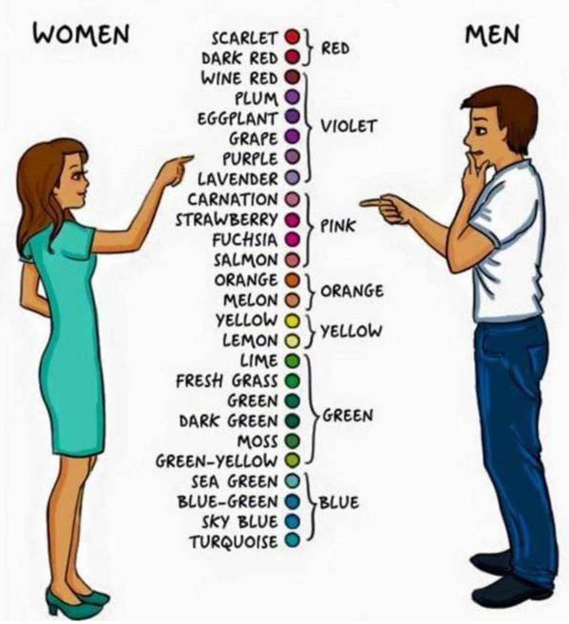
Image Processing II

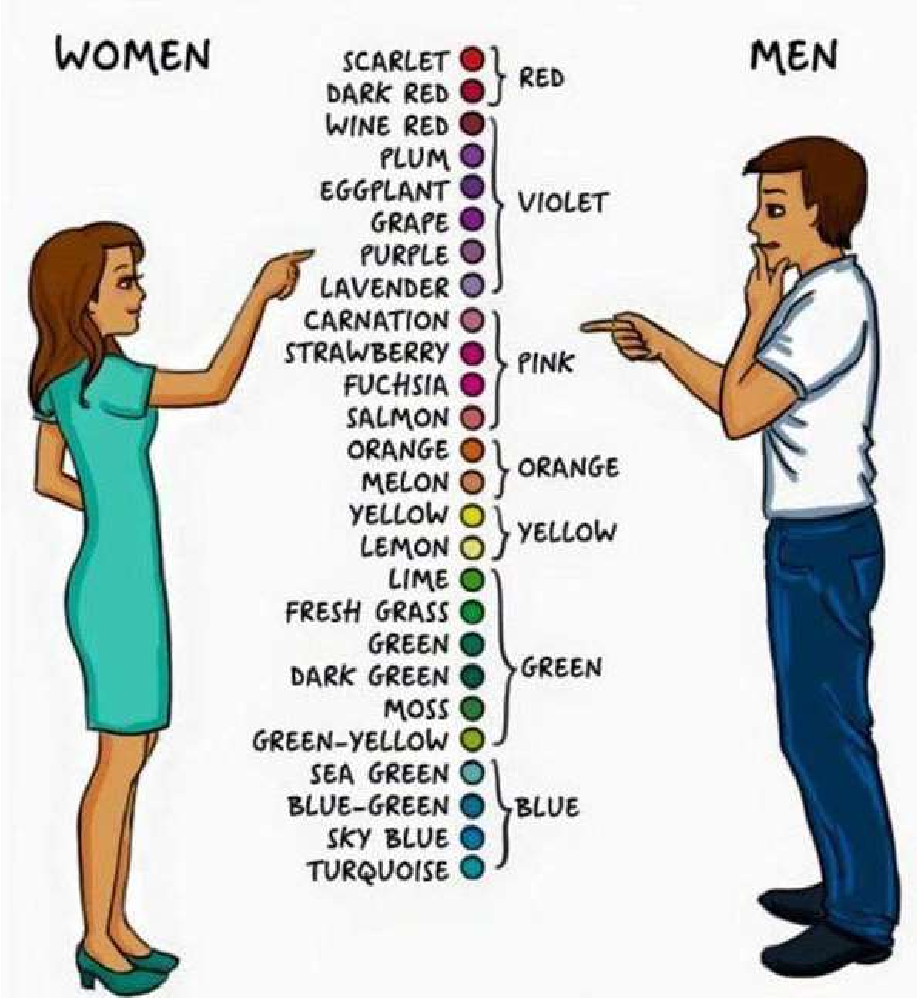
Color images

Part 2 – Standardization of colors



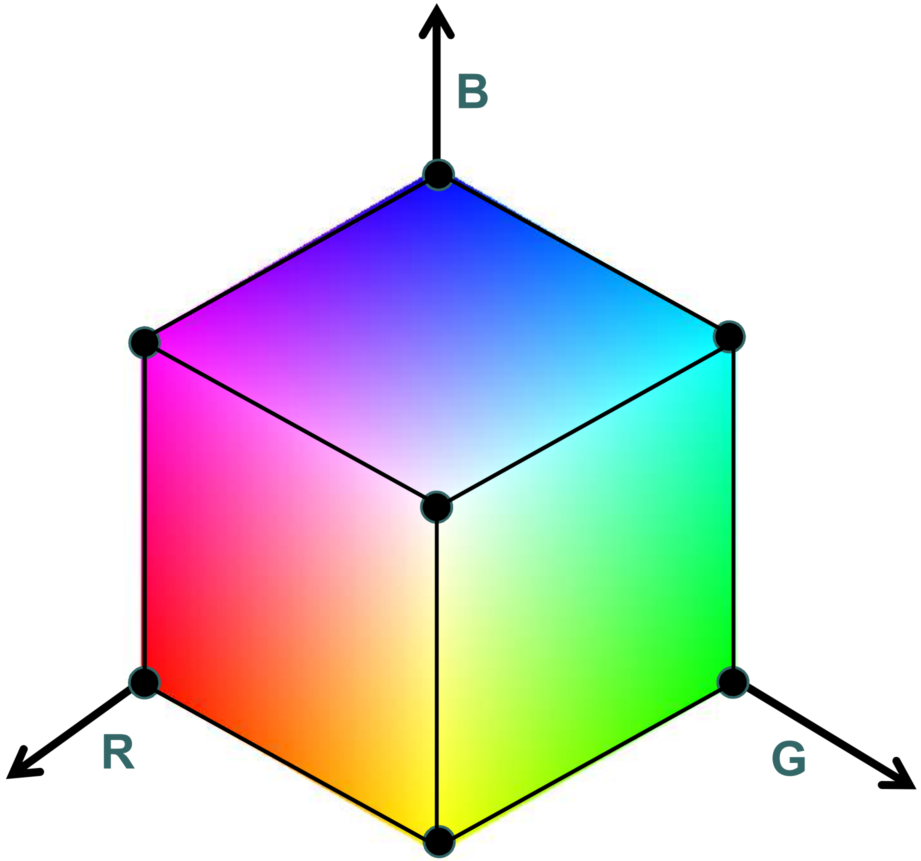
Standardization of colors

How we see colors…



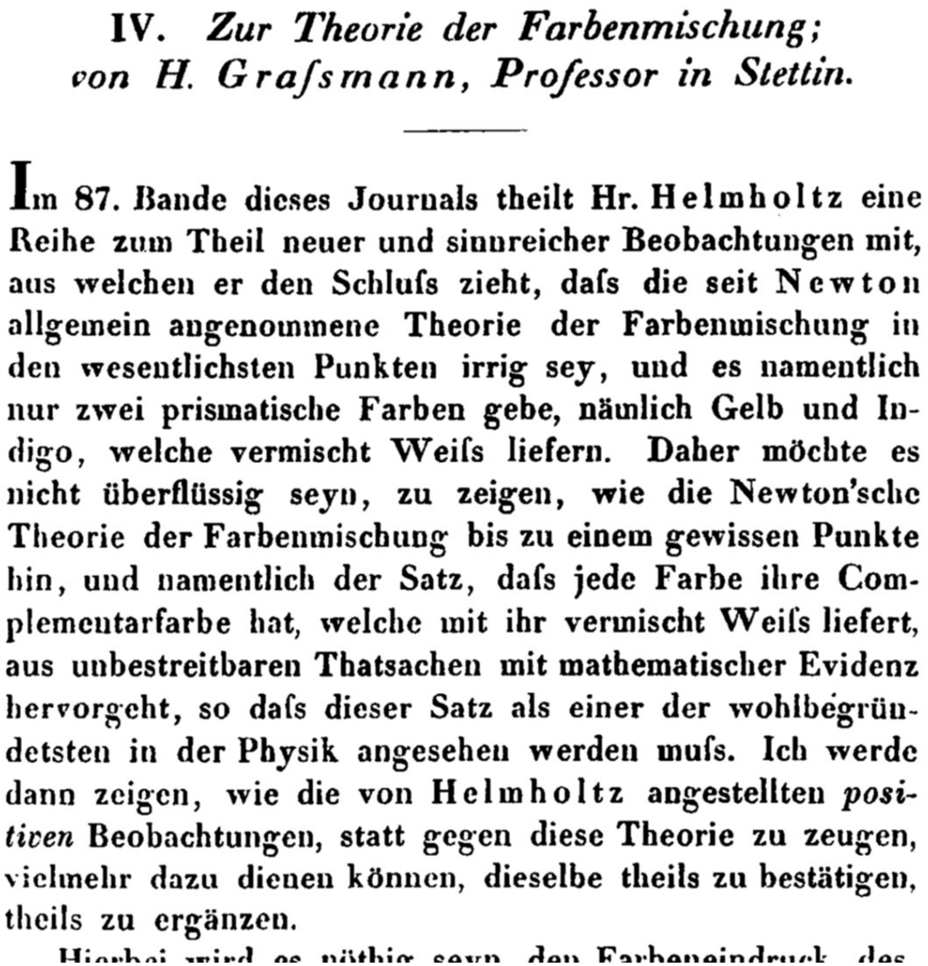
Standardization of colors

Additive and subtractive color mixing



Standardization of colors

Graßmann’s laws



IV. *Zur Theorie der Farbenmischung;*

von H. Graſsmann, Profeſsor in Stettin.

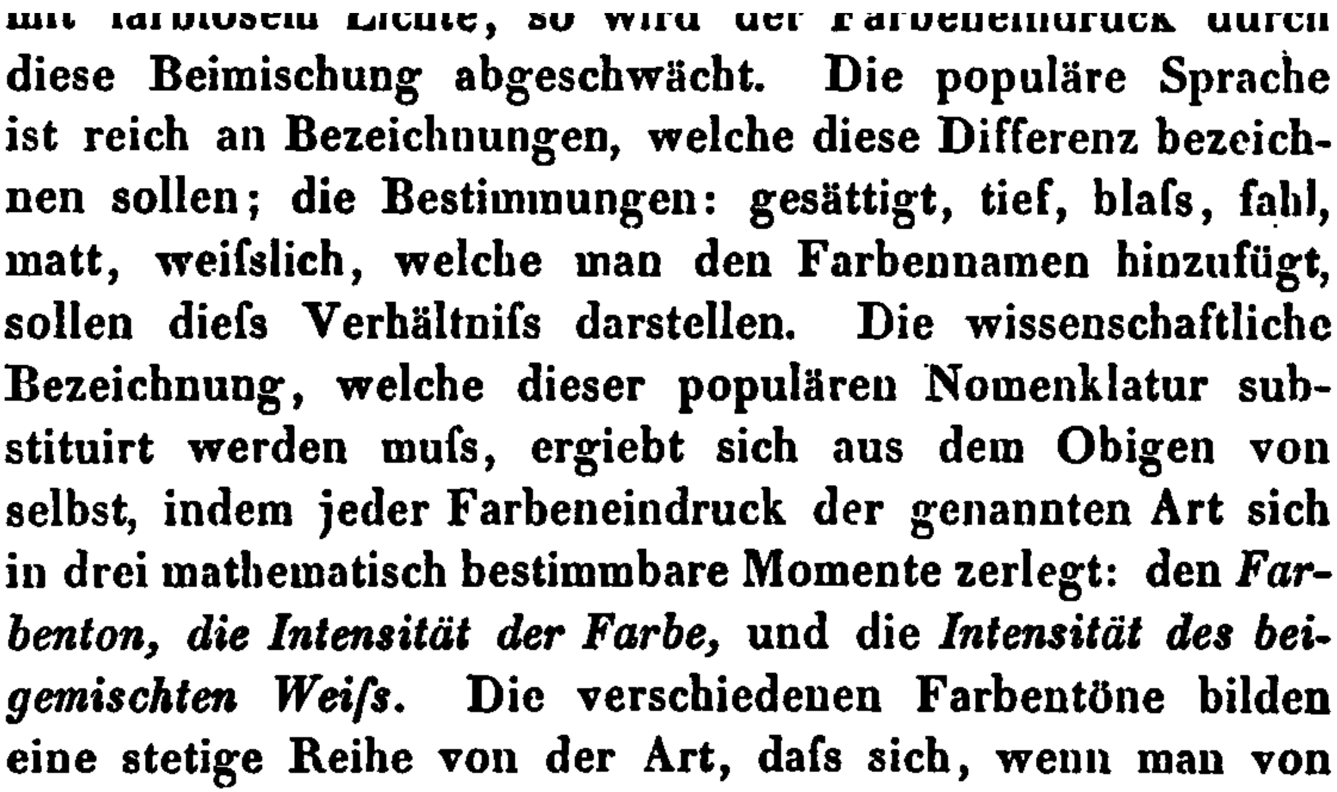
Im 87. Bande dieses Journals theilt Hr. Helmholtz eine Reihe zum Theil neuer und sinnreicher Beobachtungen mit, aus welchen er den Schluſs zieht, daſs die seit Newton allgemein angenommene Theorie der Farbenmischung in den wesentlichsten Punkten irrig sey, und es namentlich nur zwei prismatische Farben gebe, nämlich Gelb und Indigo, welche vermischt Weiſs liefern. Daher möchte es nicht überflüssig seyn, zu zeigen, wie die Newton'sche Theorie der Farbenmischung bis zu einem gewissen Punkte hin, und namentlich der Satz, daſs jede Farbe ihre Complementarfarbe hat, welche mit ihr vermischt Weiſs liefert, aus unbestreitbaren Thatsachen mit mathematischer Evidenz hervorgeht, so daſs dieser Satz als einer der wohlbegründetsten in der Physik angesehen werden muſs. Ich werde dann zeigen, wie die von Helmholtz angestellten *positiven* Beobachtungen, statt gegen diese Theorie zu zeugen, vielmehr dazu dienen können, dieselbe theils zu bestätigen, theils zu ergänzen.

