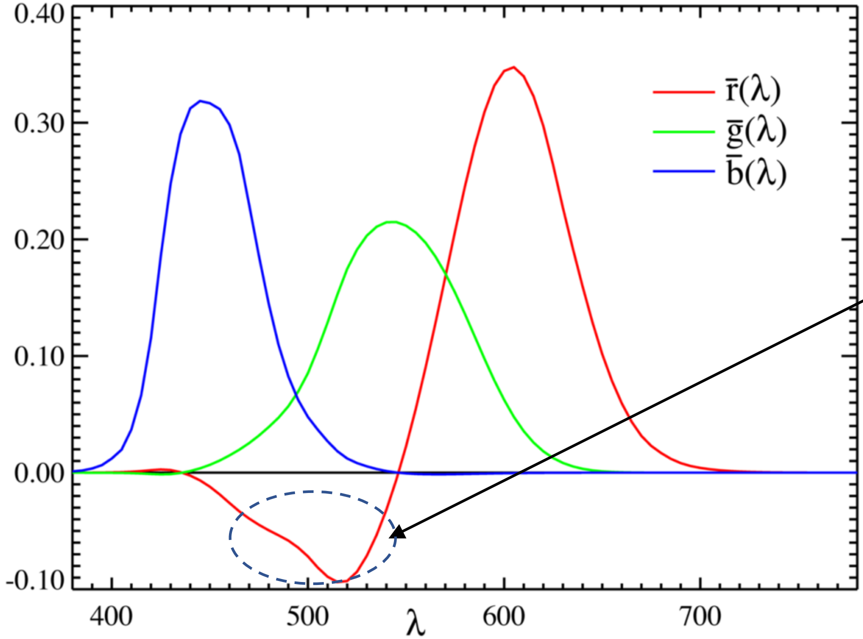

Color Matching
Test Color
Red
Green
Blue
© CBlackwell 2012

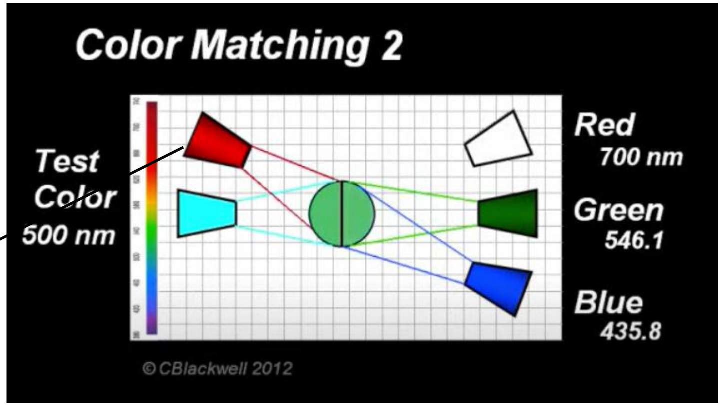

Color Matching 2
Test Color 500 nm
Red 700 nm
Green 546.1
Blue 435.8
© CBlackwell 2012


Color Matching 2
Test Color 500 nm
Red 700 nm
Green 546.1
Blue 435.8
© CBlackwell 2012

Color matching functions

- The graph of the tristimulus values as a function of wavelength $r(\lambda), g(\lambda), b(\lambda)$

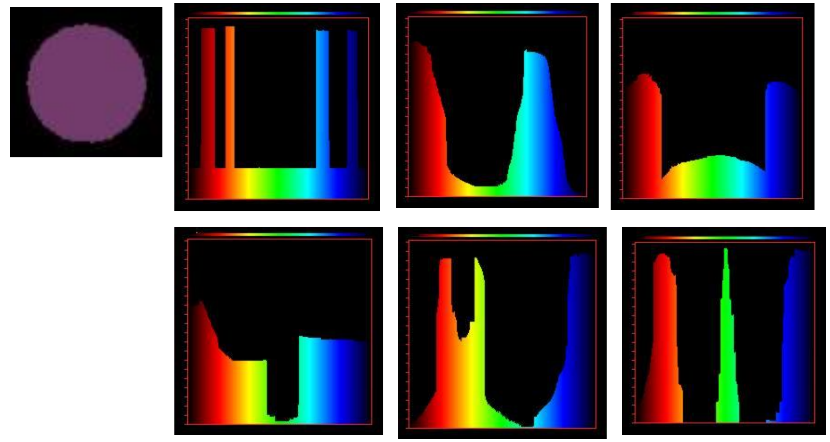




The CIE 1931 RGB Color matching functions

http://en.wikipedia.org/wiki/CIE_1931_color_space

Metamer



- A **metamer** refers to two or more colors that look identical to the human eye under certain lighting conditions but are made up of different wavelengths of light. In other words, metamers have different spectral power distributions but appear the same to an observer due to the way our visual system processes color.
- Metamers occur because human vision relies on three types of photoreceptors (cones), which **respond to broad ranges of light** rather than specific wavelengths. As a result, different combinations of wavelengths can stimulate the cones in the same way, leading to the perception of the same color, even though the **underlying light spectra are different**.

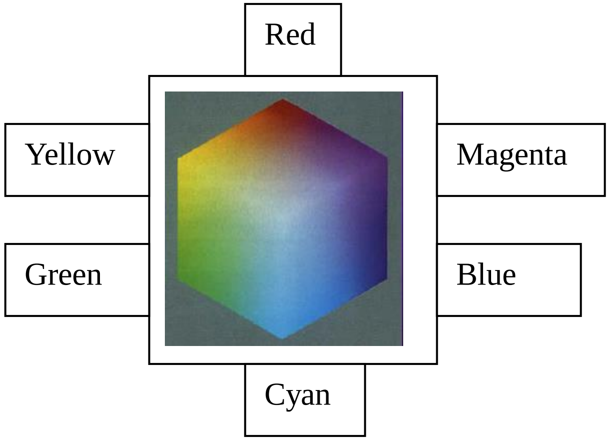
Color in standards

- **CIE** (Commission Internationale de l'Éclairage) is the primary organization that defines color metric standards
- **CIE RGB** - Primary colors definition (1931)
  - Red (700nm)
  - Green (546.1nm)
  - Blue (435.8 nm)

Chromaticity coordinates

- **Tri-chromaticity coordinates**:
  - Ratio of each tri-stimulus value to their sum

$$r = \frac{R}{R+G+B} \qquad g = \frac{G}{R+G+B} \qquad b = \frac{B}{R+G+B}$$



1R + 1G + 1B = White

CIE's XYZ coordinate system

- In 1931, the CIE proposed a new set of primaries: **XYZ**
  - Negative coefficients were eliminated
  - The primaries are not real colors
  - Y corresponds to the luminous efficiency functions giving the relative eye sensitivity to energy at different wavelength (luminance).
    - Also specified as Yxy
  - Used to specify colors

Tristimulus

- Let X, Y, and Z be the *tristimulus* values.
- A color can be specified by its *trichromatic coefficients*, defined as

$$x = \frac{X}{X+Y+Z} \longrightarrow \text{X ratio}$$

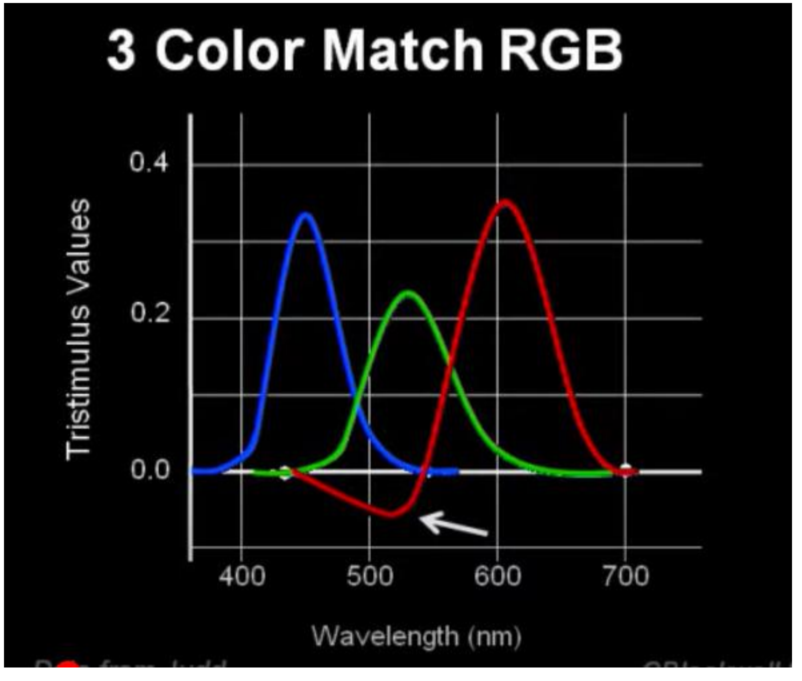
$$y = \frac{Y}{X+Y+Z} \longrightarrow \text{Y ratio}$$

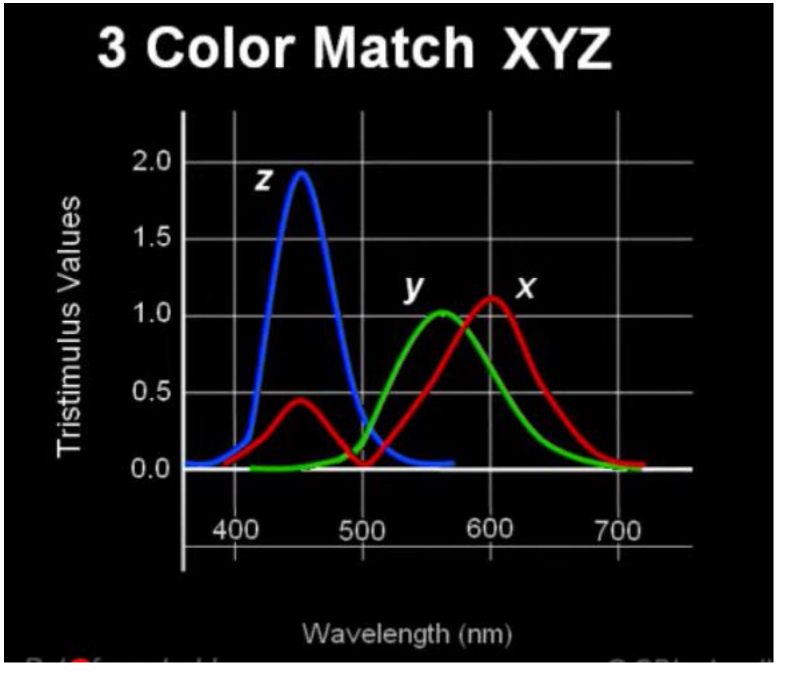
$$z = \frac{Z}{X+Y+Z} \longrightarrow \text{Z ratio}$$

Two trichromatic coefficients are enough to specify a color.
($x + y + z = 1$)

CIE's XYZ coordinate system

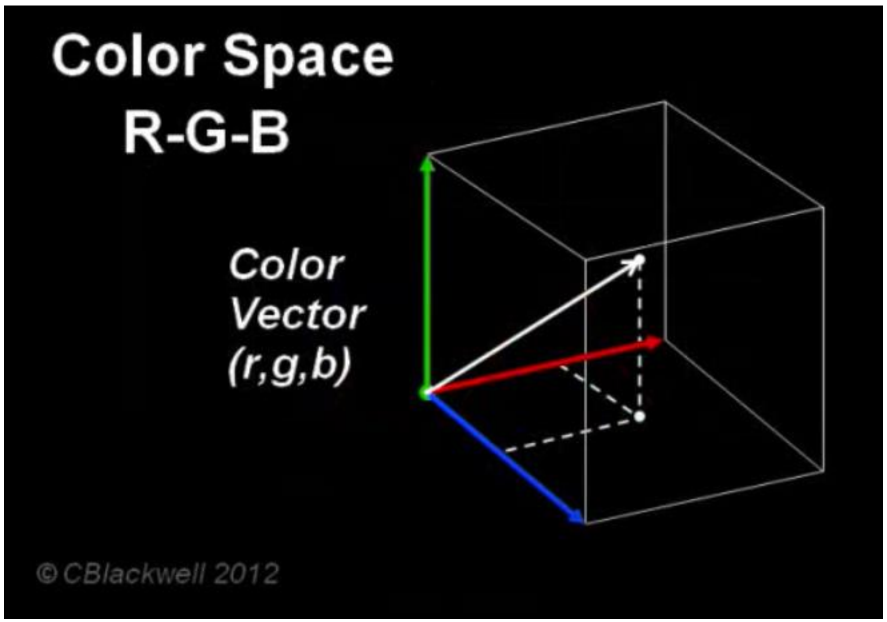
- **RGB -> CIE's XYZ**

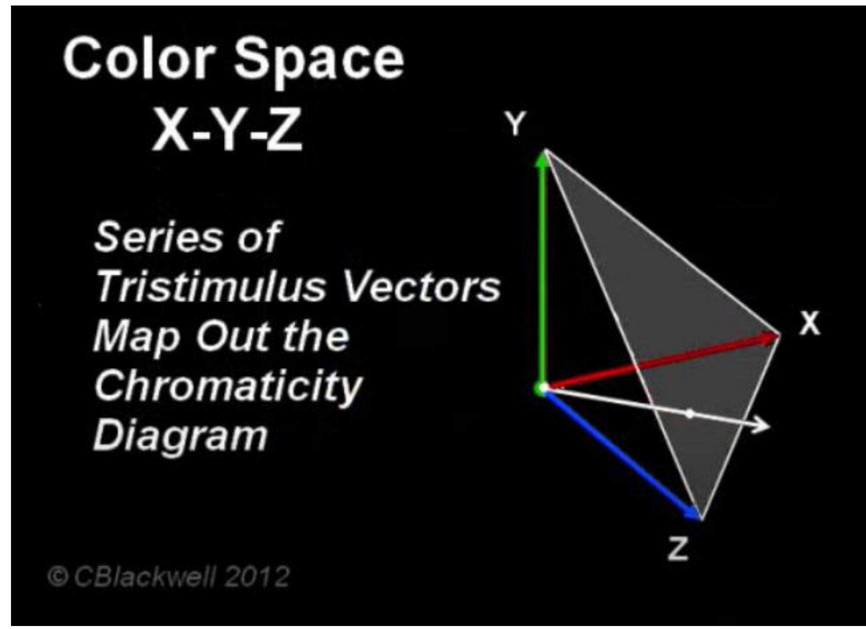




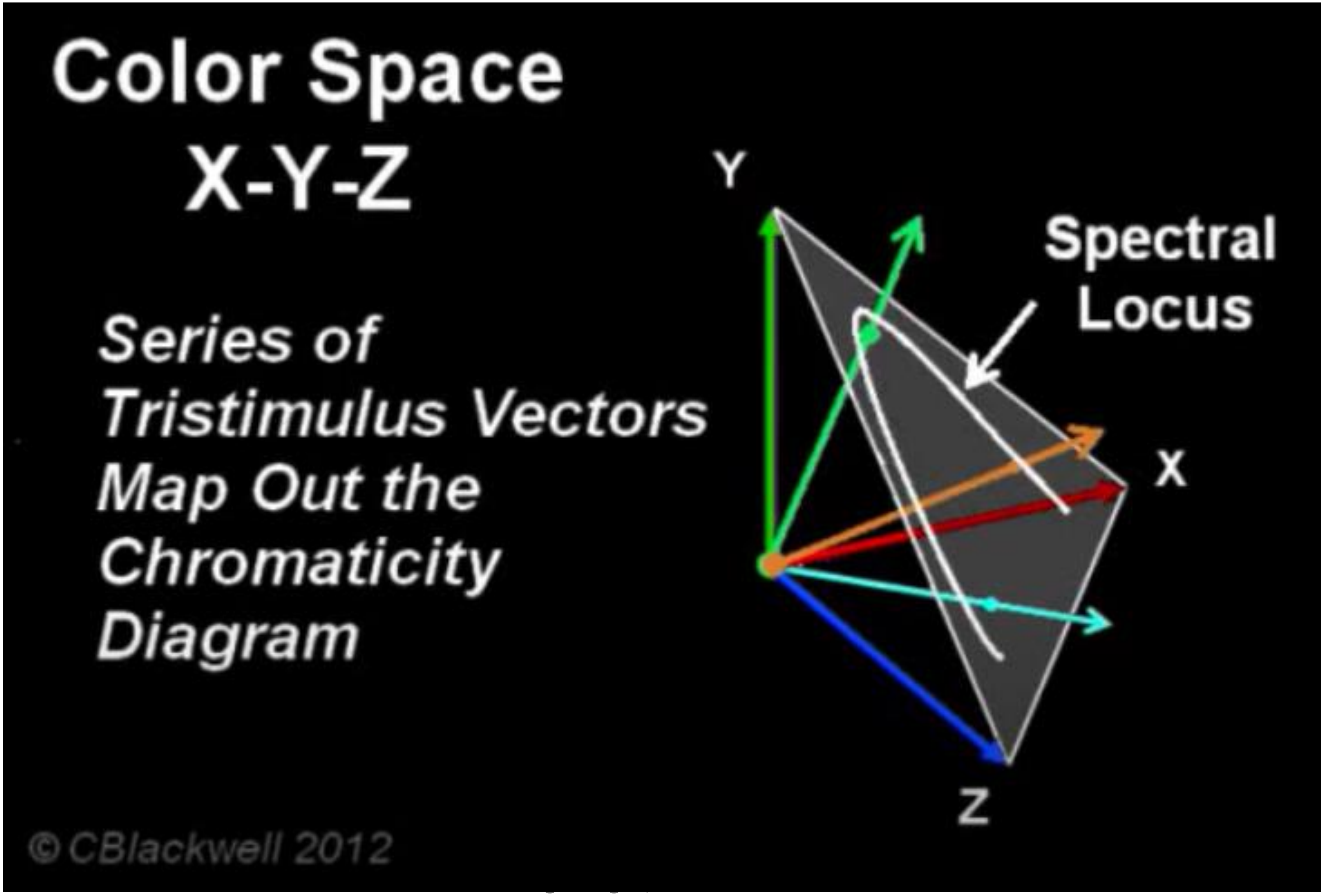
https://www.youtube.com/watch?v=KDiTxWcD3ZE