Hierbei wird es nöthig seyn, den Farbeneindruck des

Graßmann, Ann Phys Chem 165, 69–84 (1853).

Standardization of colors

Graßmann’s laws

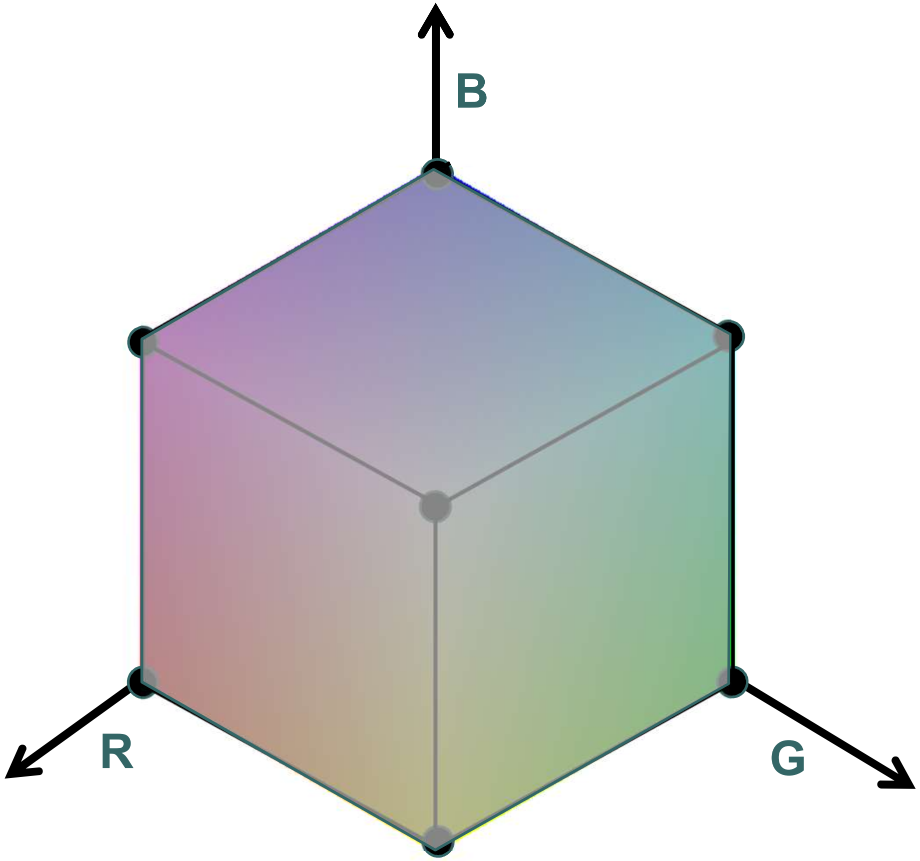


mit farblosem Lichte, so wird der Farbeneindruck durch diese Beimischung abgeschwächt. Die populäre Sprache ist reich an Bezeichnungen, welche diese Differenz bezeichnen sollen; die Bestimmungen: gesättigt, tief, blaſs, fahl, matt, weiſslich, welche man den Farbennamen hinzufügt, sollen dieſs Verhältniſs darstellen. Die wissenschaftliche Bezeichnung, welche dieser populären Nomenklatur substituirt werden muſs, ergiebt sich aus dem Obigen von selbst, indem jeder Farbeneindruck der genannten Art sich in drei mathematisch bestimmbare Momente zerlegt: den *Farbenton, die Intensität der Farbe,* und die *Intensität des beigemischten Weiſs.* Die verschiedenen Farbentöne bilden eine stetige Reihe von der Art, daſs sich, wenn man von

Graßmann, Ann Phys Chem 165, 69–84 (1853).

Standardization of colors

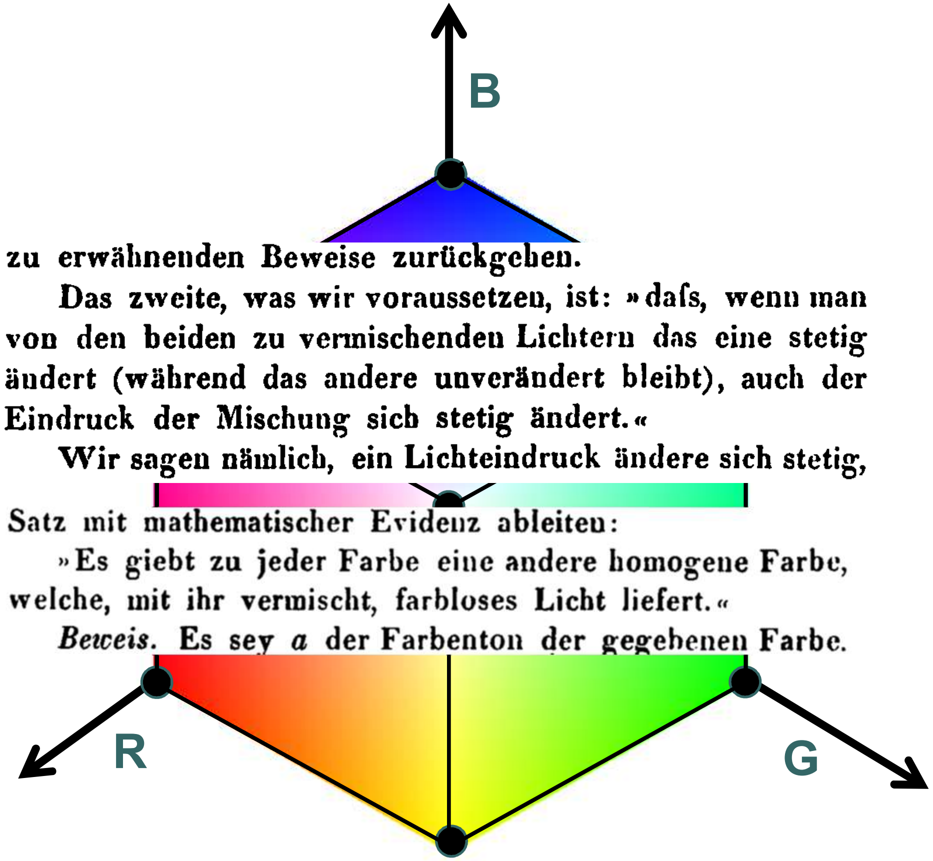
Graßmann's laws



1. Every impression of color may be analyzed into three mathematically determinable elements, the hue, the intensity of color, and the intensity of the intermixed white.