Color space in 3D

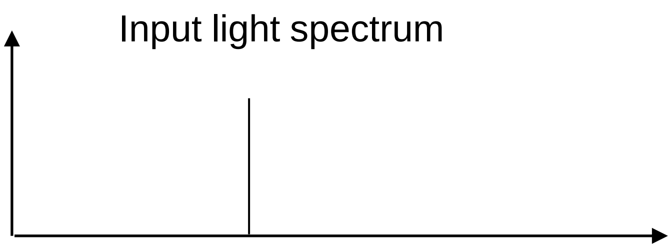


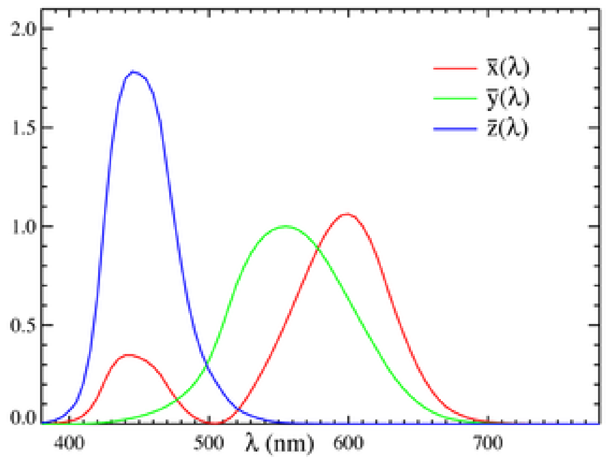


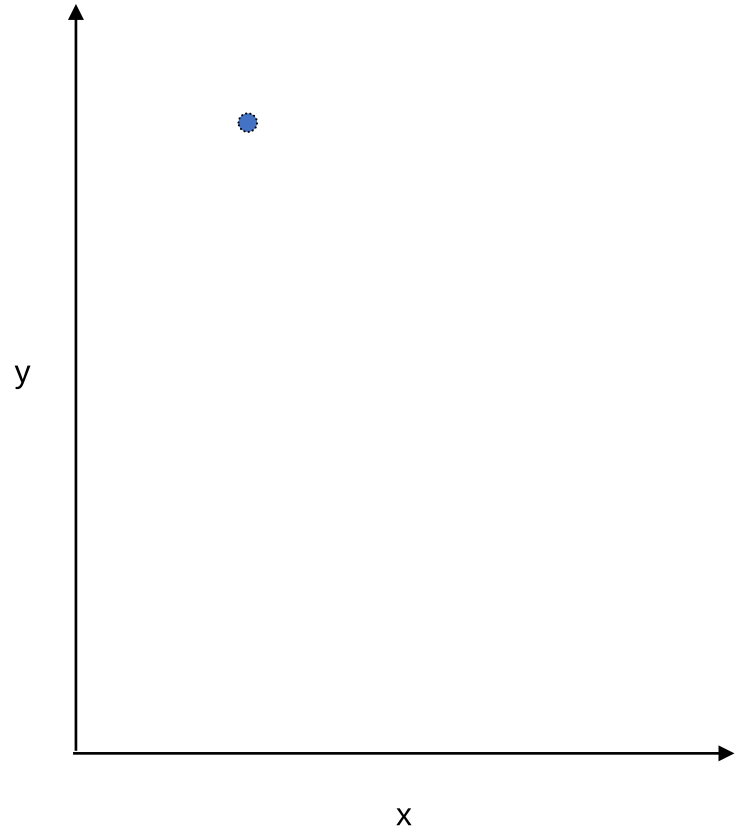
Chromaticity diagram



CIE chromaticity diagram

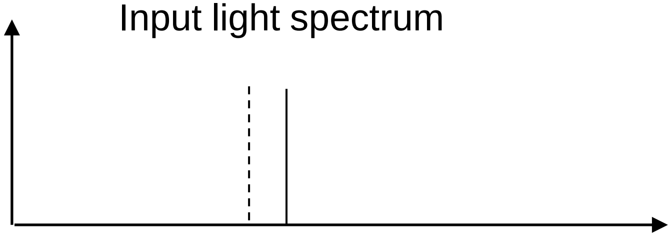


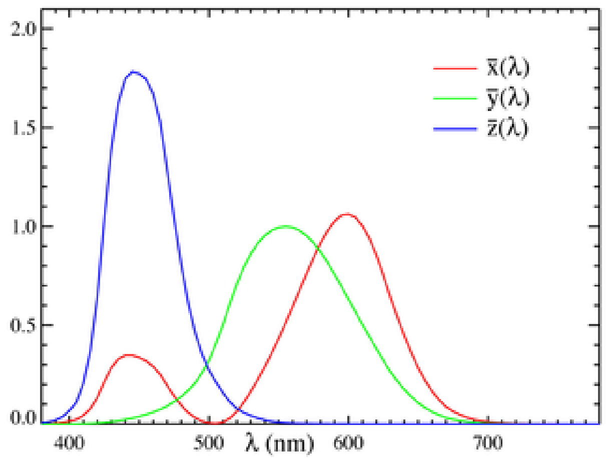


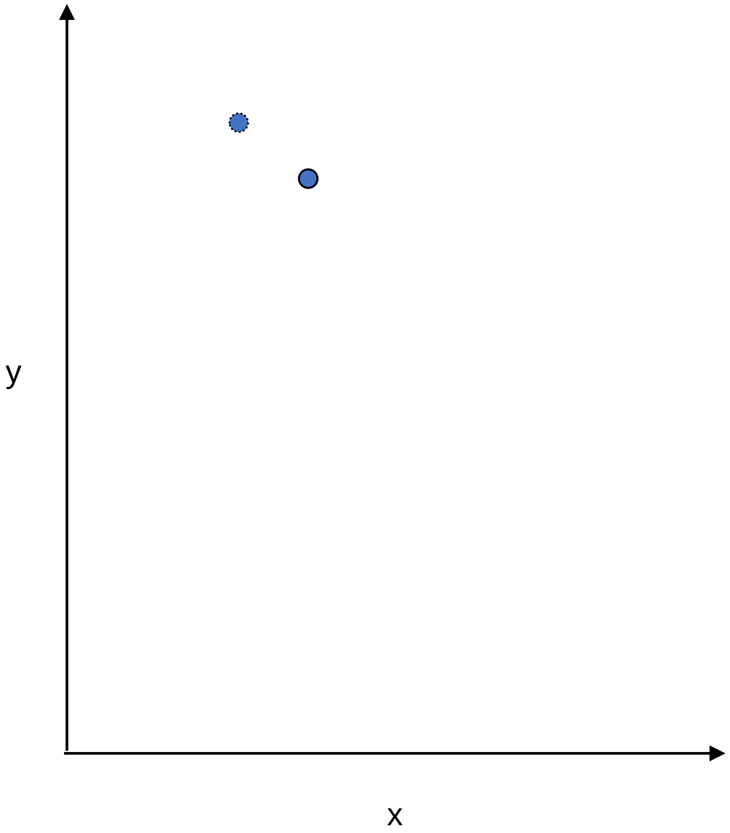


CIE chromaticity diagram

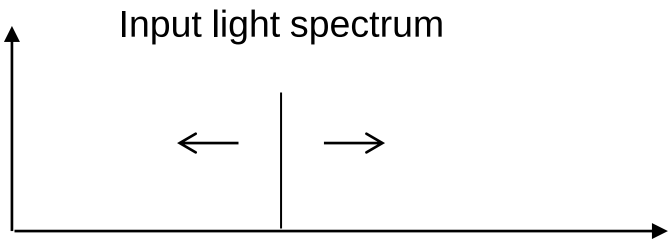
Input light spectrum

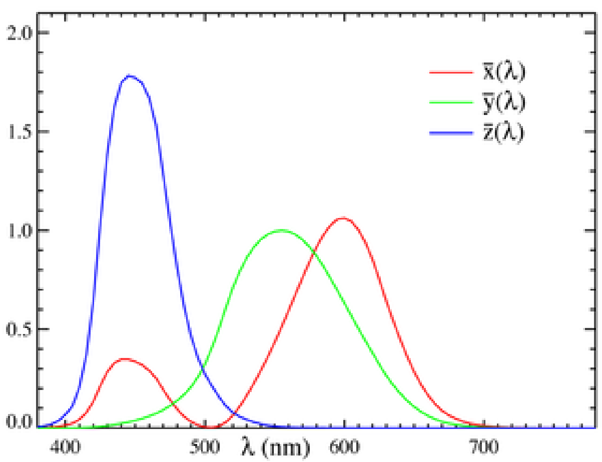


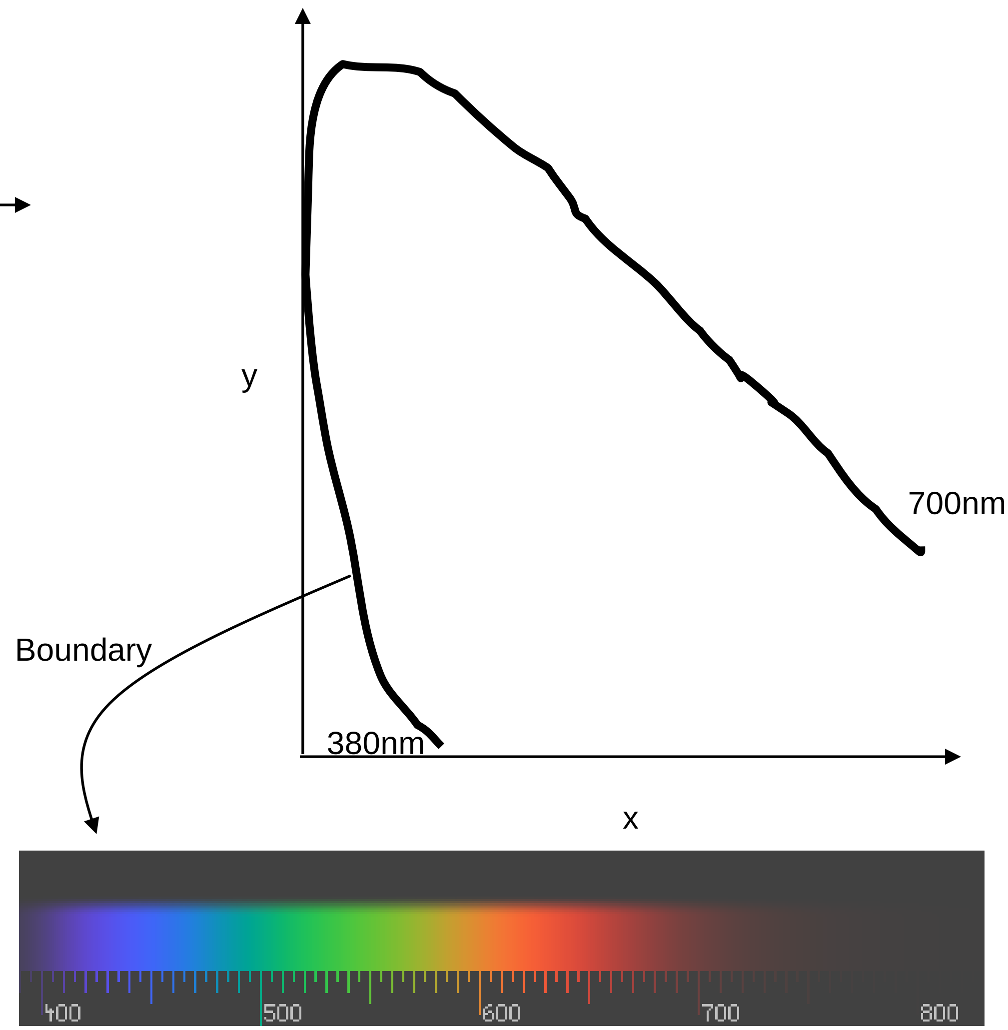




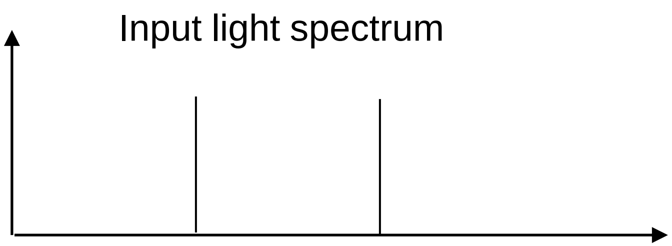
CIE chromaticity diagram

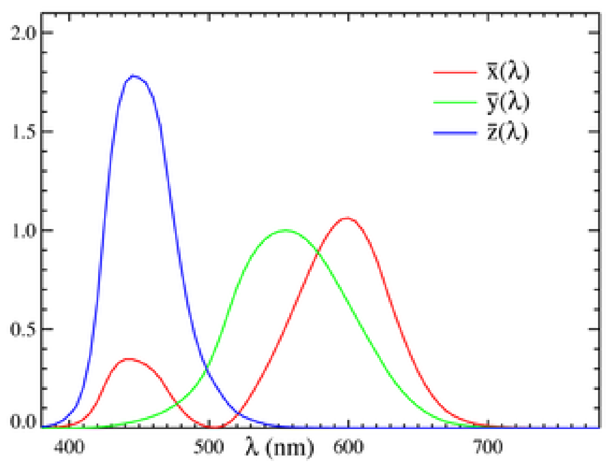


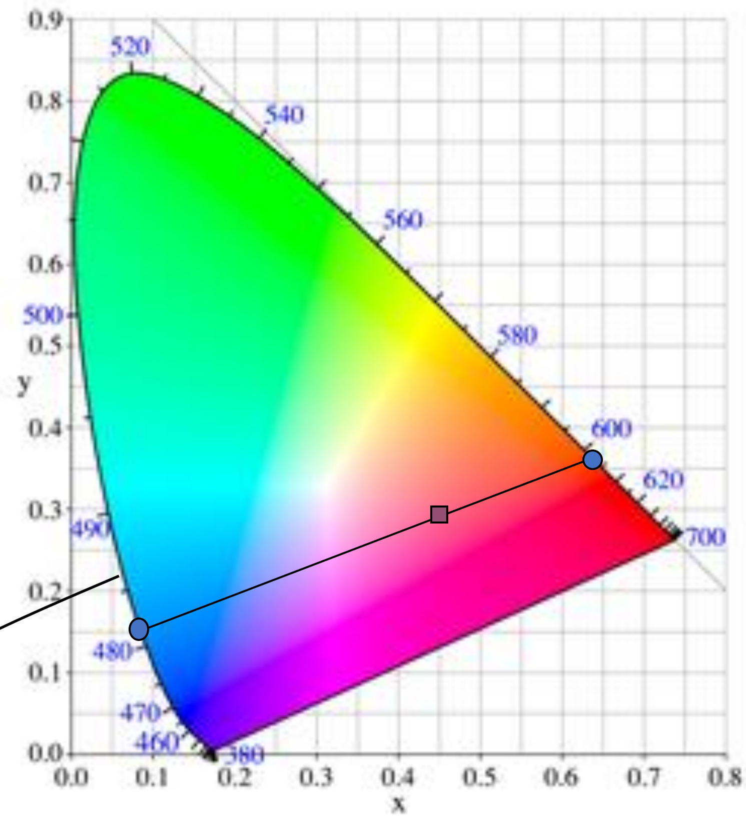




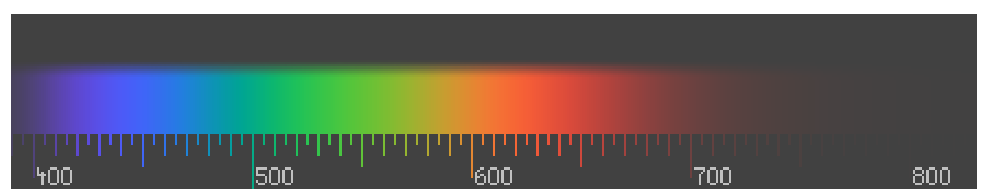
CIE chromaticity diagram



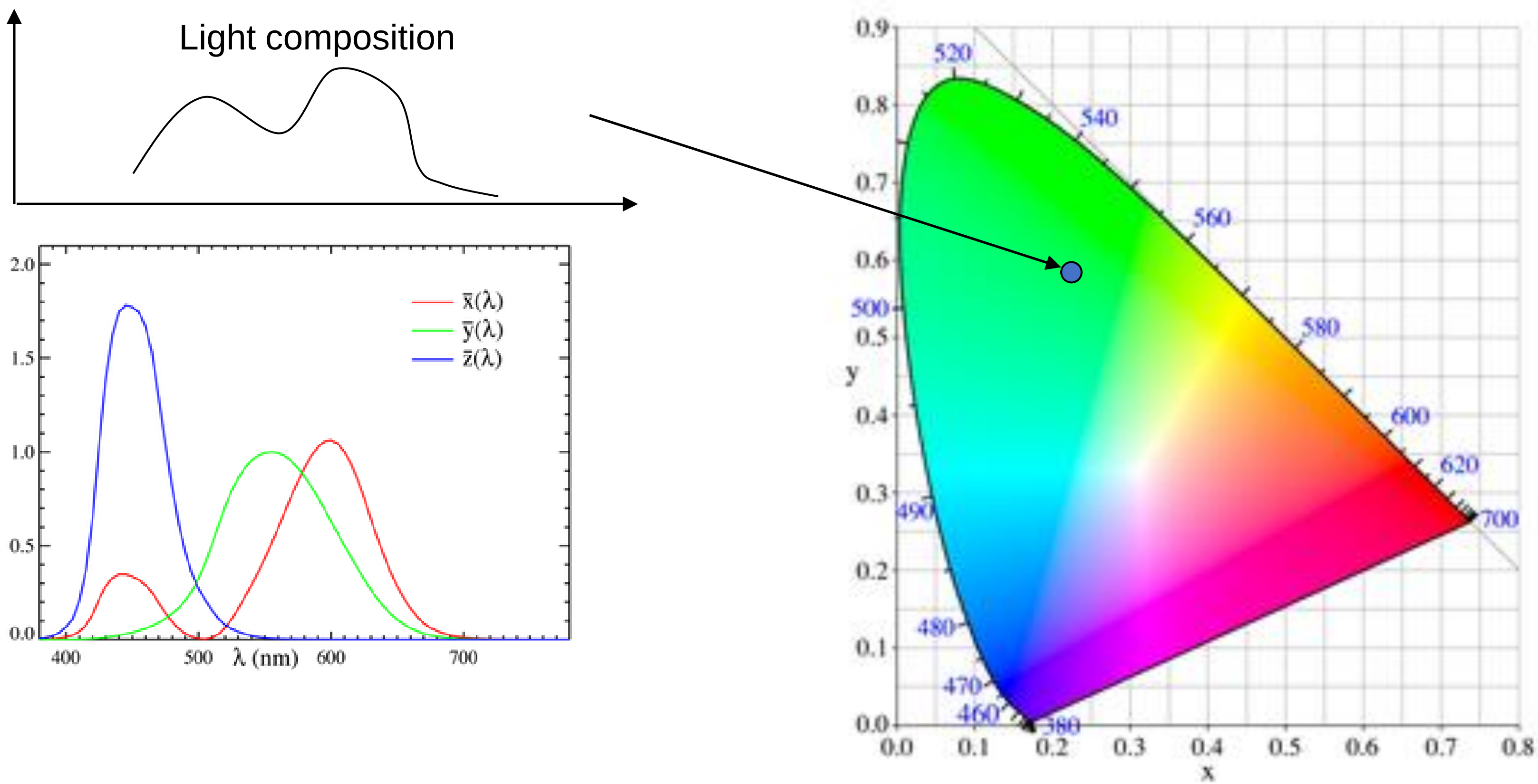




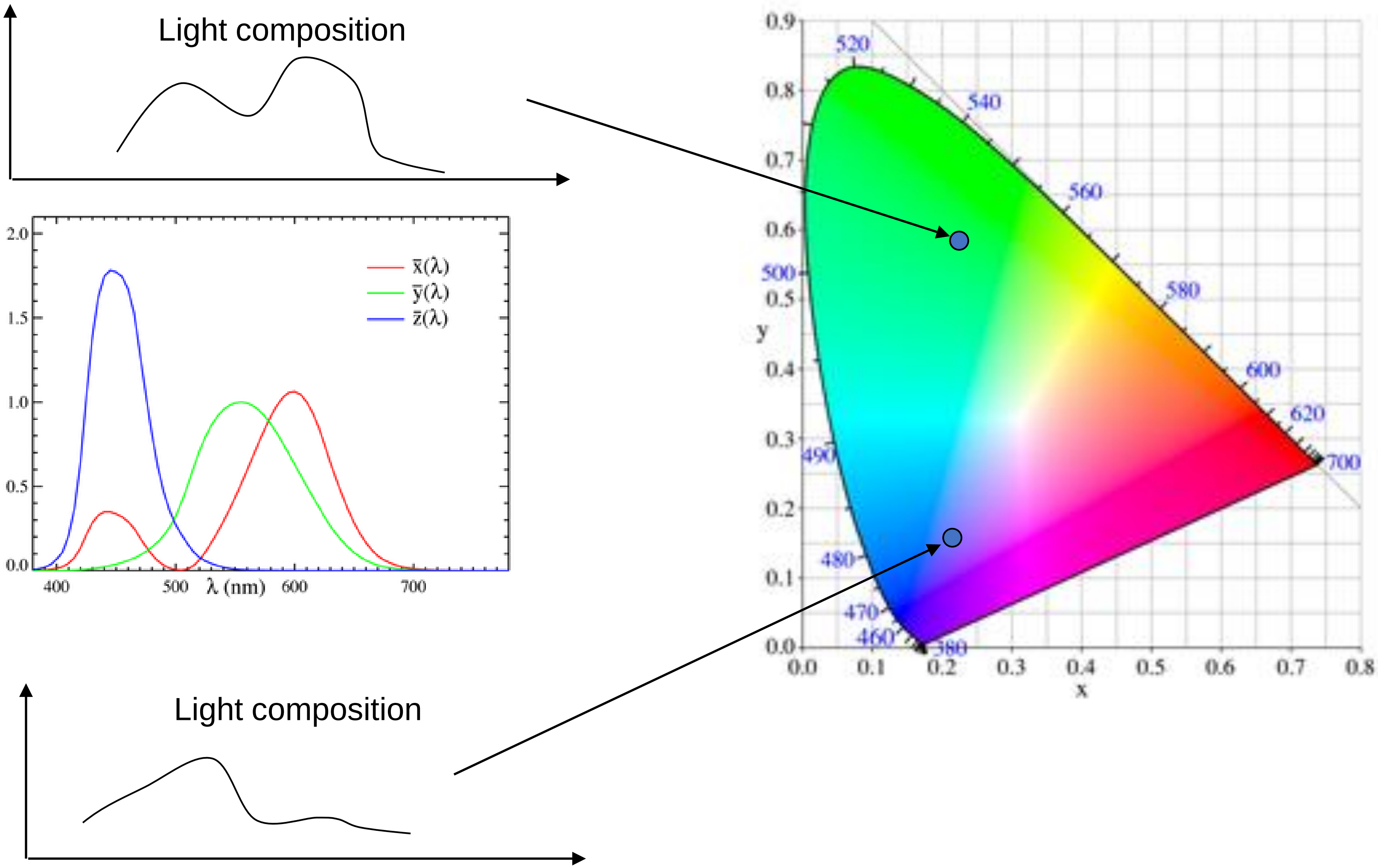
Boundary



CIE chromaticity diagram

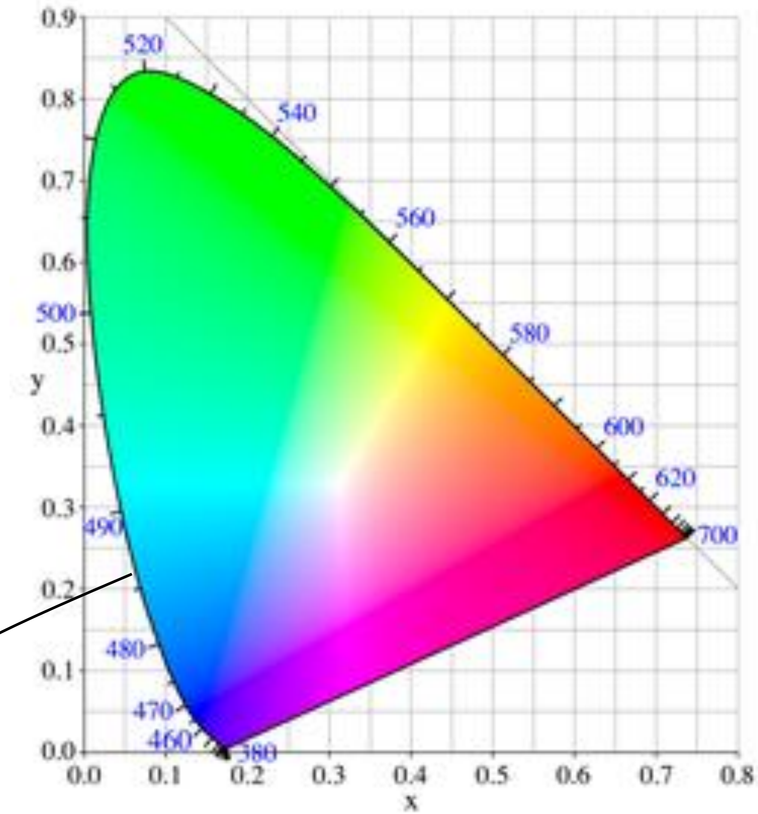


CIE chromaticity diagram

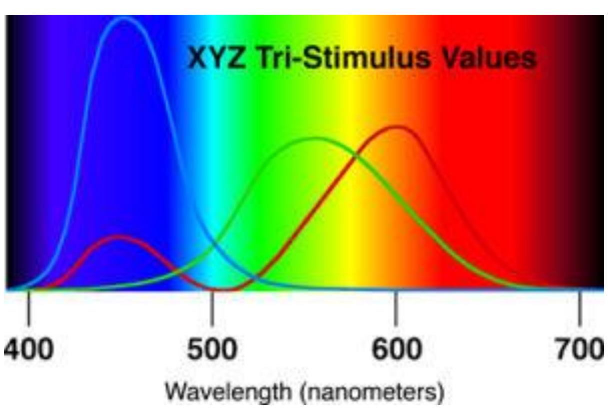


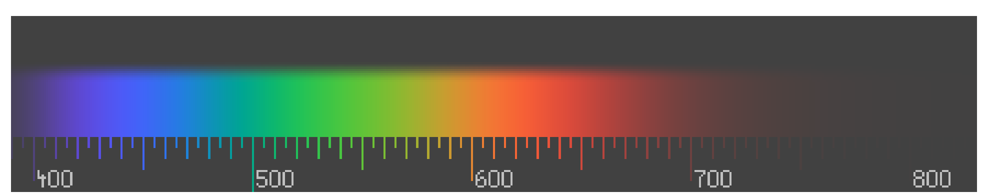
CIE chromaticity diagram

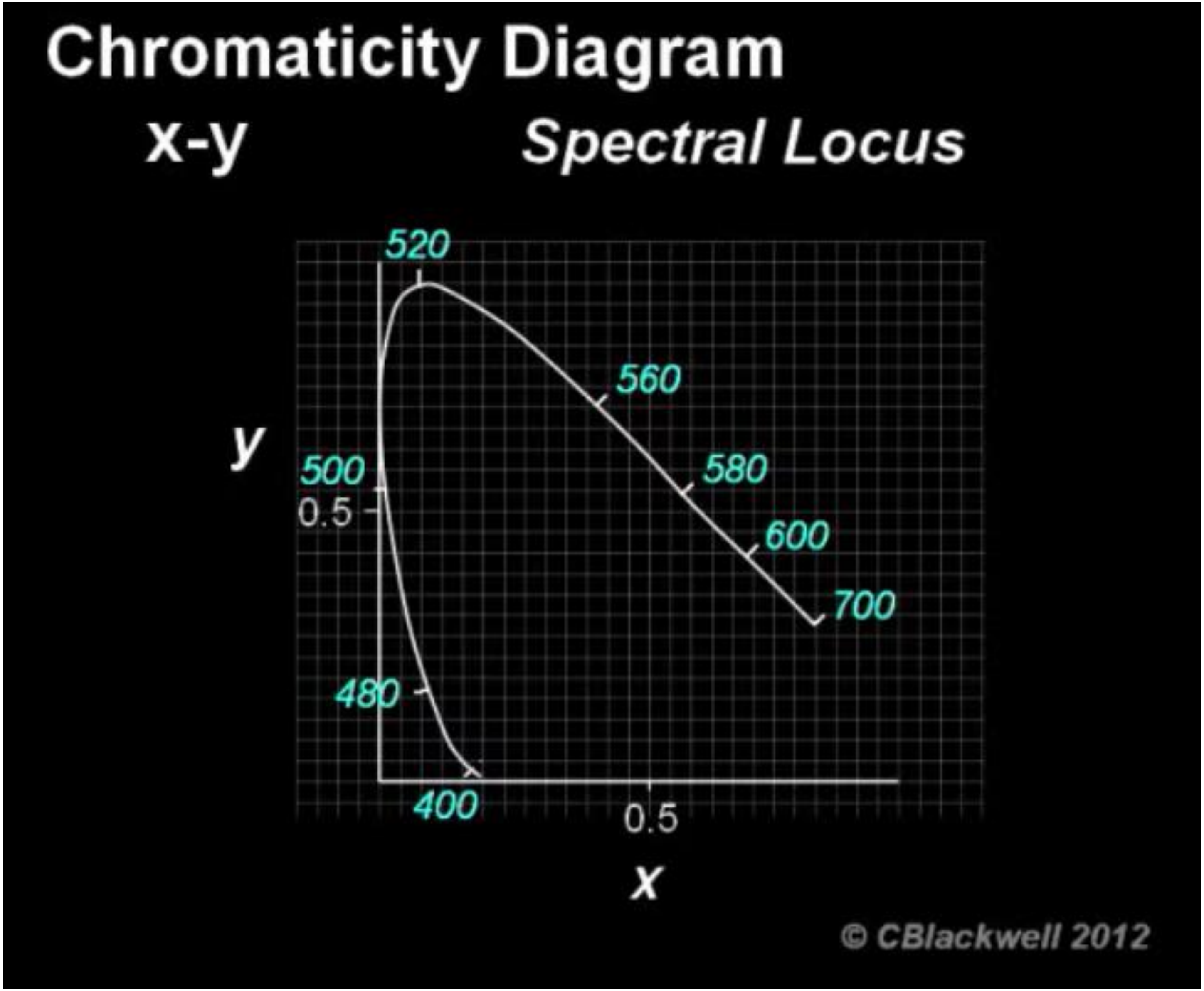
- The **CIE chromaticity diagram** shows the **human color space** as a function of x and y
- Boundary indicates pure spectrum colors (full saturation)
- Inside the boundary shows mixture of spectrum colors



Boundary

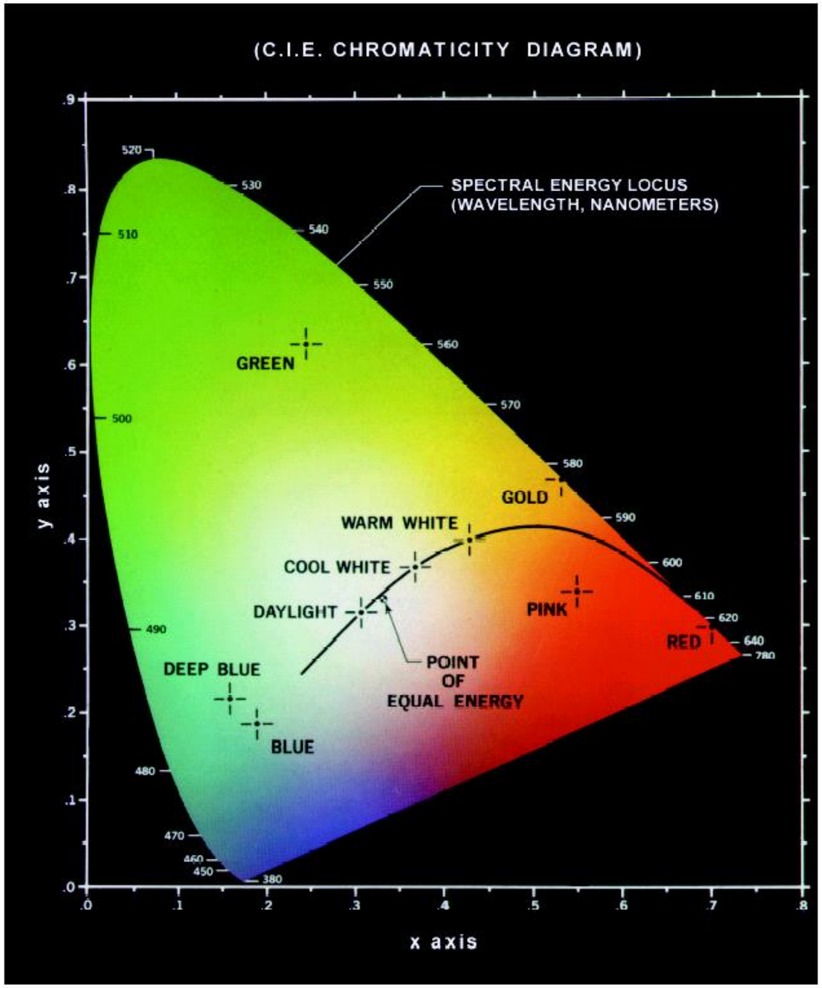





Chromaticity Diagram
x-y
Spectral Locus
520
560
580
600
700
500
0.5
480
400
0.5
y
x
© CBlackwell 2012

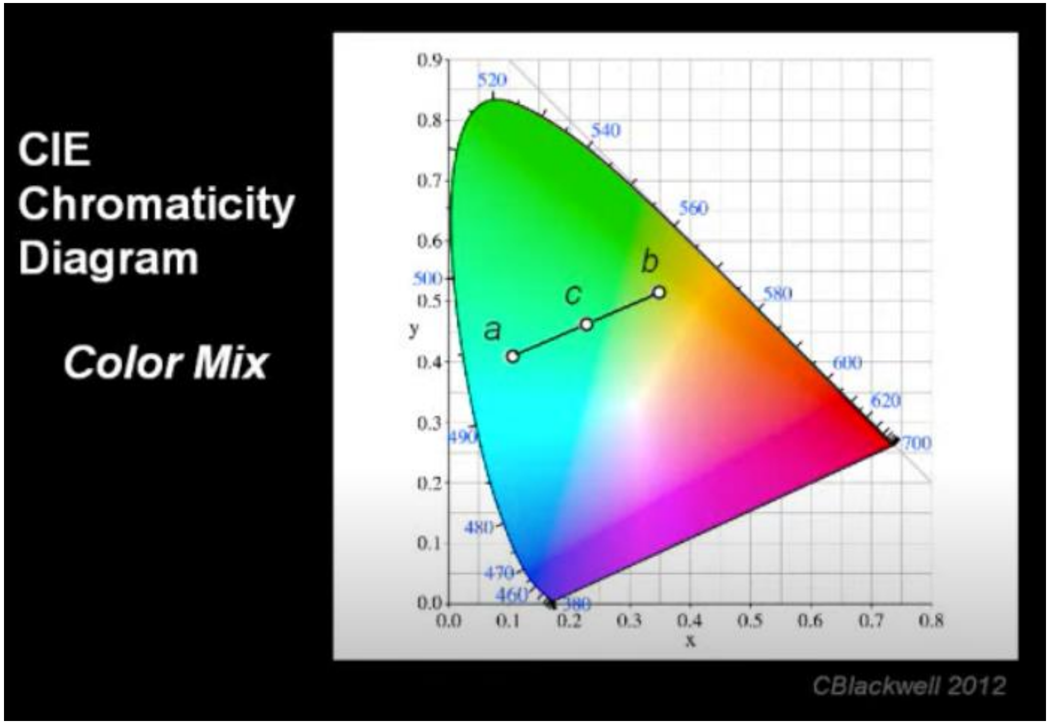
CIE chromaticity diagram

- CIE system uses a parameter Y to measure brightness and parameters x and y to specify the chromaticity which covers the properties of hue and saturation on a 2D chromaticity diagram
  - The diagram represents **all chromaticities visible to the average person**
- Spectrum colors (**pure colors**) are around the boundary
- Point of equal energy
  - White light has zero saturation as it contains all visible wavelengths of light in equal intensity

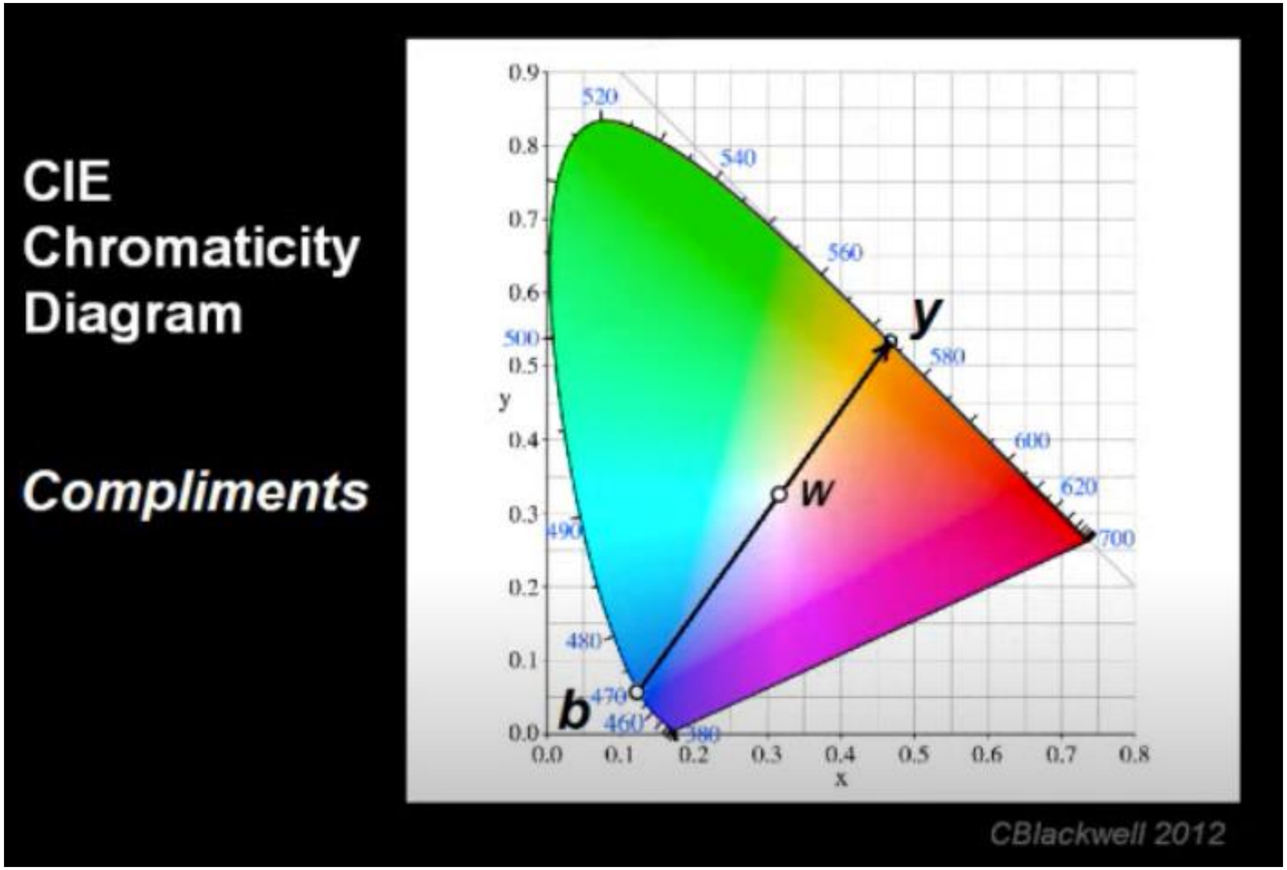


Color mix -> gamut of colors

- If choosing two points of color on the chromaticity diagram, all the colors that lie in a straight line between the two points can be formed by mixing these two colors