Standardization of colors

Graßmann's laws



zu erwähnenden Beweise zurückgeben.

Das zweite, was wir voraussetzen, ist: »daſs, wenn man von den beiden zu vermischenden Lichtern das eine stetig ändert (während das andere unverändert bleibt), auch der Eindruck der Mischung sich stetig ändert.«

Wir sagen nämlich, ein Lichteindruck ändere sich stetig,

Satz mit mathematischer Evidenz ableiten:

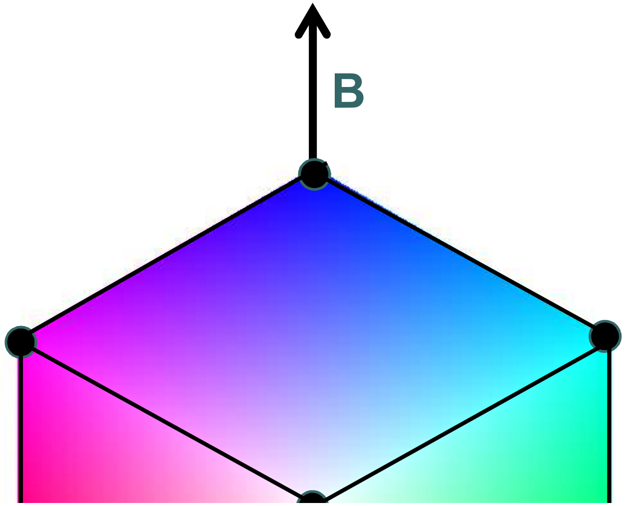
»Es giebt zu jeder Farbe eine andere homogene Farbe, welche, mit ihr vermischt, farbloses Licht liefert.«

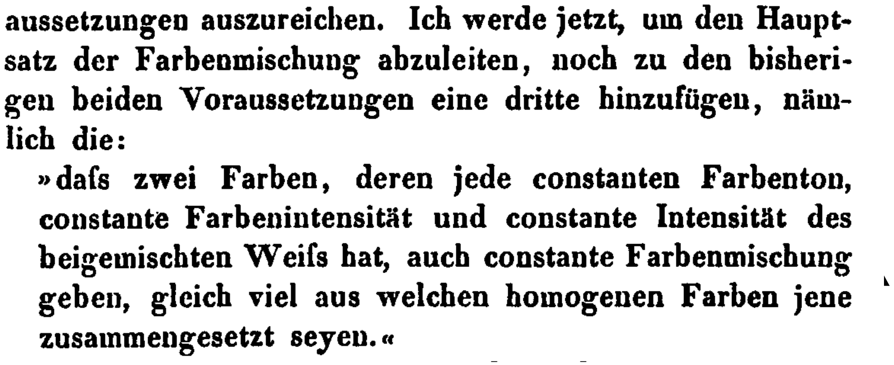
Beweis. Es sey *a* der Farbenton der gegebenen Farbe.

1. Every impression of color may be analyzed into three mathematically determinable elements, the hue, the intensity of color, and the intensity of the intermixed white.
2. If one of two mingling lights is continuously altered, while the other remains unchanged, the impression of the mixed light is also continuously changed.

Standardization of colors

Graßmann's laws



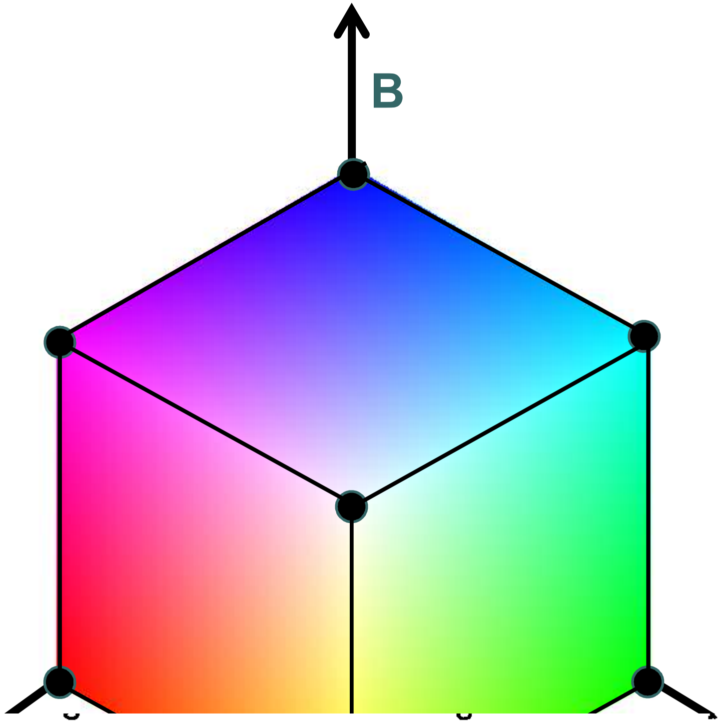

aussetzungen auszureichen. Ich werde jetzt, um den Hauptsatz der Farbenmischung abzuleiten, noch zu den bisherigen beiden Voraussetzungen eine dritte hinzufügen, nämlich die:

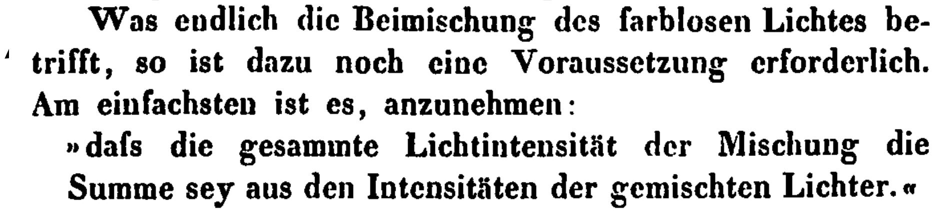
> »daſs zwei Farben, deren jede constanten Farbenton, constante Farbenintensität und constante Intensität des beigemischten Weiſs hat, auch constante Farbenmischung geben, gleich viel aus welchen homogenen Farben jene zusammengesetzt seyen.«

1. Every impression of color may be analyzed into three mathematically determinable elements, the hue, the intensity of color, and the intensity of the intermixed white.
2. If one of two mingling lights is continuously altered, while the other remains unchanged, the impression of the mixed light is also continuously changed.
3. Two colors, both of which have the same hue and the same proportion of intermixed white, also give identical mixed colors, no matter what homogeneous colors they may be composed of.