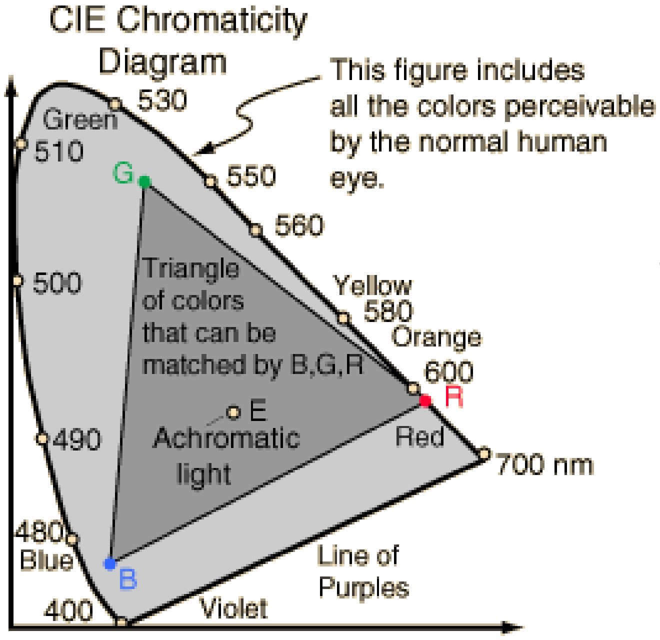


White and complements



CIE color space

- The CIE chromaticity diagram is helpful for determining the range of colors that can be obtained from any given colors in the diagram



Gamut: The range of colors that can be produced by the given primaries.

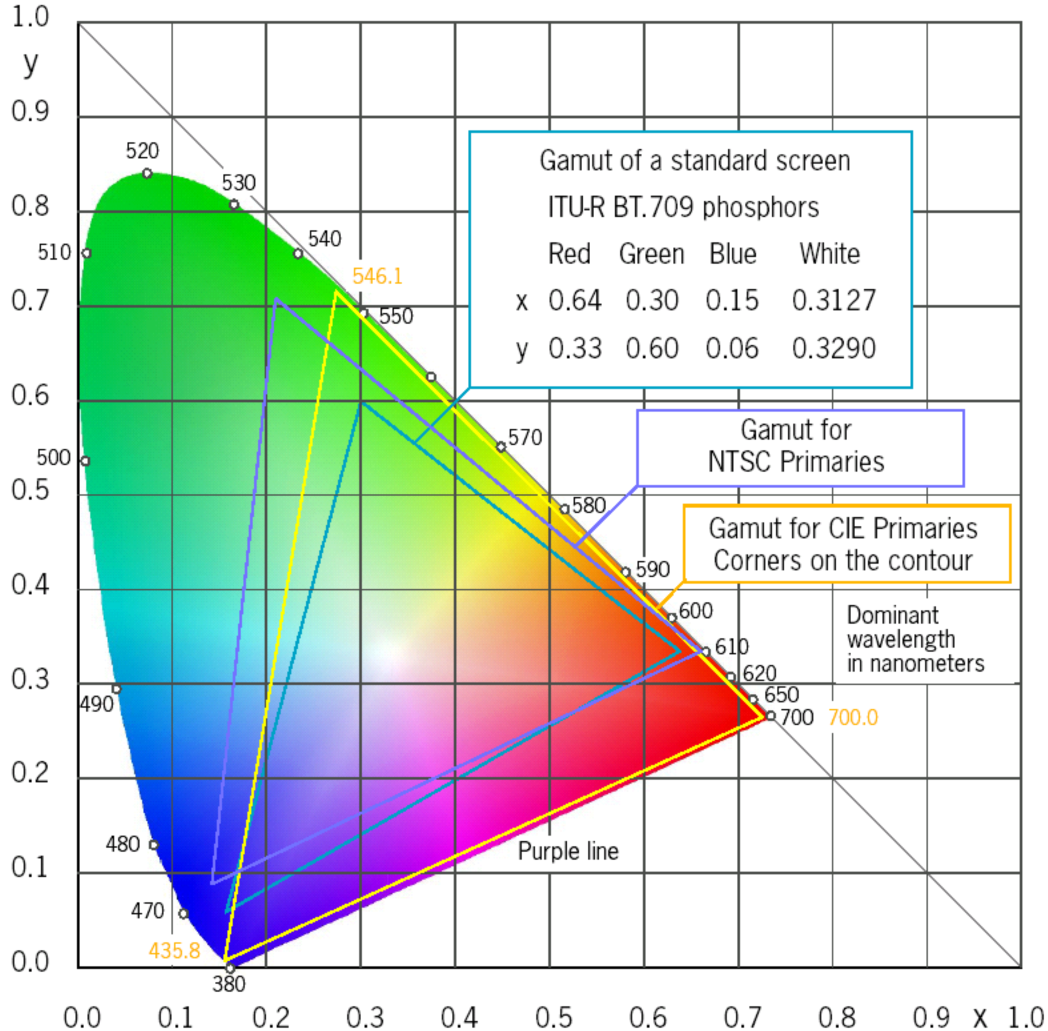
http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

Color space

- A color space relates numbers to actual colors; it contains all realizable color combinations
- A color space could be device-dependent or device-independent
- An **RGB** color space has three components: Red, Green, and Blue. But, it does not specify the exact color unless Red, Green, and Blue are defined.
- The **sRGB** is a device-independent color space. It was created in 1996 by HP and Microsoft for use on monitors and printers.
    - It is the most commonly used color space.

Color gamut

- Gamut: the entire range of colors that a system can reproduce



NTSC RGB (1953)

- **NTSC RGB** refers to the RGB color space standard used by the **National Television System Committee** (NTSC) for **analog** television in the United States. NTSC RGB is one of the earliest color spaces designed for broadcasting, used for transmitting color television signals.
- red= (x=0.670, y=0.330); green=(x=0.210,y=0.710); blue=(x=0.140,y=0.880)
- Reference white: xn=0.310063 yn=0.316158 zn=0.373779
- Conversion between XYZ and RNTSC GNTSC BNTSC:

X = 0.607*R + 0.174*G + 0.200*B

Y = 0.299*R + 0.587*G + 0.114*B

Z = 0.000*R + 0.066*G + 1.116*B

R = 1.910*X - 0.532*Y - 0.288*Z

G =-0.985*X + 1.999*Y - 0.028*Z

B = 0.058*X - 0.118*Y + 0.898*Z

New NTSC standard

- The new NTSC standard is now SMPTE-C (1979)
- Reference white (D65): xn= 0.3127 yn= 0.3290

$$X = 0.3935*R + 0.3653*G + 0.1916*B$$
$$Y = 0.2124*R + 0.7011*G + 0.0866*B$$
$$Z = 0.0187*R + 0.1119*G + 0.9582*B$$

$$R = 3.5058*X - 1.7397*Y - 0.5440*Z$$
$$G = -1.0690*X + 1.9778*Y + 0.0352*Z$$
$$B = 0.0563*X - 0.1970*Y + 1.0501*Z$$

ITU-R Rec. BT. 709 or CCIR Rec709 or **sRGB**

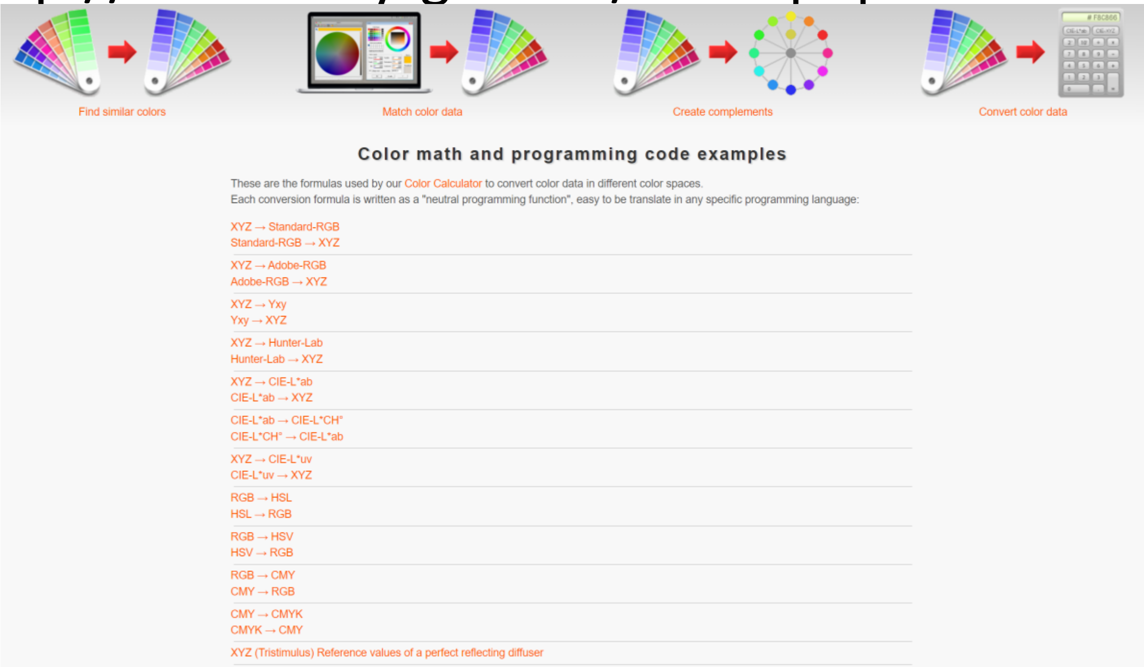
- most 8-bit digital images
- Reference white (D65): xn= 0.3127 yn= 0.3290

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Color conversion

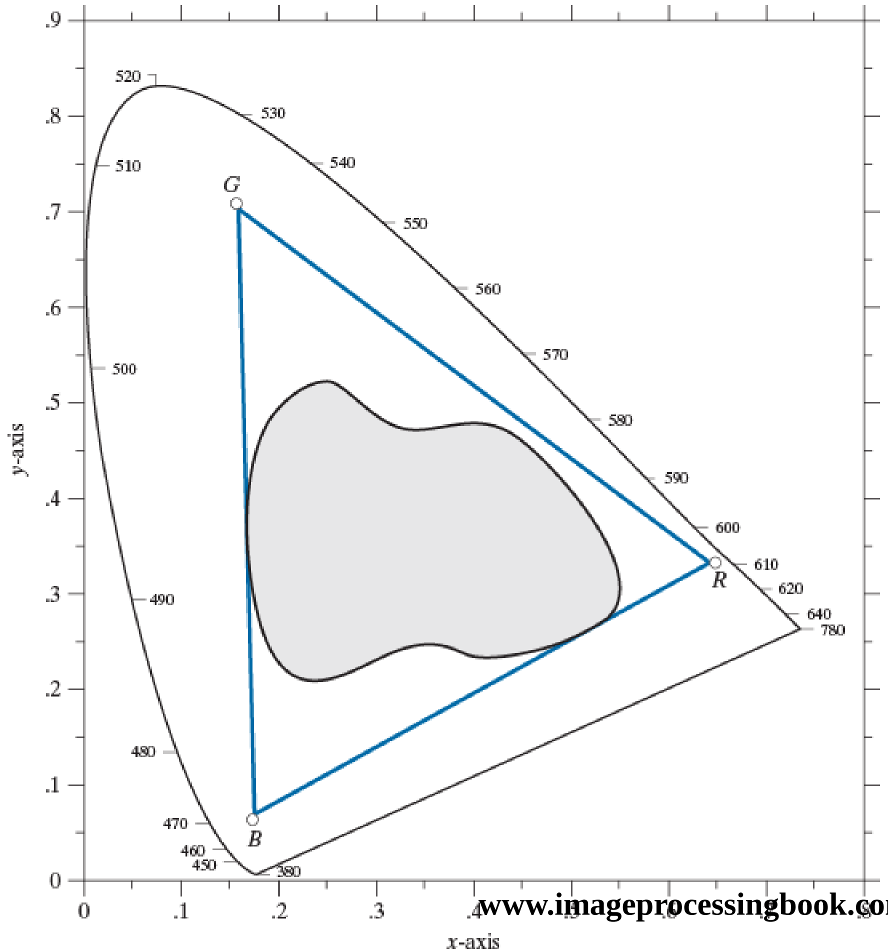
- Conversion algorithms
  - http://www.cs.rit.edu/~ncs/color/t_convert.html#RGB%20to%20HSV%20&%20HSV%20to%20RGB
  - http://www.easyrgb.com/math.php?MATH=M20



Color gamut of printers

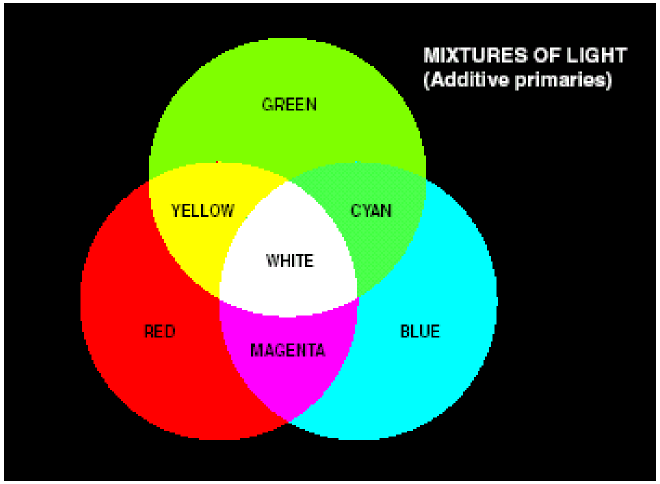
- Irregular shape because color printing is a combination of **additive** and **subtractive** color mixing, more difficult to control than displaying colors on a monitor

FIGURE 7.6 Illustrative color gamut of color monitors (triangle) and color printing devices (shaded region).



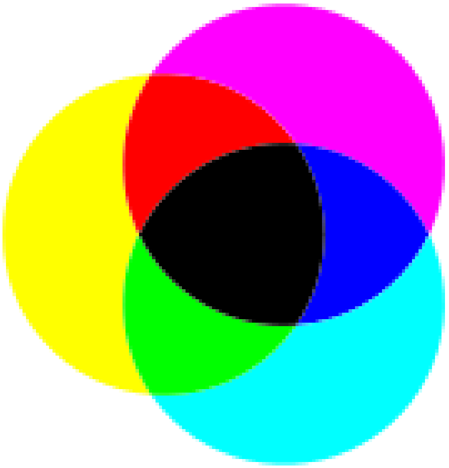
Mixture of light

- The **primary colors** (**primaries**) can be added to produce the secondary colors of light
  - Example: Color TV displays use this additive nature of colors. An electron gun hits red, green, blue phosphors (with different energies) in a small region to produce different shades of color



Mixtures of paints

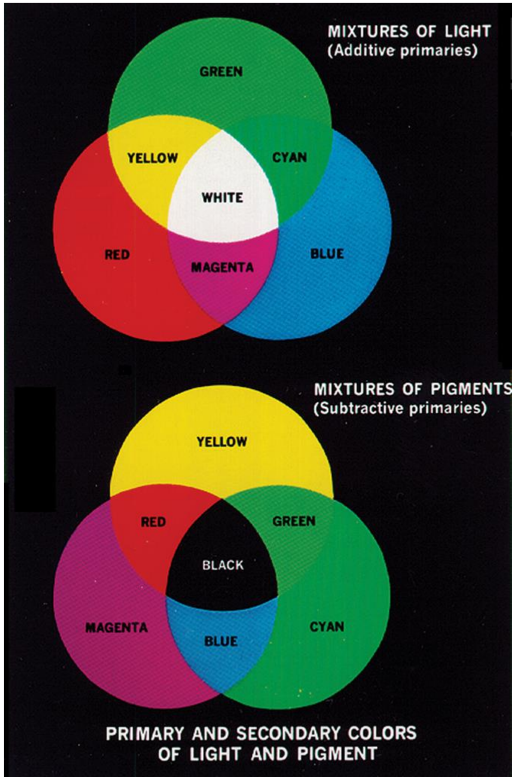
- In printing, **subtractive primaries** are used
  - In printing, **cyan**, **magenta**, and **yellow** are called **subtractive primaries** because they work by absorbing (subtracting) certain wavelengths of light and reflecting others, which creates color. This is the opposite of the **additive primaries** (red, green, blue) used in light-based systems like monitors, where colors are created by adding different wavelengths of light.
    - Cyan absorbs only Red
    - Magenta absorbs only Green
    - Yellow absorbs only Blue
- In printing, dark colors may be obtained by addition of black ink. Such color systems are known as **CMYK** systems



Primary and secondary colors of light and pigment

a
b

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



www.imageprocessingbook.com

Color models

- **RGB**
  - Red, Green, Blue
- **CMY** and CMYK
  - Cyan, Magenta, Yellow (+ Black for CMYK used for color printer)
- **HSB** and HSI
  - Hue, Saturation, Brightness (Intensity)
- **YUV**
  - Y stands for the luminance component (the brightness) and U and V are the chrominance (color) components.

Chromaticity

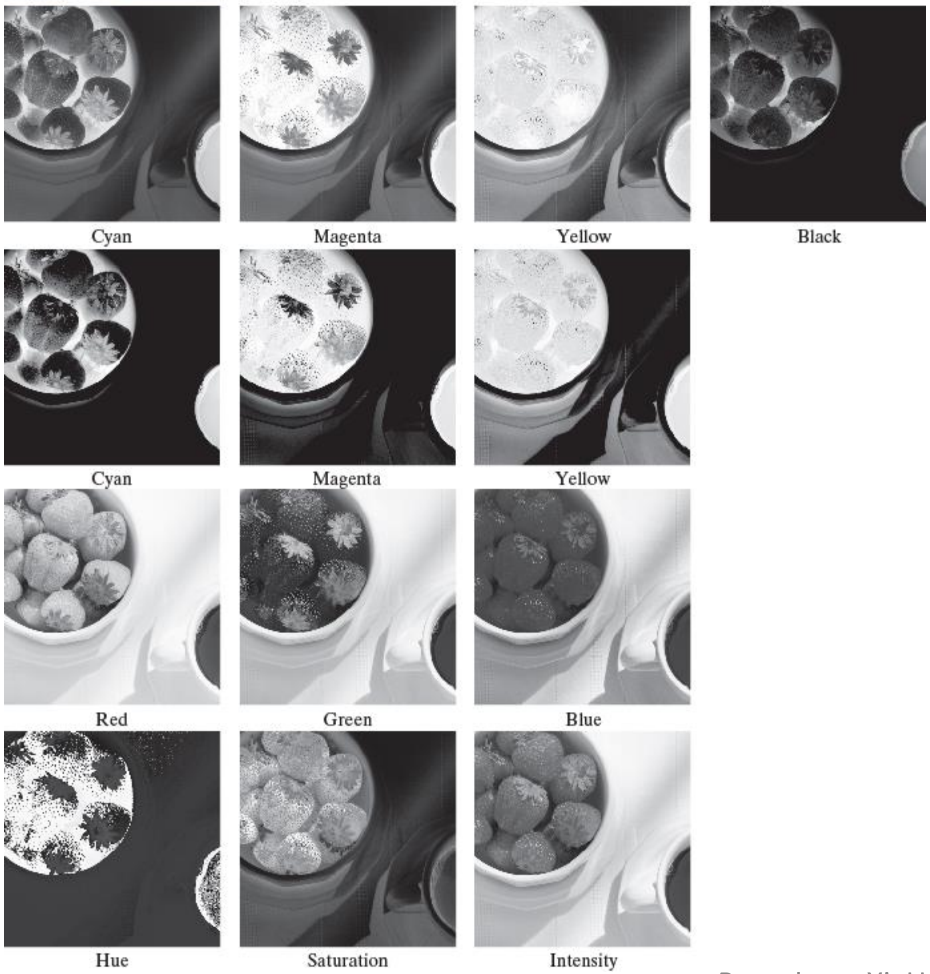
- Chromaticity – hue and saturation
  - Color = chromaticity and brightness

RGB

- Three components

RGB, CMYK, HSI

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



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Color spaces

- Color space in 3D
- CIE RGB and XYZ color spaces
- Chromaticity coordinates

RGB color cube

FIGURE 7.7
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).

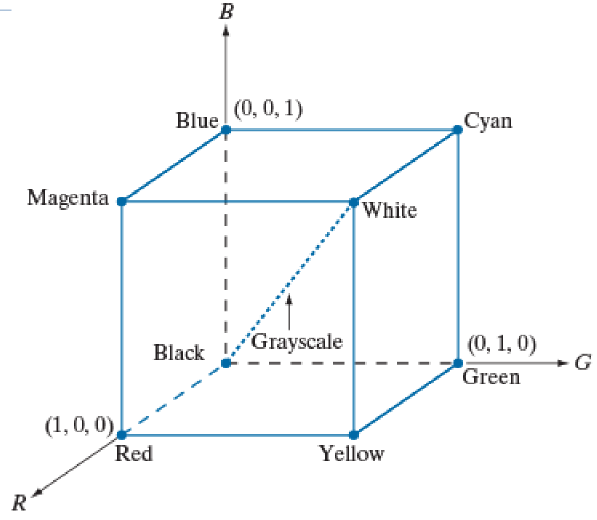
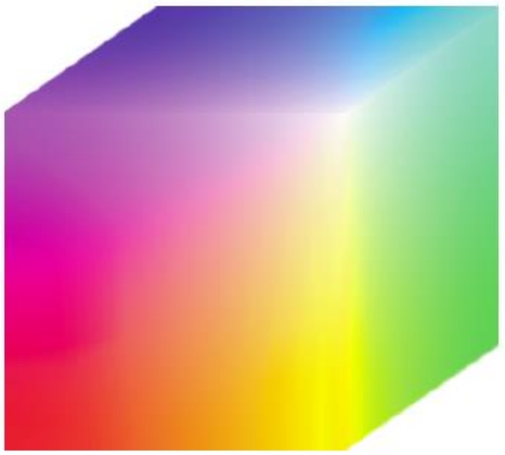


FIGURE 7.8
A 24-bit RGB color cube.

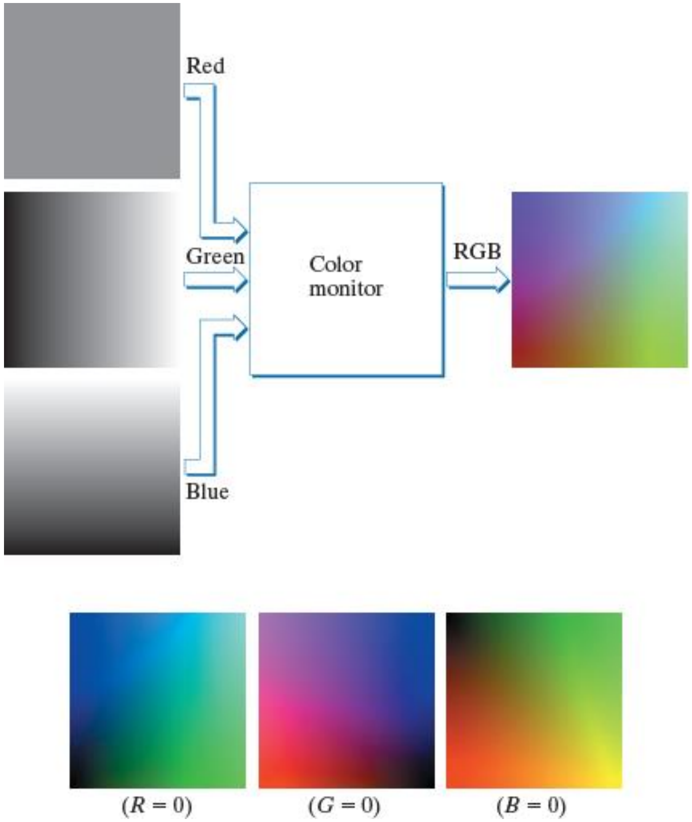


www.imageprocessingbook.com

RGB image generation

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.



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Color models (cont.)

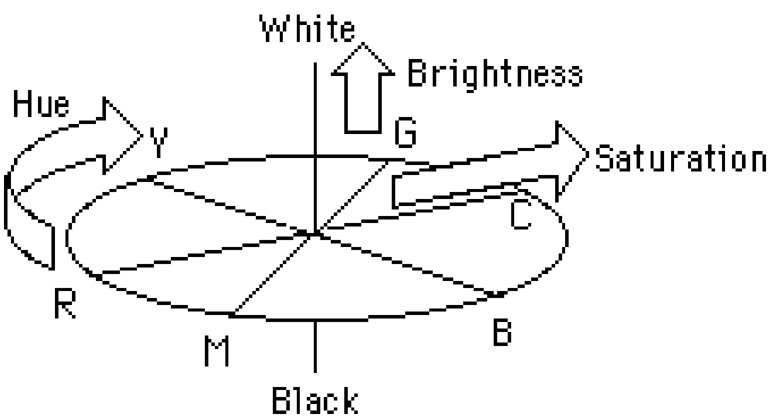
- RGB, CMYK, HSB, HSI, YUV models
- sRGB
- Perceptually uniform color spaces

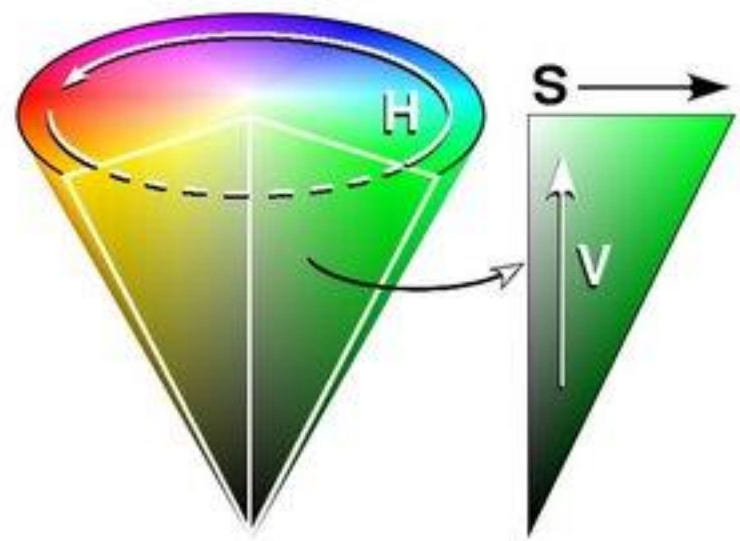
HSB

- <u>HSB</u>: (Hue, Saturation, Brightness) or <u>HSI</u> (Intensity) or <u>HSV</u> (Value)
  - The Hue/Saturation/Value model was created by A. R. Smith in 1978
- **Hue**:
  - defines the color type (express as an **angle**)
- **Saturation**
  - a measure of how vivid the color is (**purity**, colorfulness).
- **Brightness**:
  - a visual sensation of the color intensity
- Lightness:
  - perceptual response to luminance= (max(R,G,B)+min(R,G,B))/2
- Intensity:
  - (R+G+B)/3
- Value :
  - max(R,G,B)

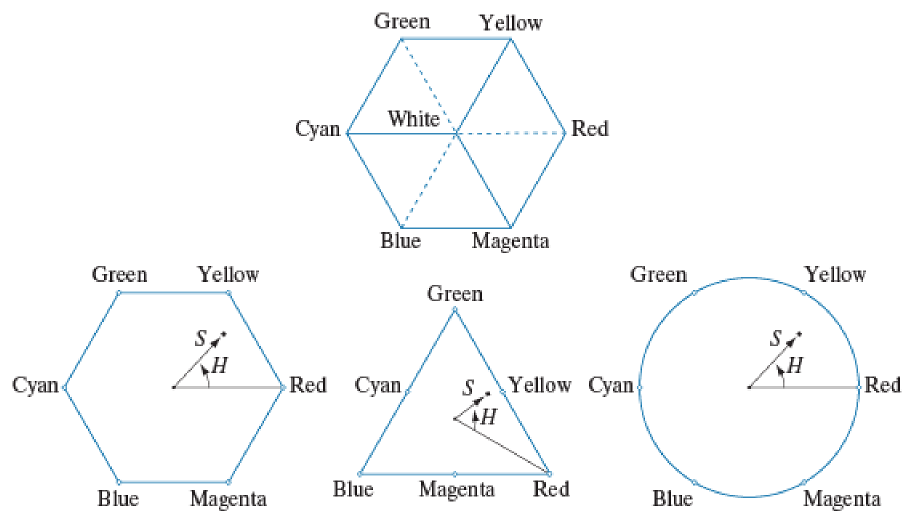
HSV

- HSV is not device-independent. It is defined in terms of RGB intensities
- It is commonly used in computer graphics applications





HSI color model



a
b c d

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.

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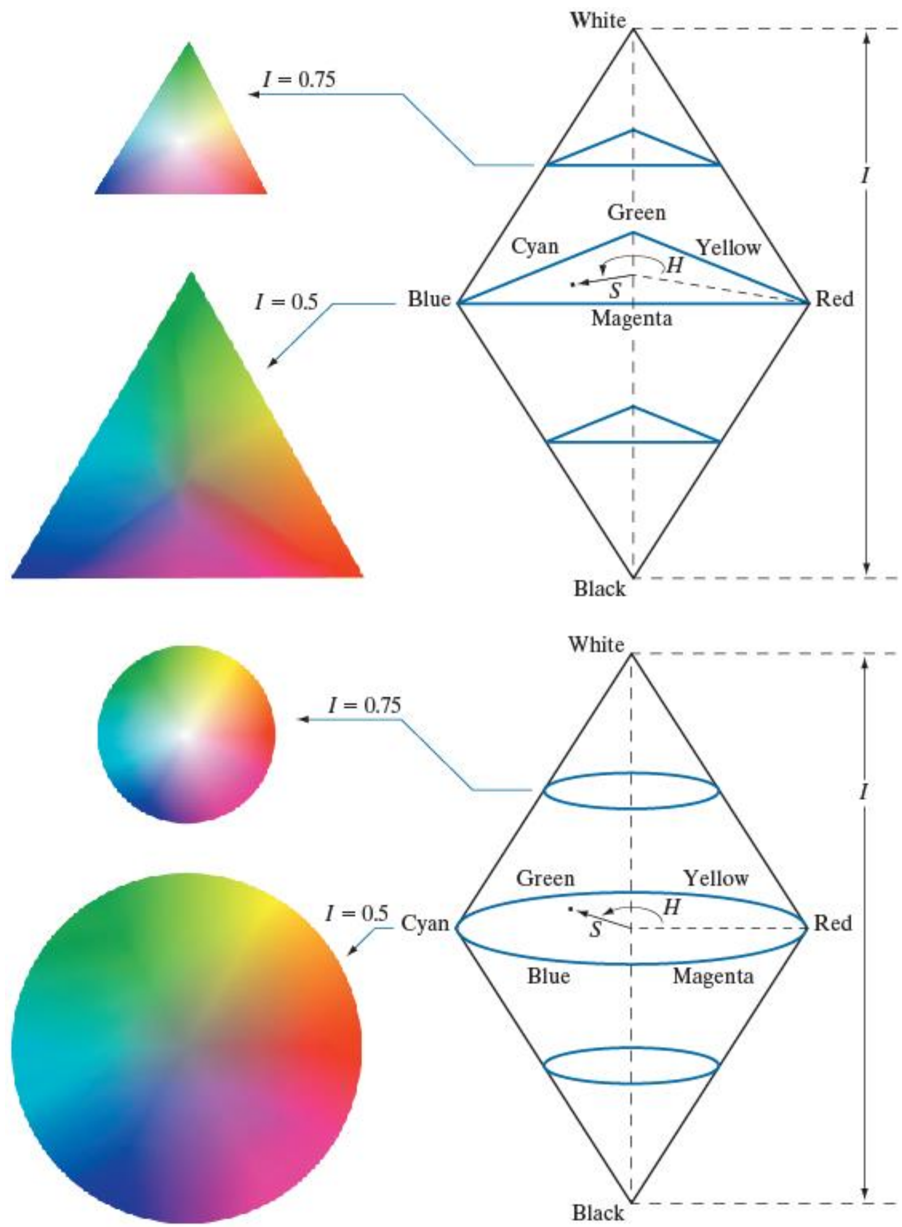
HSI

- Cross sections



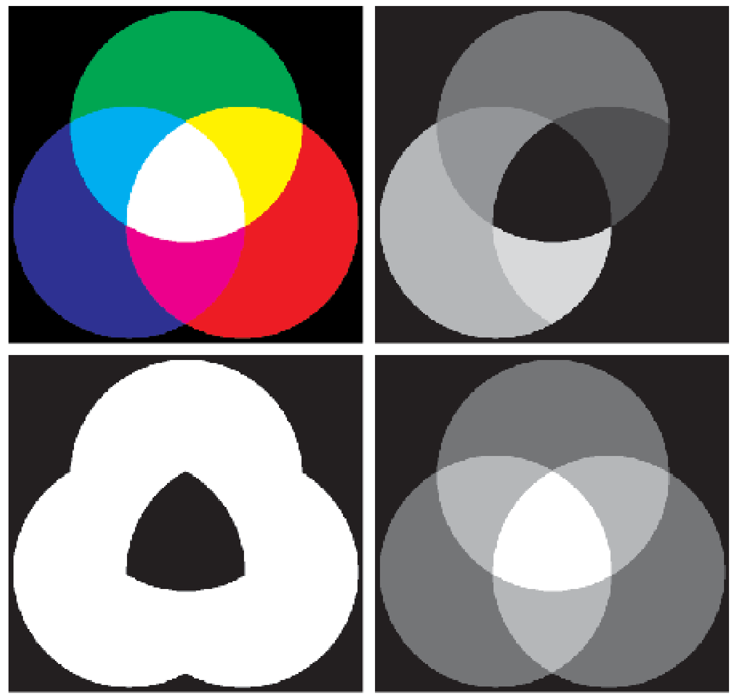
a
b

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.

RGB and HSI images

a b
c d

FIGURE 7.14
(a) RGB image and the components of its corresponding HSI image:
(b) hue,
(c) saturation, and
(d) intensity.



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Compute HS using the RGB cube

$$H = \arccos \frac{(R-G)+(R-B)}{2\sqrt{(R-G)\text{^}2+(R-B)(G-B)}}$$ if B>G then H= 360-H

or

$$H = \begin{cases} 60\dfrac{G-B}{R-\min(R,G,B)} \\ 60\dfrac{B-R}{G-\min(R,G,B)}+120 \\ 60\dfrac{R-G}{B-\min(R,G,B)}+240 \end{cases}$$

- S= 1-min(R,G,B) or S= (max(R,G,B)-min(R,G,B))/max(R,G,B)
- A fully saturated color (S=1) is one on the edges of the triangle shown before.

Steps to calculate hue and saturation

- Normalize RGB values $$R' = \frac{R}{255}, \quad G' = \frac{G}{255}, \quad B' = \frac{B}{255}$$

- Find the max and min values

$$C_{\max} = \max(R', G', B'), \quad C_{\min} = \min(R', G', B')$$

$$\Delta = C_{\max} - C_{\min}$$

Steps to calculate hue and saturation (cont.)

- Calculate hue

  - If $C_{\max} = R'$:

$$\text{Hue} = 60^\circ \times \left(\frac{G' - B'}{\Delta} \right) \bmod 360^\circ$$

  - If $C_{\max} = G'$:

$$\text{Hue} = 60^\circ \times \left(2 + \frac{B' - R'}{\Delta} \right)$$

  - If $C_{\max} = B'$:

$$\text{Hue} = 60^\circ \times \left(4 + \frac{R' - G'}{\Delta} \right)$$

If delta is zero, the hue is undefined, and is typically set to zero.

Steps to calculate hue and saturation (cont.)