Standardization of colors

Graßmann’s laws





Was endlich die Beimischung des farblosen Lichtes betrifft, so ist dazu noch eine Voraussetzung erforderlich. Am einfachsten ist es, anzunehmen:

»daſs die gesammte Lichtintensität der Mischung die Summe sey aus den Intensitäten der gemischten Lichter.«

1. Every impression of color may be analyzed into three mathematically determinable elements, the hue, the intensity of color, and the intensity of the intermixed white.
2. If one of two mingling lights is continuously altered, while the other remains unchanged, the impression of the mixed light is also continuously changed.
3. Two colors, both of which have the same hue and the same proportion of intermixed white, also give identical mixed colors, no matter what homogeneous colors they may be composed of.
4. The total intensity of any mixture is the sum of the intensities of the lights mixed.

Standardization of colors

Color matching experiments

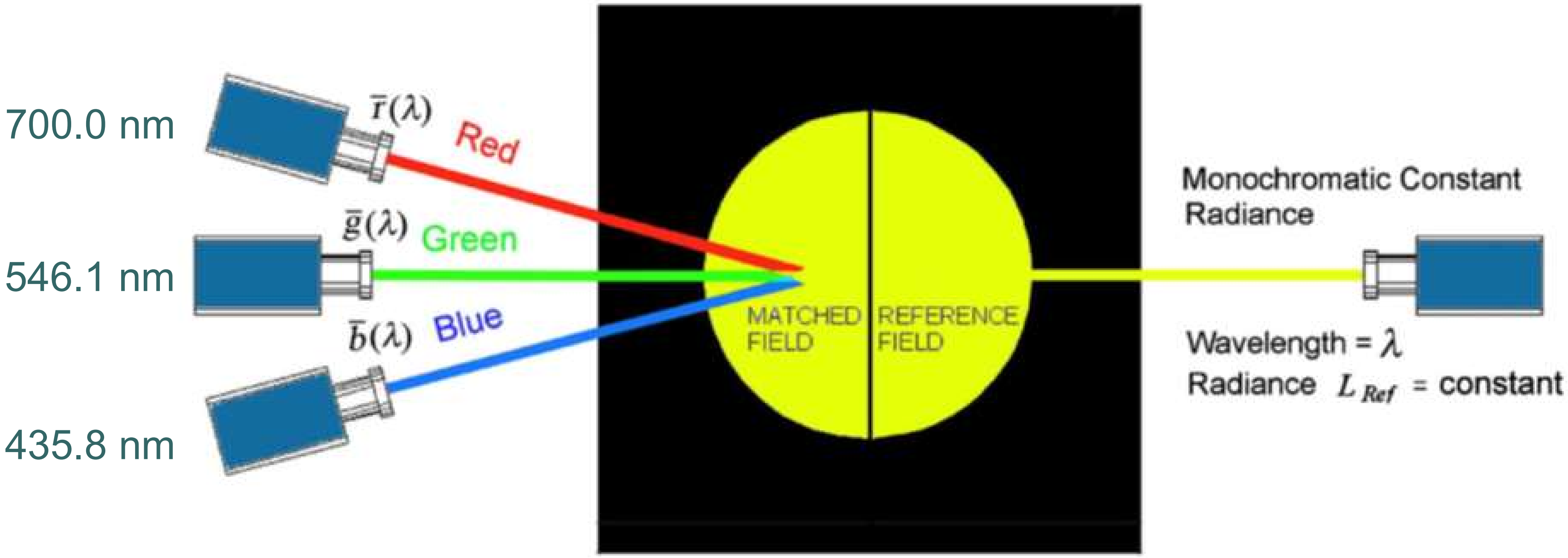
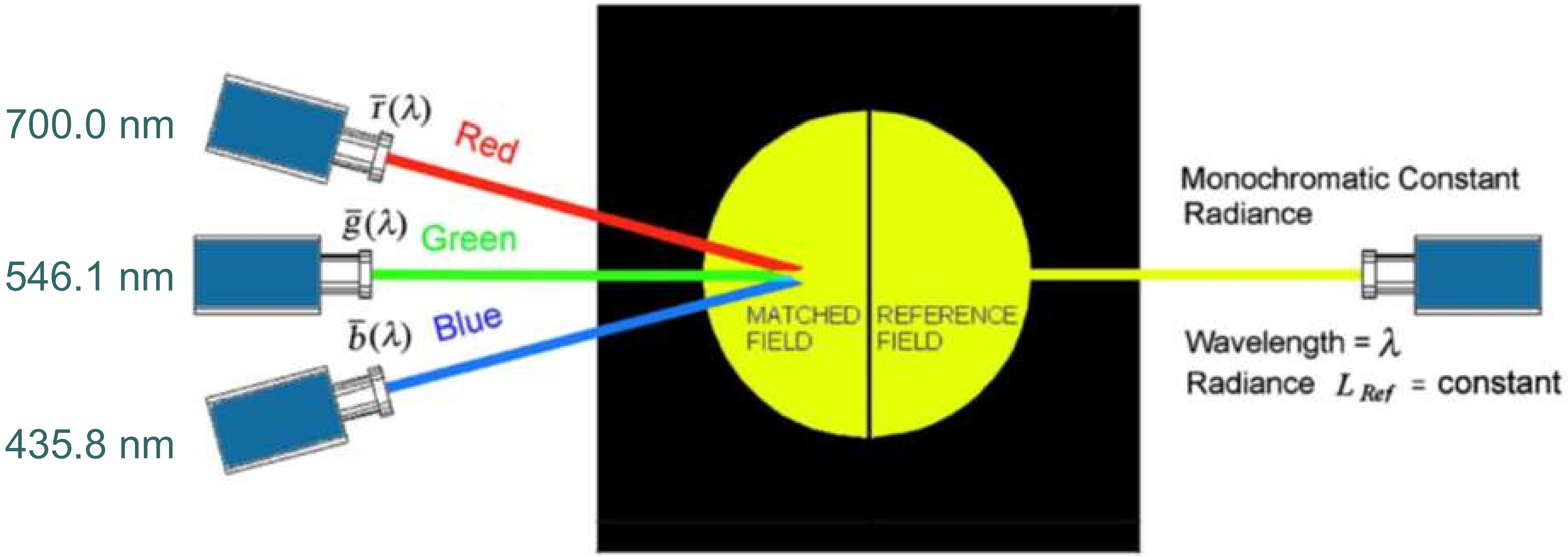