- Calculate saturation

$$\text{Saturation} = \frac{\Delta}{C_{\max}}$$

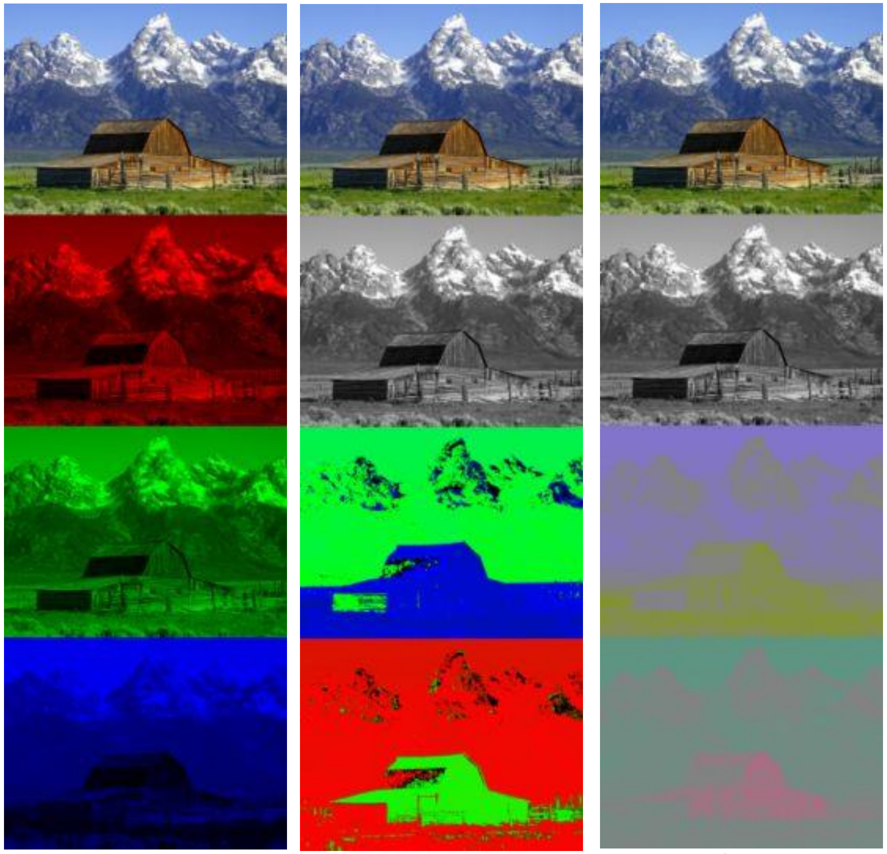
- Calculate value (in the HSV model)

$$\text{Value} = C_{\max}$$

YUV

- Y (luminance) U and V (color)
  - YPbPr color space used in analog component video
  - YCbCr for digital color television
    - Cb and Cr the blue and red chroma components
  - convert any RGB to YCrCb
    - The Y signal corresponds to the B&W television signal:
    - Y= 0.299R+0.587G+0.114B
    - U (Cb) and V (Cr) subtract the luminance values from R and B (can be negative)
    - Cr= 0.5R-0.4187G-0.0813B
    - Cb= -0.1687R-0.3313G+0.5B
  - 8-bit representation:
    - Y8= 219Y+16
    - Cr= 112(R-Y)/0.701 + 128
    - Cb= 112(B-Y)/0.886 + 128

YUV

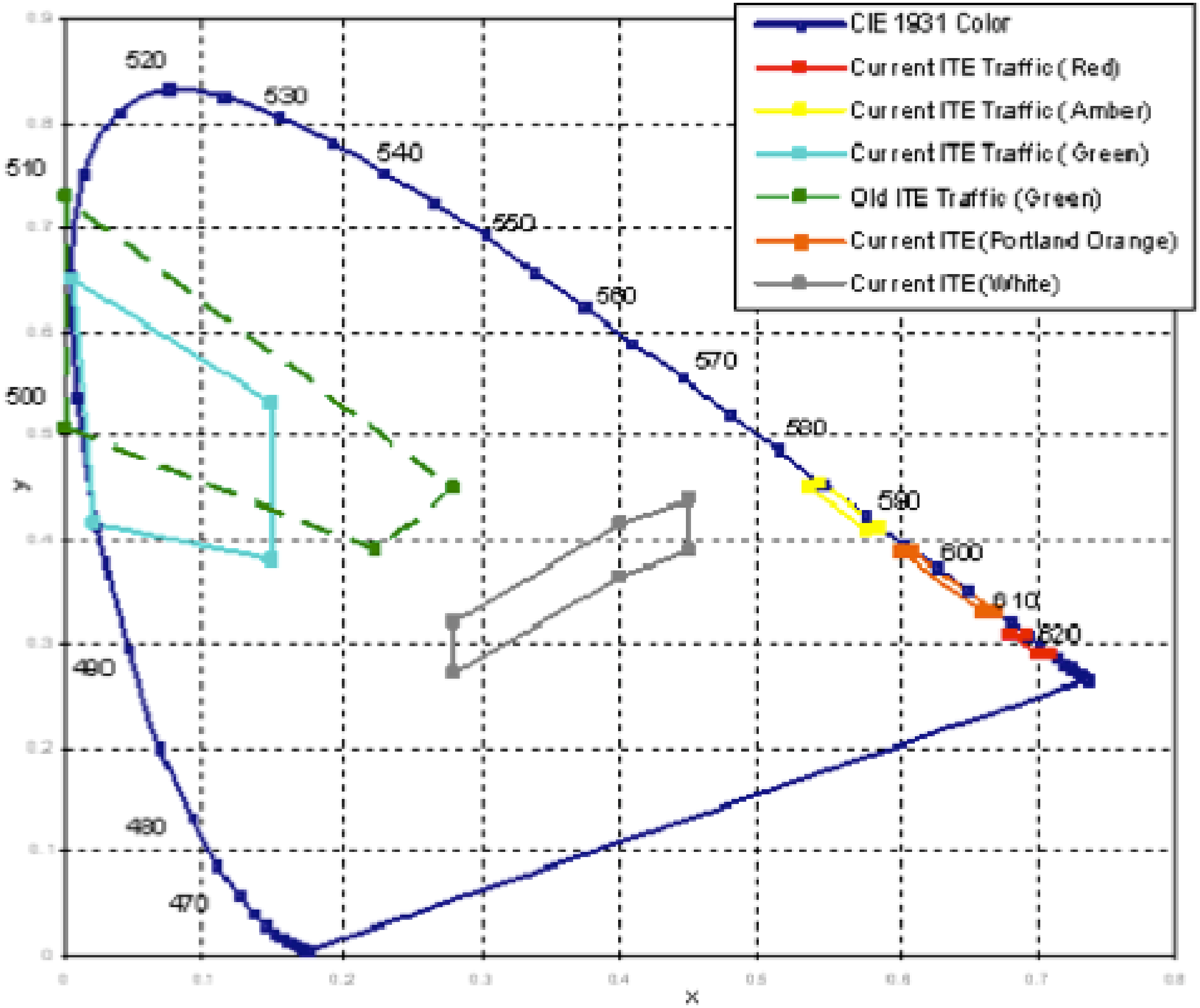


RGB YUV YCbCr

Perceptually uniform color space

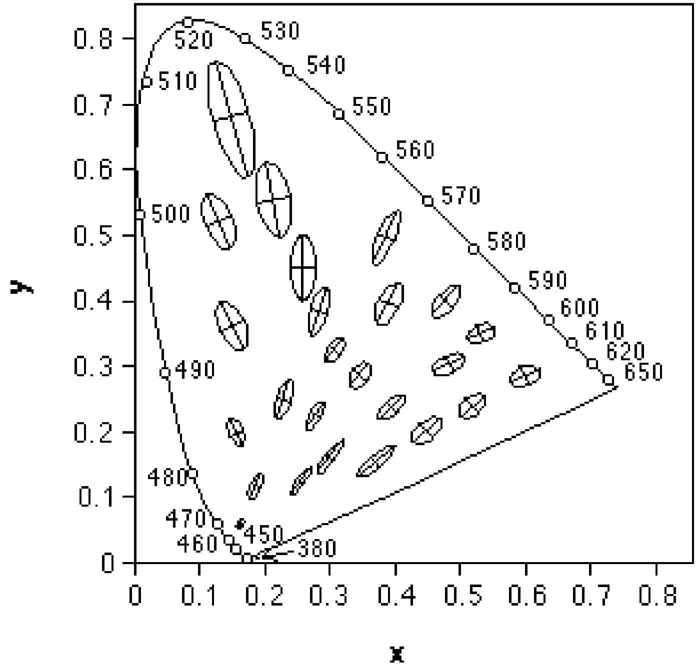
- A system is *perceptually uniform* if a small perturbation to a component value is approximately equally perceptible across the range of that value.
- The perceptual difference between two colors is not proportional to their distance in the x-y color space.
- Finding a transformation of XYZ into a reasonably perceptually-uniform space consumed a decade or more at the CIE and in the end no single system could be agreed. So the CIE standardized two systems, *L*u*v** and *L*a*b**, sometimes written **CIELUV** and **CIELAB**.

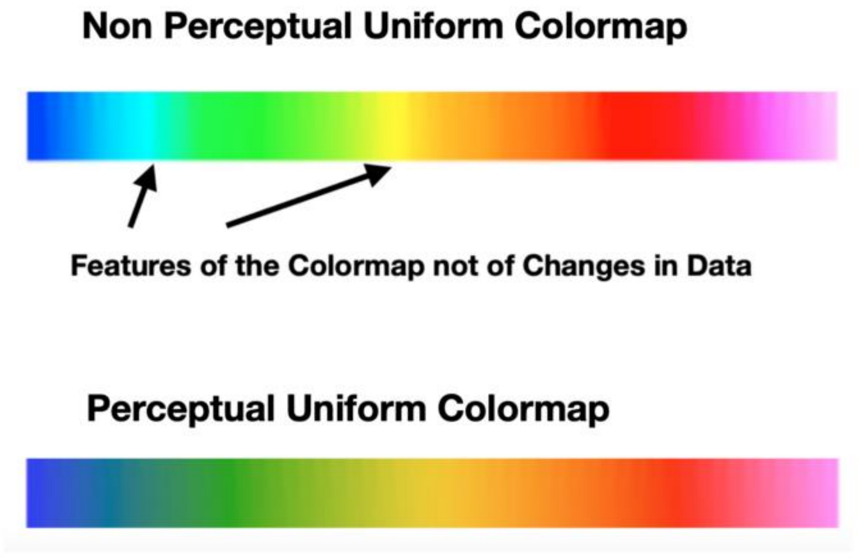
ITE Traffic Light Color



Perceptually uniform color space

- A **system** is perceptually uniform if a small perturbation to a component value is approximately equally perceptible across the range of that value.
- A **color space** is perceptually uniform if a change of length in any direction X of the color space is perceived by a human as the same change





https://medium.com/nightingale/color-in-a-perceptual-uniform-way-1eebd4bf2692

Perceptually uniform color space

- *CIELAB (CIE L*a*b*)*
  - *the most complete color model used conventionally to describe all the colors visible to the human eye*
    - L* - intensity
    - a* b* - color for red minus green and for green minus blue respectively
  - Colorimetric
    - Colors perceived as matching are encoded identically
  - Perceptually uniform
    - Color differences among various hues are perceived uniformly
  - Device independent

Perceptually uniform color space

- *XYZ to (CIELAB)*

$$L^* = 116\, f(Y/Y_n) - 16$$

$$a^* = 500\, [f(X/X_n) - f(Y/Y_n)]$$

$$b^* = 200\, [f(Y/Y_n) - f(Z/Z_n)]$$

where

$$f(t) = t^{1/3} \quad \text{for} \quad t > 0.008856$$

$$f(t) = 7.787\, t + 16/116 \quad \text{otherwise}$$

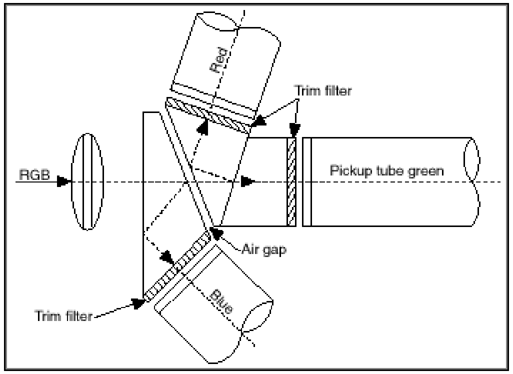
Xn, *Yn* and *Zn* are the CIE XYZ values of the reference white point

Color in imaging systems

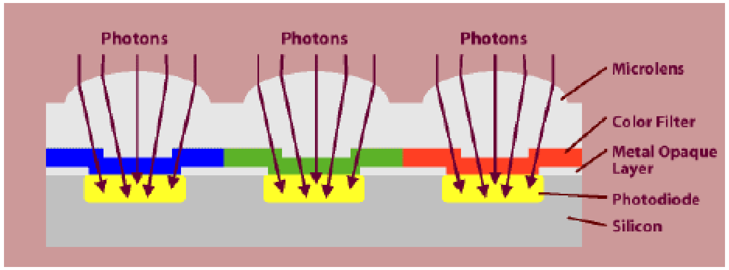
- Color cameras (sensors)
- Artifacts of Bayer filter
- Anti-aliasing techniques

Color camera

- Use 3 sensors (beam filter + color filters)

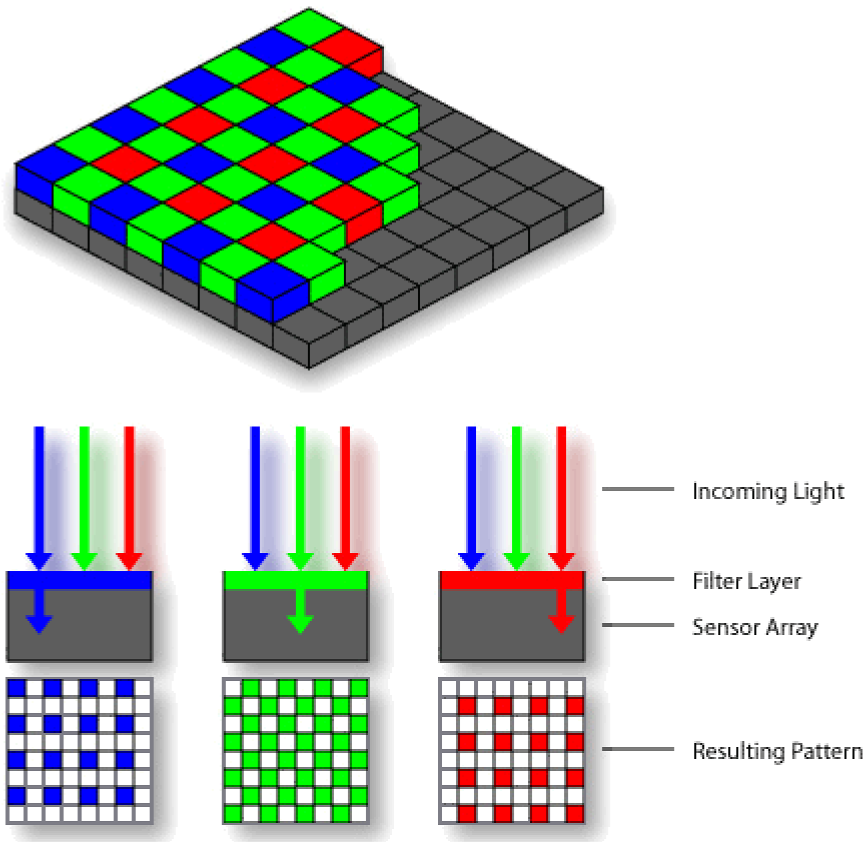


- Use 1 sensor and a Bayer filter pattern (color filter mosaic array)



Color cameras

- A **Bayer filter** mosaic is a color filter array (CFA) for arranging RGB color filters on a square grid of photosensors.
- *Bayer pattern* image
    - The raw output of Bayer-filter cameras.
- Since each pixel is filtered to record only one of three colors, two-thirds of the color data is missing from each.
- To obtain a full-color image, various demosaicing algorithms can be used to interpolate a set of complete red, green, and blue values for each point.



http://en.wikipedia.org/wiki/Bayer_filter

Color camera

- Original image →Bayer pattern of the image → Linear interpolation (False color artifacts and Zippering artifact are introduced)

the false color demosaicing artifact.

the zippering artifact

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

How to prevent/reduce artifacts of Bayer filter

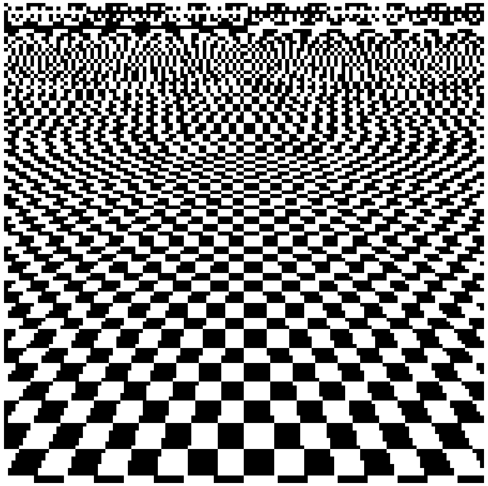
- False color artifacts
  - Smooth hue transition interpolation is used during the demosaicing to prevent false colors
- Zippering artifacts
  - Pattern recognition interpolation, adaptive color plane interpolation, and directionally weighted interpolation all attempt to prevent zippering
- Virtually every photographic digital sensor incorporates something called an optical low-pass filter (OLPF) or an anti-aliasing (AA) filter.

Anti-aliasing techniques

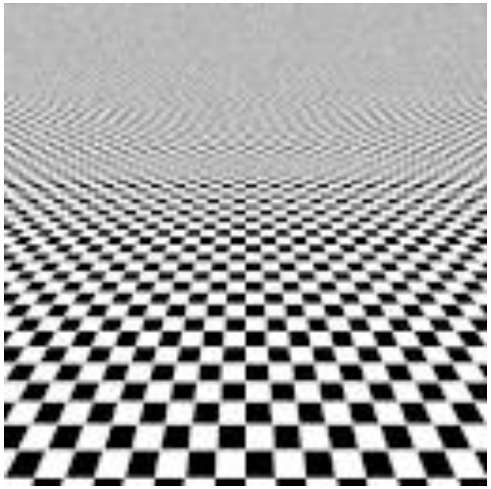
- Optical solution
  - An optical low-pass filter, blur filter
    - Birefringent material spreads each optical point into a cluster of four points
- Oversampling
  - Nyquist rate
- Bandpass signals
  - Instead of lowpass filtering

Aliasing and anti-aliasing

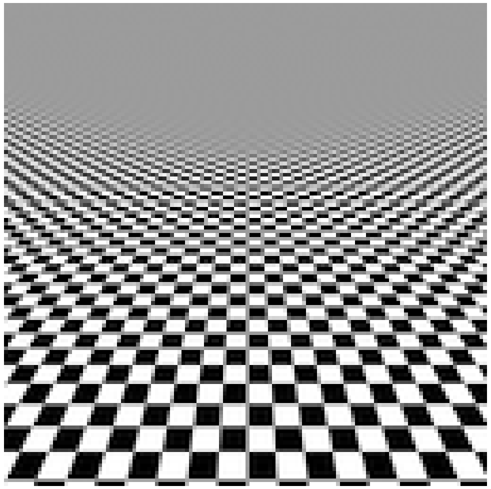
- Spatial anti-aliasing



(a) visual distortion is shown

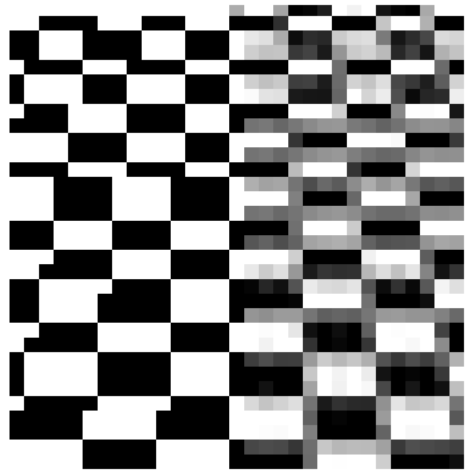


(b) anti-aliasing



(c) another anti-aliasing

Spatial anti-aliasing



(a) (c)

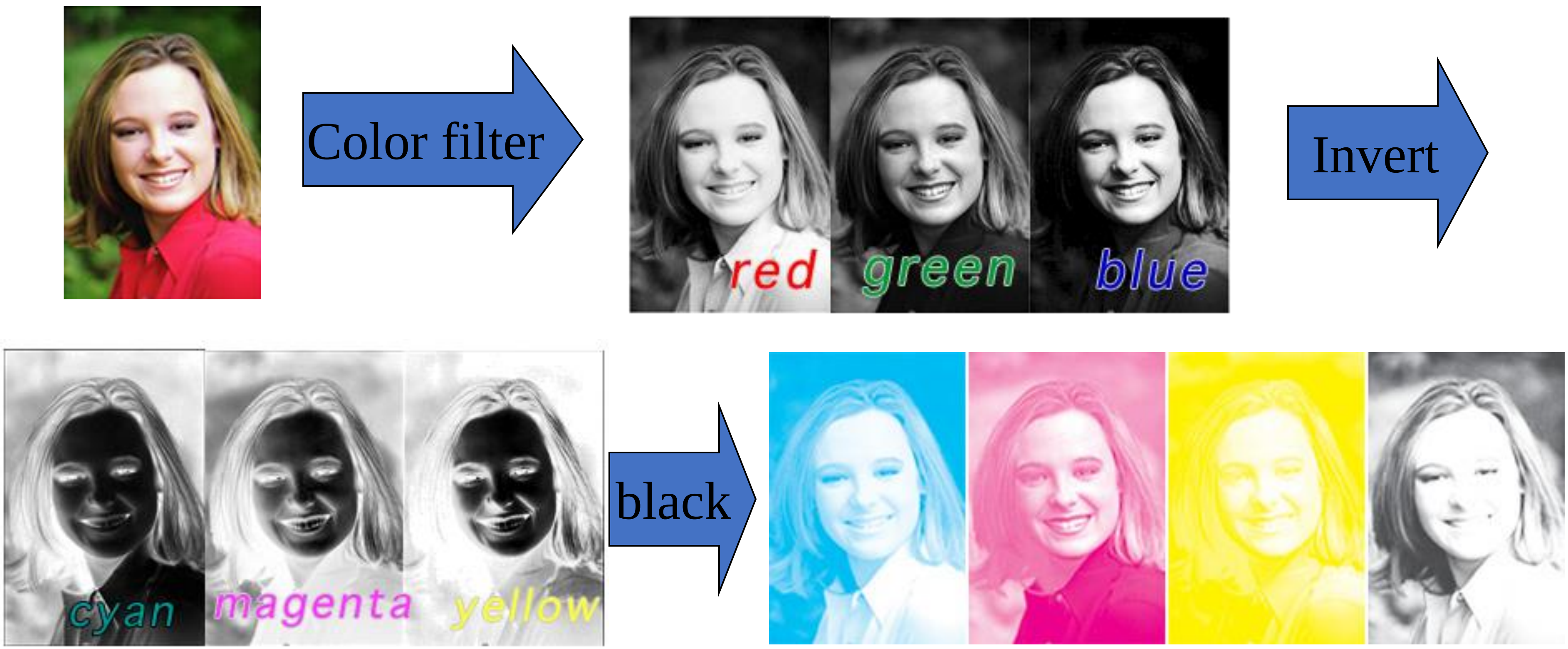
(c) anti-aliasing has **interpolated** (based on Sinc Filter) the brightness of the pixels at the boundaries to produce gray pixels since the space is occupied by both black and white tiles

Color in output devices

- Color printing (CMYK)
- Halftone screening and patterns
- Moiré effects
- Stochastic screening

Color printing (CMYK)

- Color separation process



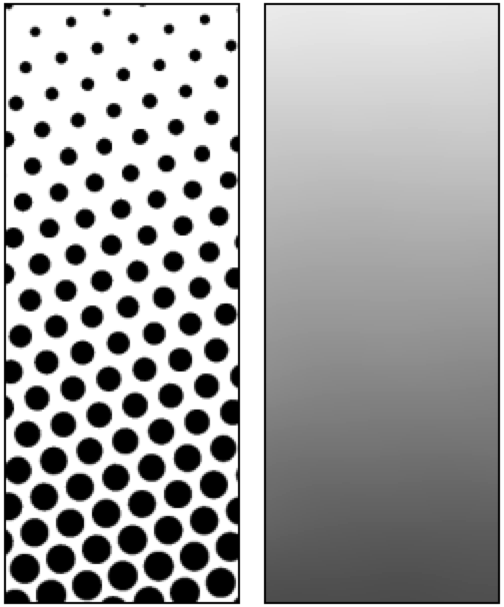
How much of each ink to apply

Color printing

- Screening
  - Since printers can’t produce every shade and tone through direct color mixing, halftone screening creates the illusion of gradients and continuous tones by using small dots of varying size, spacing and color.
  - A process that represents lighter shades as tiny dots, rather than solid areas, of ink
  - In process color printing, the screened image, or halftone for each ink color is printed in succession.
  - The screen grids are set at different angles, and the dots therefore create tiny rosettes, which, through a kind of optical illusion, appear to form a continuous-tone image
  - It may use ink efficiently by avoiding over-saturation of colors, the primary purpose of half-tone screening is to reproduce images with a wide range of tones using only a few colors

Color printing

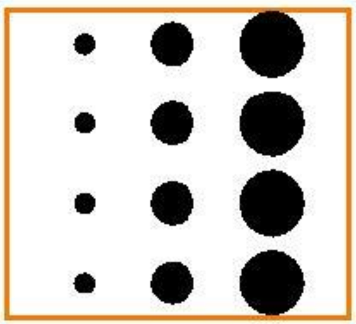
- Halftone screening
  - Left: halftone spots
  - Right: how human eyes would see this, when viewed from a sufficient distance



Classical halftoning

- Use of dots of varying size to represent intensities
- Area of dots proportional to intensity in image

I(x,y)

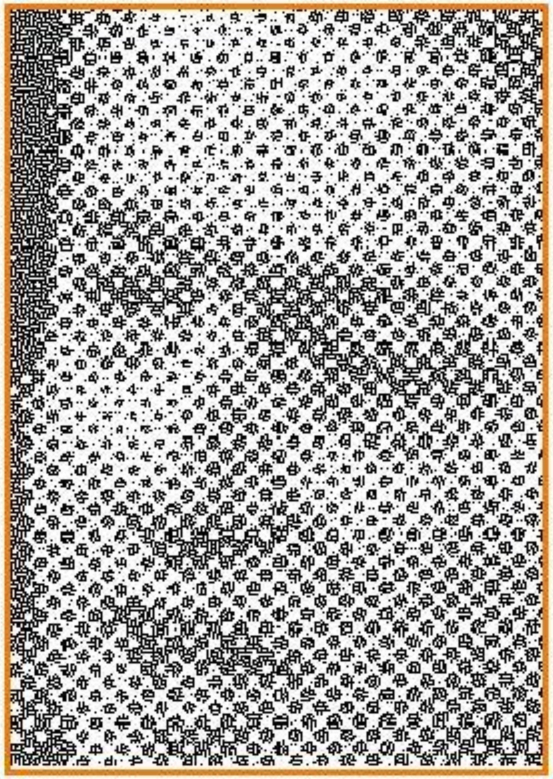


P(x,y)

http://www.cs.princeton.edu/courses/archive/fall99/cs426/lectures/dither/sld011.htm

Classical halftoning

Newspaper Image

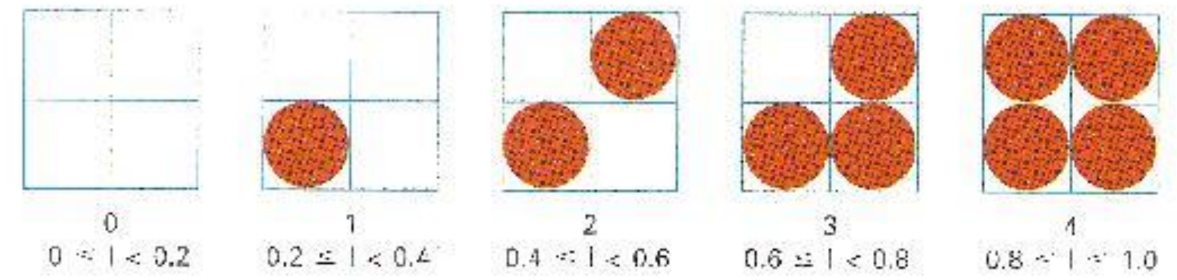


From New York Times, 9/21

http://www.cs.princeton.edu/courses/archive/fall99/cs426/lectures/dither/sld012.htm

Halftone patterns

- Use cluster of pixels to represent intensity
  - Trade spatial resolution for intensity resolution
  - ***create the illusion*** of many grey levels in a binary image

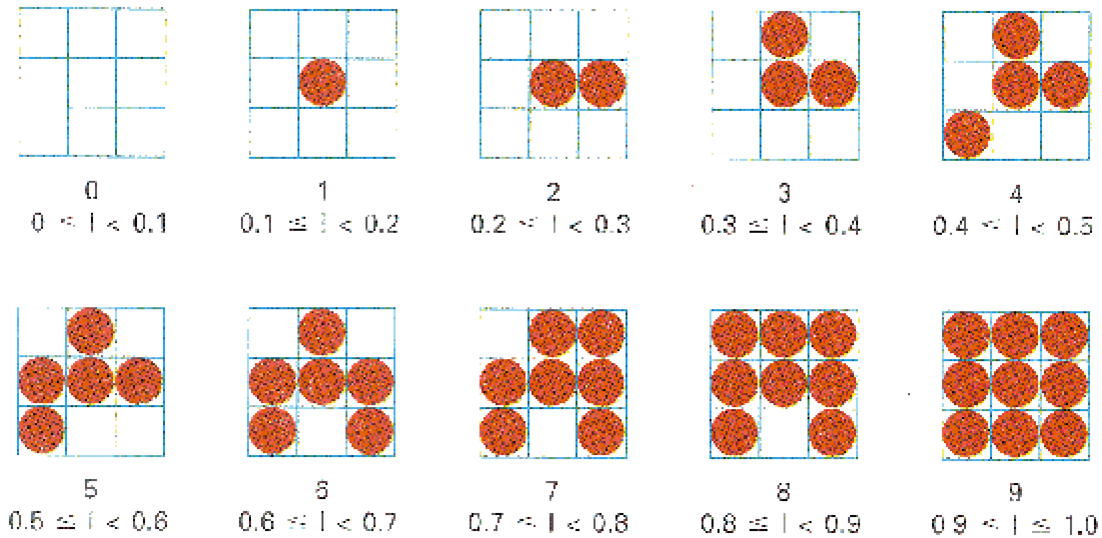


  - with 2 x 2 binary pixel grids, we can represent 5 different "effective" intensity levels.

http://www.cs.princeton.edu/courses/archive/fall99/cs426/lectures/dither/sld012.htm

Halftone patterns

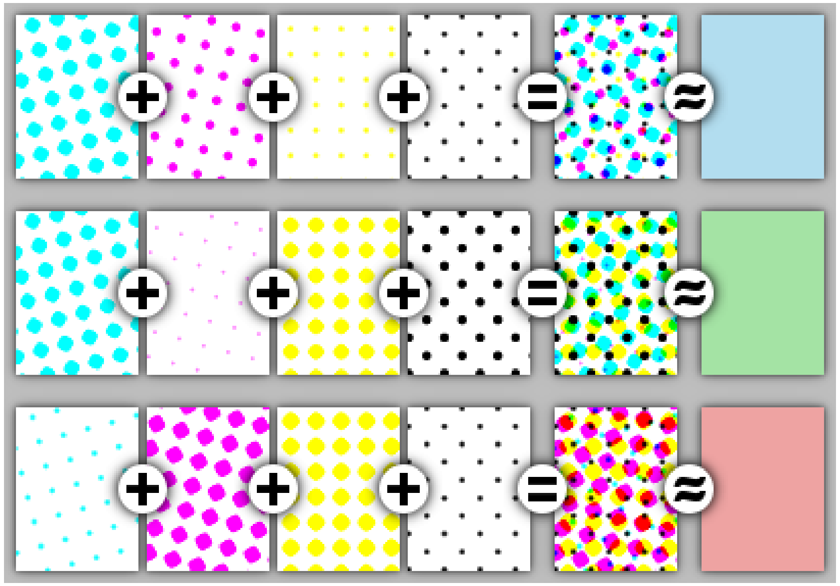
- How many intensities in a *nxn* cluster?



http://www.cs.princeton.edu/courses/archive/fall99/cs426/lectures/dither/sld012.htm

Color printing

- Color halftone
  - Three examples of color halftoning with CMYK separations

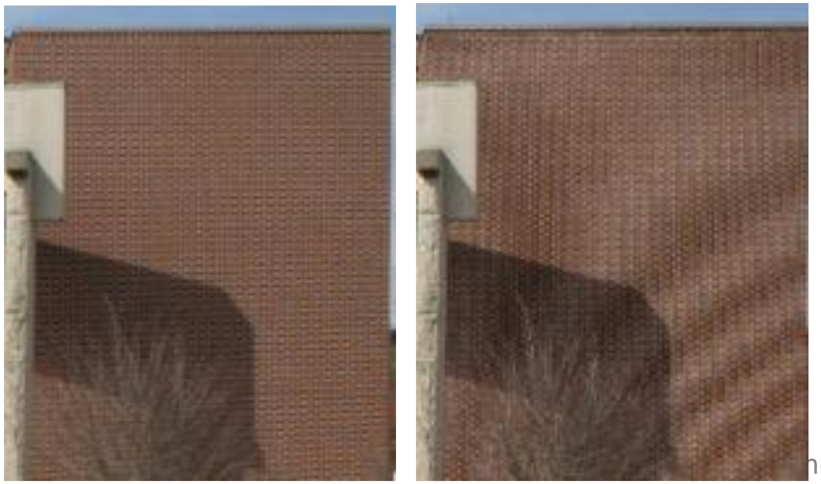


Color printing

- Examples
  - Cyan, magenta, yellow, and black (CMYK) separations with halftone exaggerated to show detail

Color printing

- The moiré effects
  - Generated by traditional halftones
- Stochastic screening
  - The dots are the same size and randomly placed
    - Moiré effects are eliminated
  - Almost all inkjet devices use it

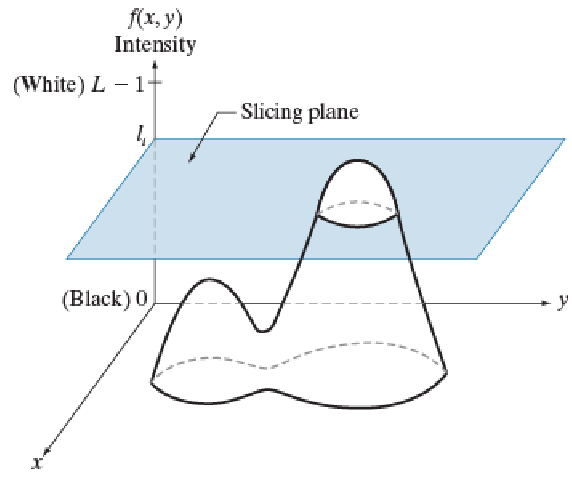


Color operations

- Color conversions
- Color complements
- Mixture of light vs mixture of paints

Intensity slicing

FIGURE 7.16
Graphical interpretation of the intensity-slicing technique.



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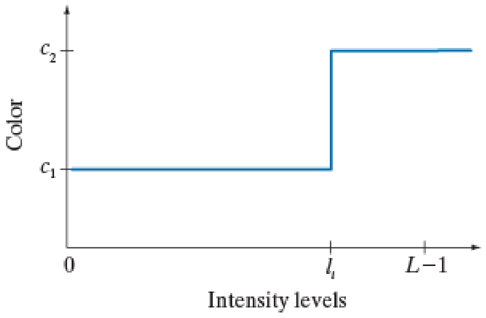
Intensity slicing

FIGURE 7.17
An alternative representation of the intensity-slicing technique.



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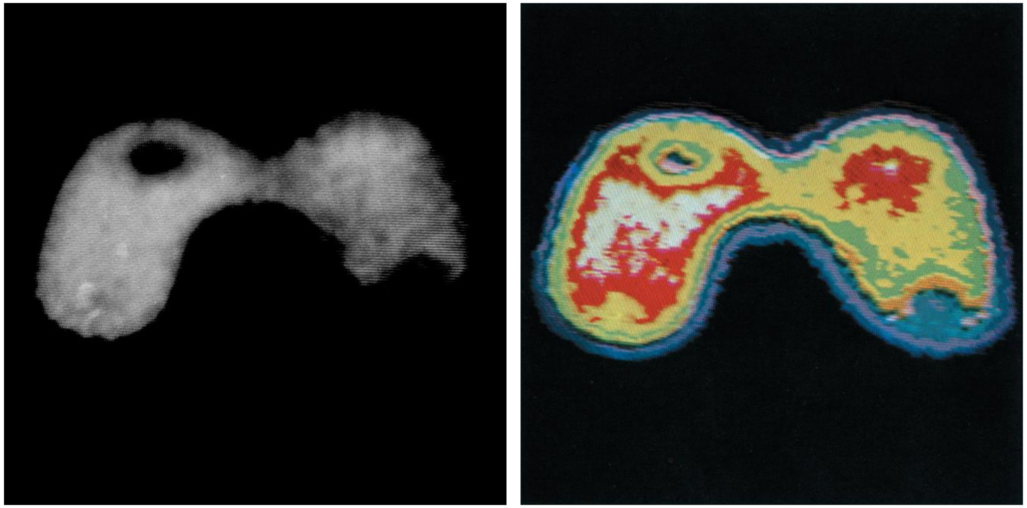
Intensity slicing



a b

FIGURE 7.18
(a) Grayscale image of the Picker Thyroid Phantom.
(b) Result of intensity slicing using eight colors.
(Courtesy of Dr. J. L. Blankenship, Oak Ridge National Laboratory.)