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 61

Standardization of colors

Color matching experiments



700.0 nm

546.1 nm

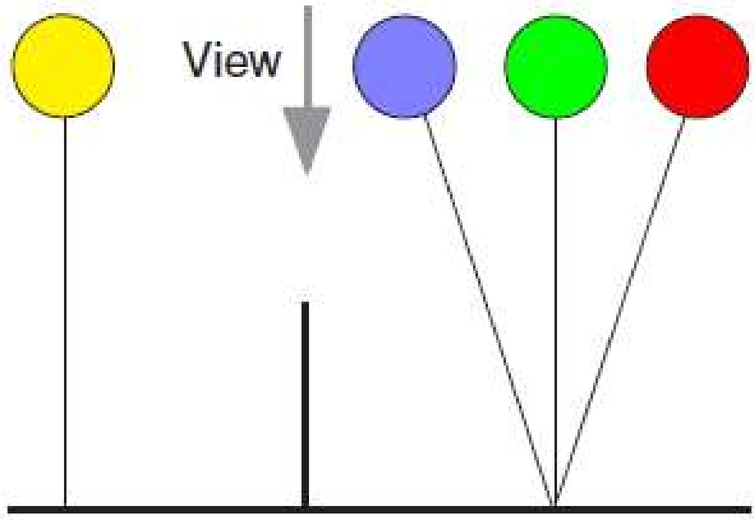
435.8 nm

Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 61

Standardization of colors

Color matching experiments

The color matching experiment was invented by Hermann Graßmann (1809 – 1877) about 1853.



A spectrometer selects a given wavelength and generates a color impression. The test person has to adjust the intensities of three light sources (primaries) such that the color impression matches the color selected by the spectrometer.

Standard primaries used by the Commission International de l'Eclairage (CIE) (1931) are 435.8 nm (blue), 546.1nm (green) and 700nm (red).

Standardization of colors

Color matching experiments

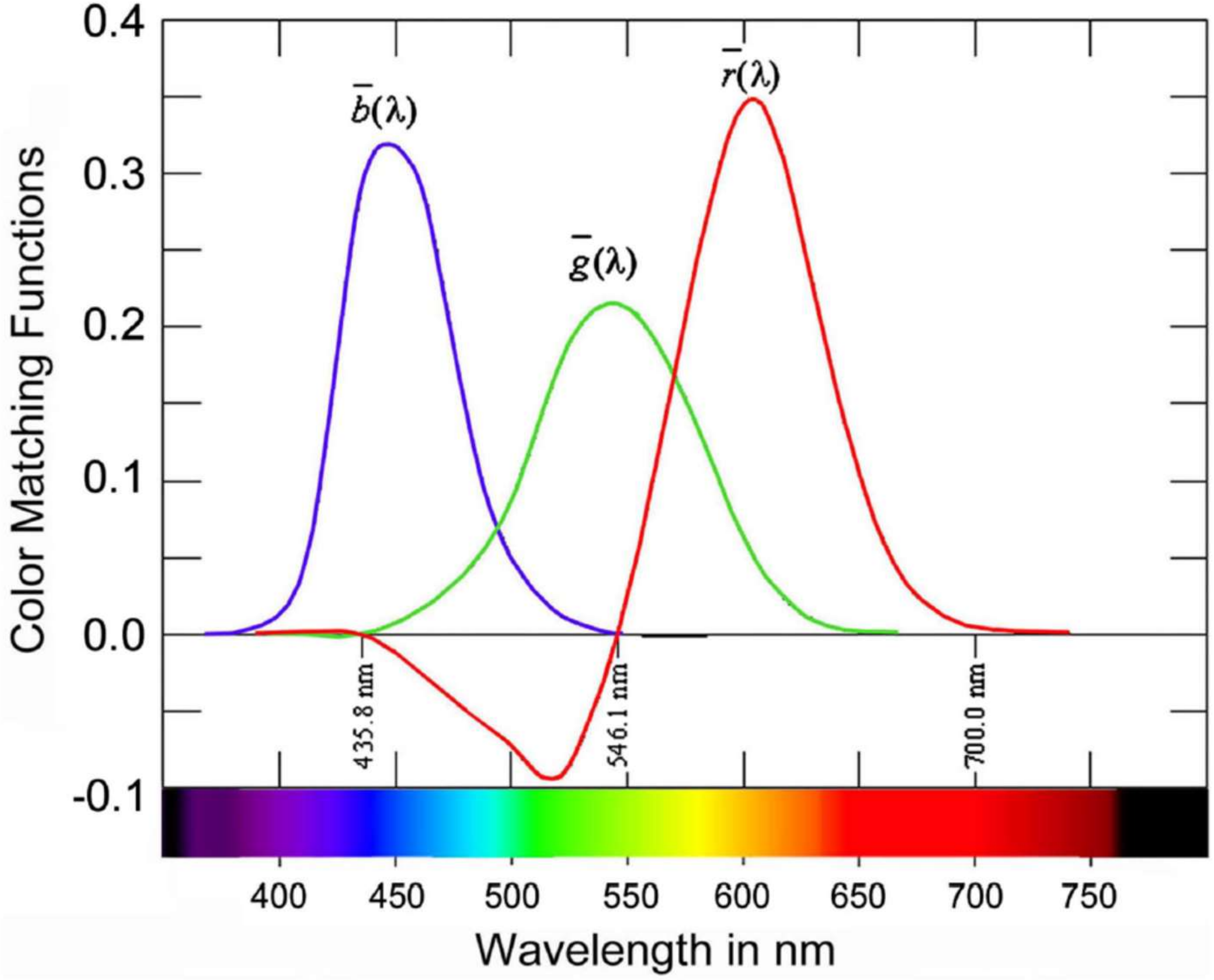


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 61

Standardization of colors

Transformation to CIE chromaticity coordinates

No three monochromatic colors exist that can be mixed in positive amounts to match the full spectrum.

Instead only sums of monochromatic colors can form a basis set, which can be mixed in positive amounts to reproduce the full spectrum.

The transformation chosen by the Commission International de l'Eclairage (CIE) is:

$$\begin{bmatrix} X(\lambda) \\ Y(\lambda) \\ Z(\lambda) \end{bmatrix} = \begin{bmatrix} 2.76888 & 1.75175 & 1.13016 \\ 1 & 4.59070 & 0.06010 \\ 0 & 0.05651 & 5.59427 \end{bmatrix} * \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix}$$

The functions X(λ), Y(λ) and Z(λ) are called the tristimulus curves or CIE curves.