Advanced topics in color processing

- Pseudocolor image processing
- Color mapping

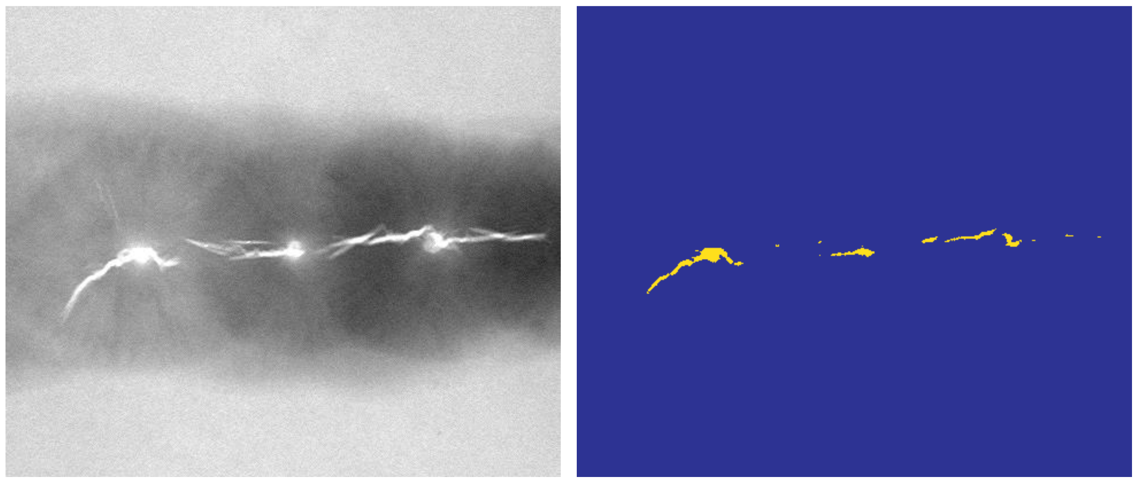
Pseudocolor image processing

- The principal use of pseudocolor is for human visualization and interpretation of gray-scale event in an image or sequence of images.
- Human can discern thousands of color shades and intensities, compared to only two dozen or so shades of gray

Color coding example

a b

FIGURE 7.19
(a) X-ray image of a weld.
(b) Result of color coding. (Original image courtesy of X-TEK Systems, Ltd.)



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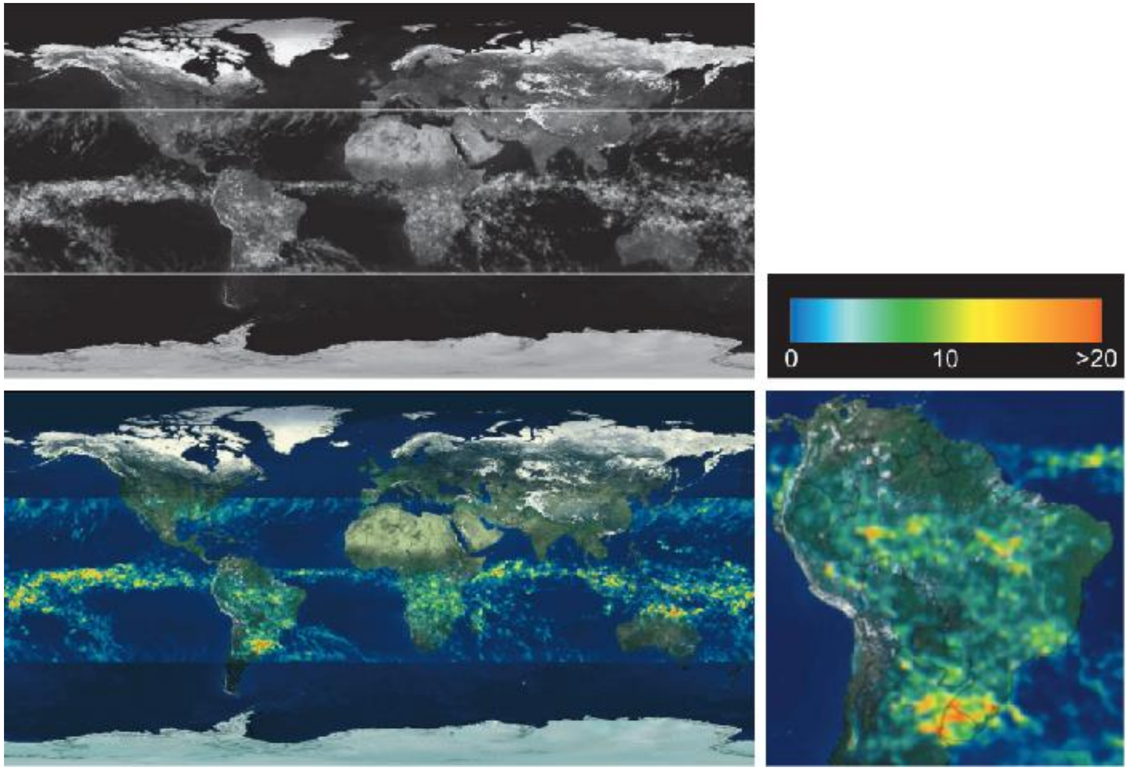
Color coding example



a b
c d

FIGURE 7.20 (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. (d) Zoom of the South American region. (Courtesy of NASA.)

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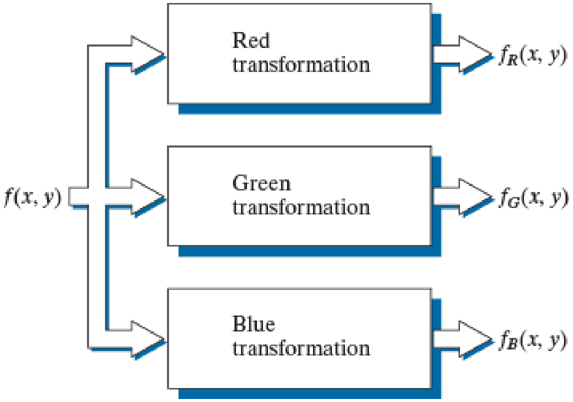
Pseudocolor image processing

FIGURE 7.21 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.



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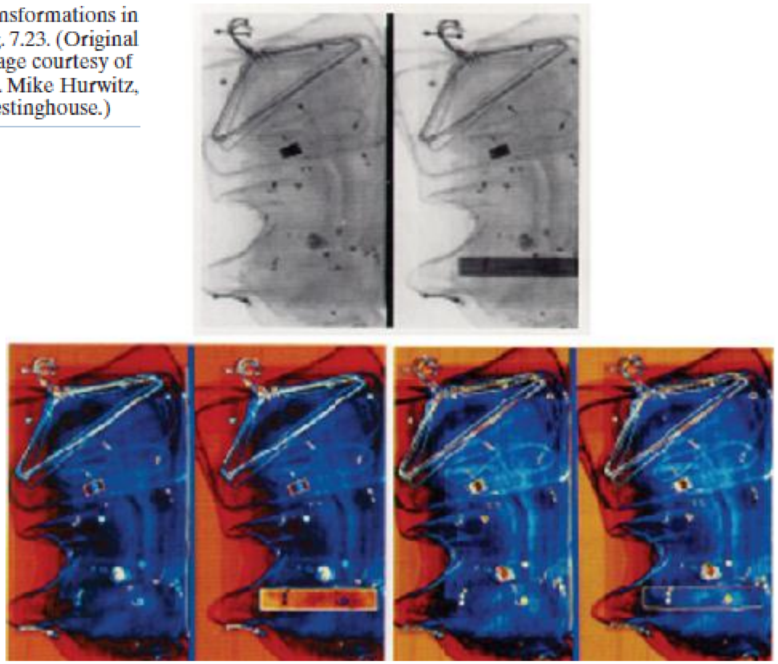
Pseudocolor enhancement

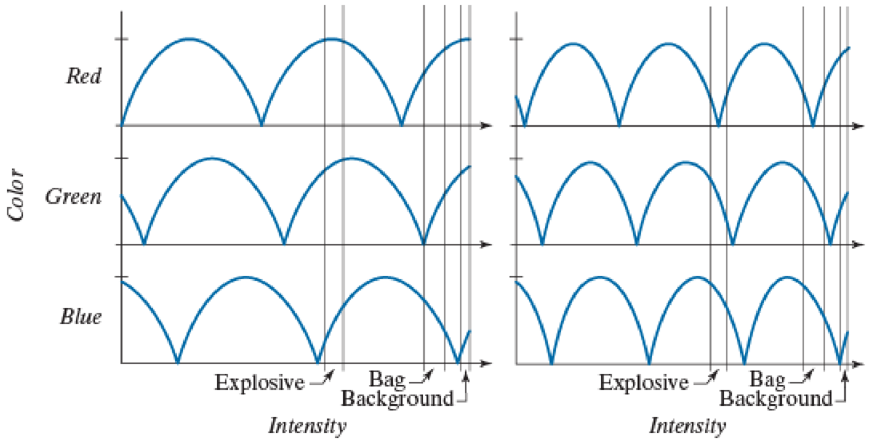
a
b c

FIGURE 7.22 Pseudocolor enhancement by using the gray level to color transformations in Fig. 7.23. (Original image courtesy of Dr. Mike Hurwitz, Westinghouse.)



a b

FIGURE 7.23 Transformation functions used to obtain the pseudocolor images in Fig. 7.22.



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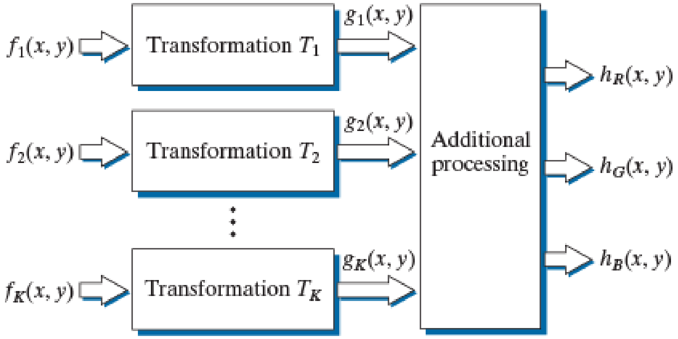
Pseudocolor coding approach

FIGURE 7.24 A pseudocolor coding approach using multiple grayscale images. The inputs are grayscale images. The outputs are the three components of an RGB composite image.



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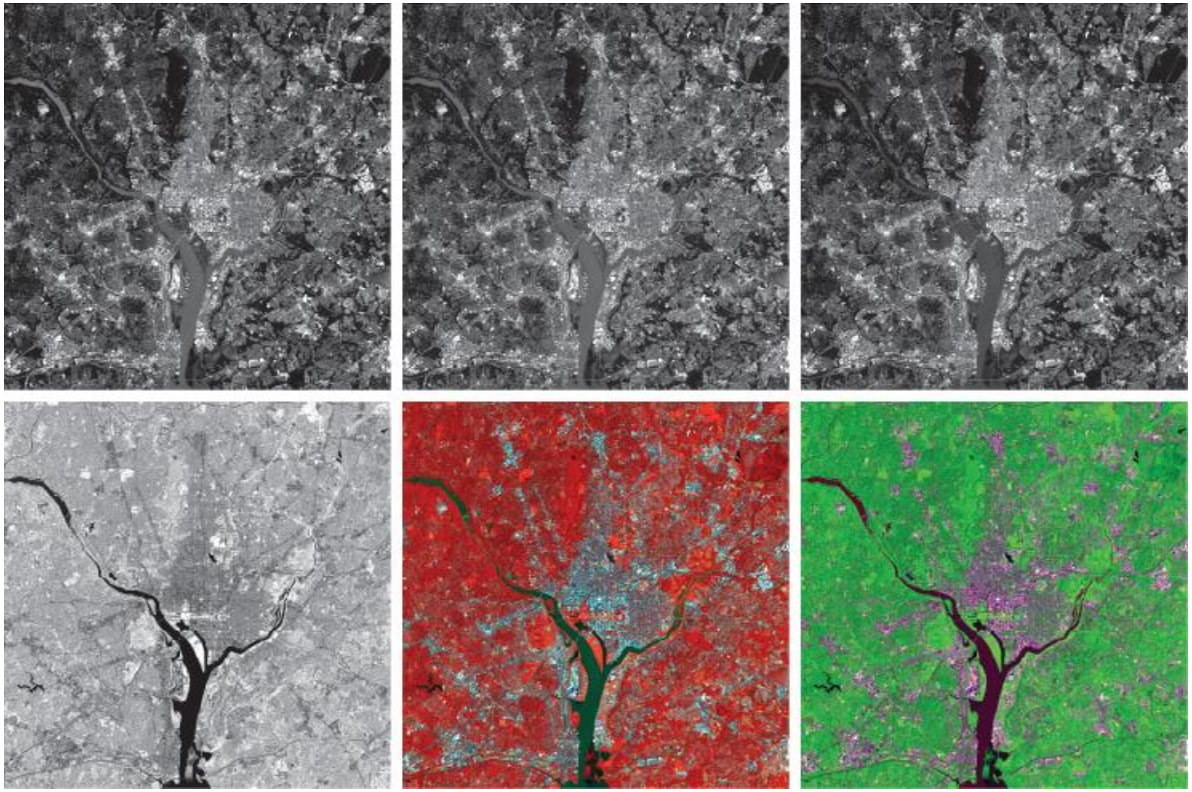

a b c
d e f

FIGURE 7.25 (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. (Original multispectral images courtesy of NASA.)

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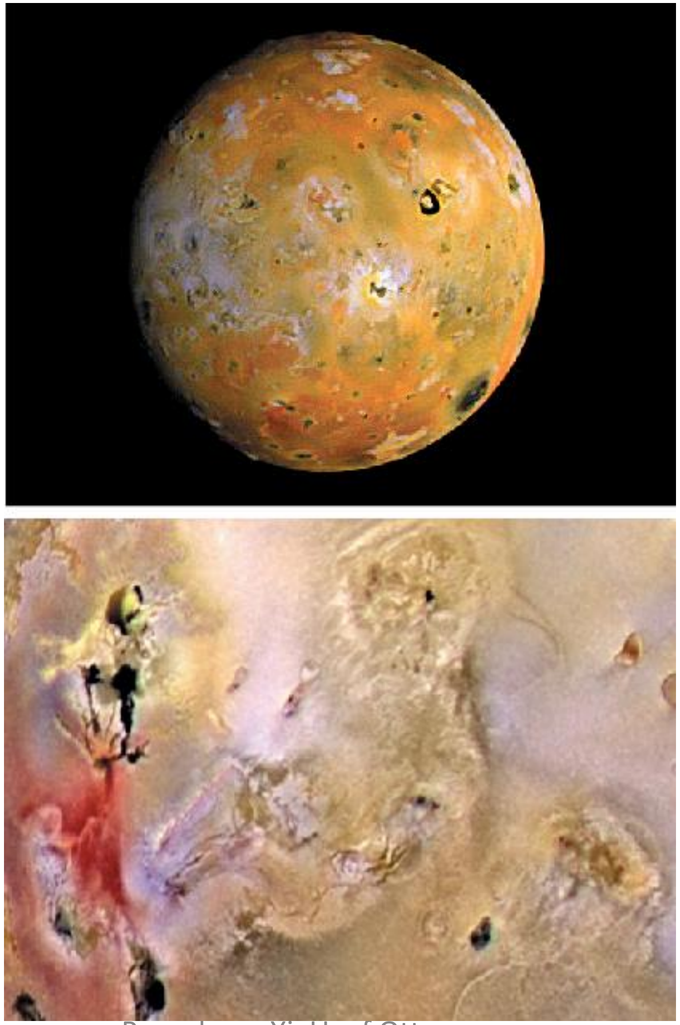
a
b

FIGURE 7.26 (a) Pseudocolor rendition of Jupiter Moon Io. (b) A close-up. (Courtesy of NASA.)



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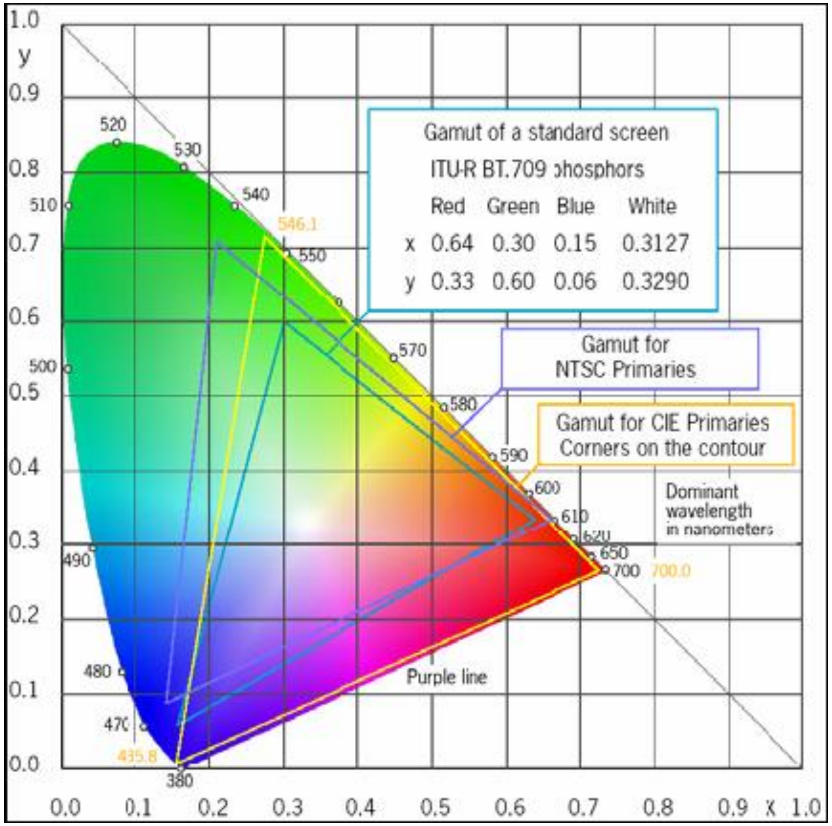
Conversion between RGB and XYZ

[Question] In the following chromaticity diagram,

1. to what RGB color corresponds the coordinate x=0.3, y=0.2?
2. To what x and y color correspondins to the R=40 G=100 B=100?



Matrix calculation

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Conversion from XYZ to RGB

- Find the z-coordinate $z = 1 - x - y$
- Convert to tristimulus values (X, Y, Z)
  - Convert the chromaticity values (x, y, z) into the CIE XYZ tristimulus values
  - The Y value is typically taken as the luminance, which can be chosen or assumed (Y=1 is a common choice)

$$X = \frac{x}{y} \cdot Y = \frac{0.3}{0.2} \cdot 1 = 1.5$$

$$Z = \frac{z}{y} \cdot Y = \frac{0.5}{0.2} \cdot 1 = 2.5$$

Conversion from XYZ to RGB (cont.)

- Convert XYZ to RGB

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 3.2406 & -1.5372 & -0.4986 \\ -0.9689 & 1.8758 & 0.0415 \\ 0.0557 & -0.2040 & 1.0570 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

- Gamma correction
  - The linear RGB values need to be adjusted to account for the non-linear response of most displays
- Clamp RGB values
  - Ensure the RGB values are clamped to the range [0, 1]

Practical applications

- Applications of color processing in
  - Photography
  - Medical imaging
  - Digital art, etc.