Standardization of colors

Transformation to CIE chromaticity coordinates

$$\begin{bmatrix} X(\lambda) \\ Y(\lambda) \\ Z(\lambda) \end{bmatrix} = \begin{bmatrix} 2.76888 & 1.75175 & 1.13016 \\ 1 & 4.59070 & 0.06010 \\ 0 & 0.05651 & 5.59427 \end{bmatrix} * \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix}$$

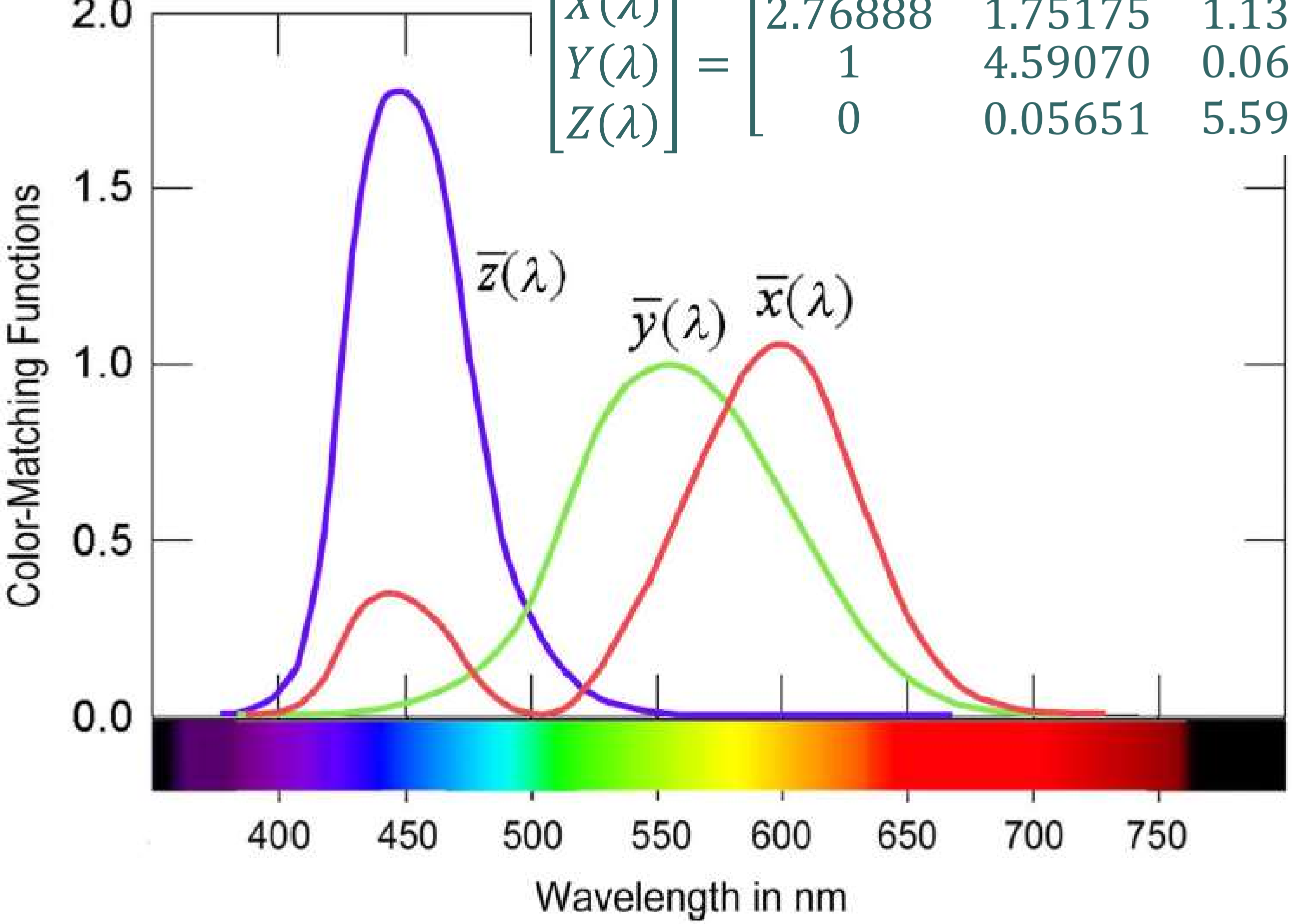


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 61

Standardization of colors

Transformation to CIE chromaticity coordinates

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The next step consists in normalizing the intensities.

$$x(\lambda) = \frac{X(\lambda)}{X(\lambda) + Y(\lambda) + Z(\lambda)} \qquad y(\lambda) = \frac{Y(\lambda)}{X(\lambda) + Y(\lambda) + Z(\lambda)}$$

The remaining variable z is not independent:

$$z(\lambda) = \frac{Z(\lambda)}{X(\lambda) + Y(\lambda) + Z(\lambda)} = 1 - x(\lambda) - y(\lambda)$$

Thus we need only two variables to describe all colors we can see.

Standardization of colors

CIE chromaticity coordinates

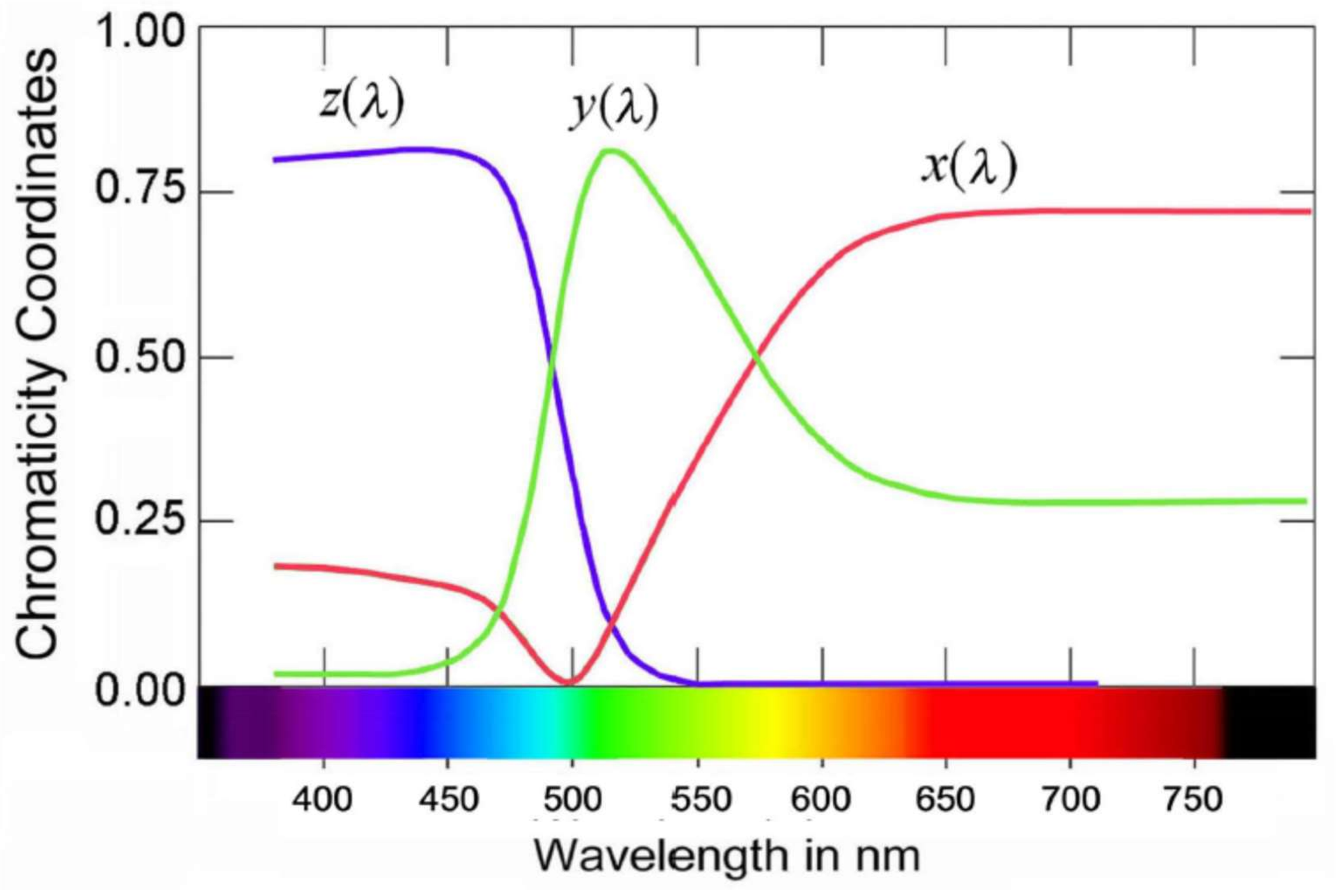
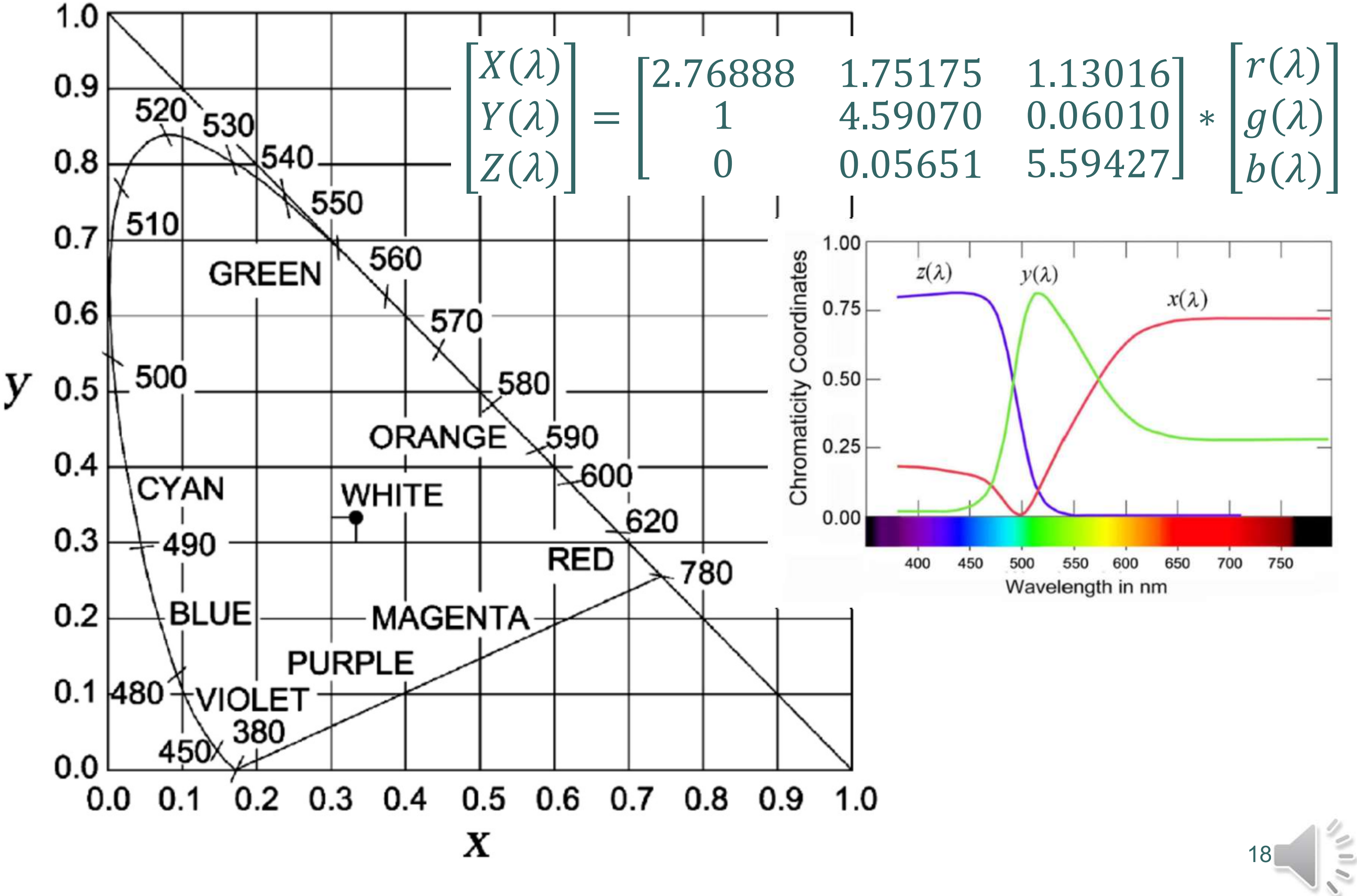


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 84

Standardization of colors

The CIE chromaticity diagram



$$\begin{bmatrix} X(\lambda) \\ Y(\lambda) \\ Z(\lambda) \end{bmatrix} = \begin{bmatrix} 2.76888 & 1.75175 & 1.13016 \\ 1 & 4.59070 & 0.06010 \\ 0 & 0.05651 & 5.59427 \end{bmatrix} * \begin{bmatrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{bmatrix}$$

Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 87

Standardization of colors

CIE chromacity coordinates

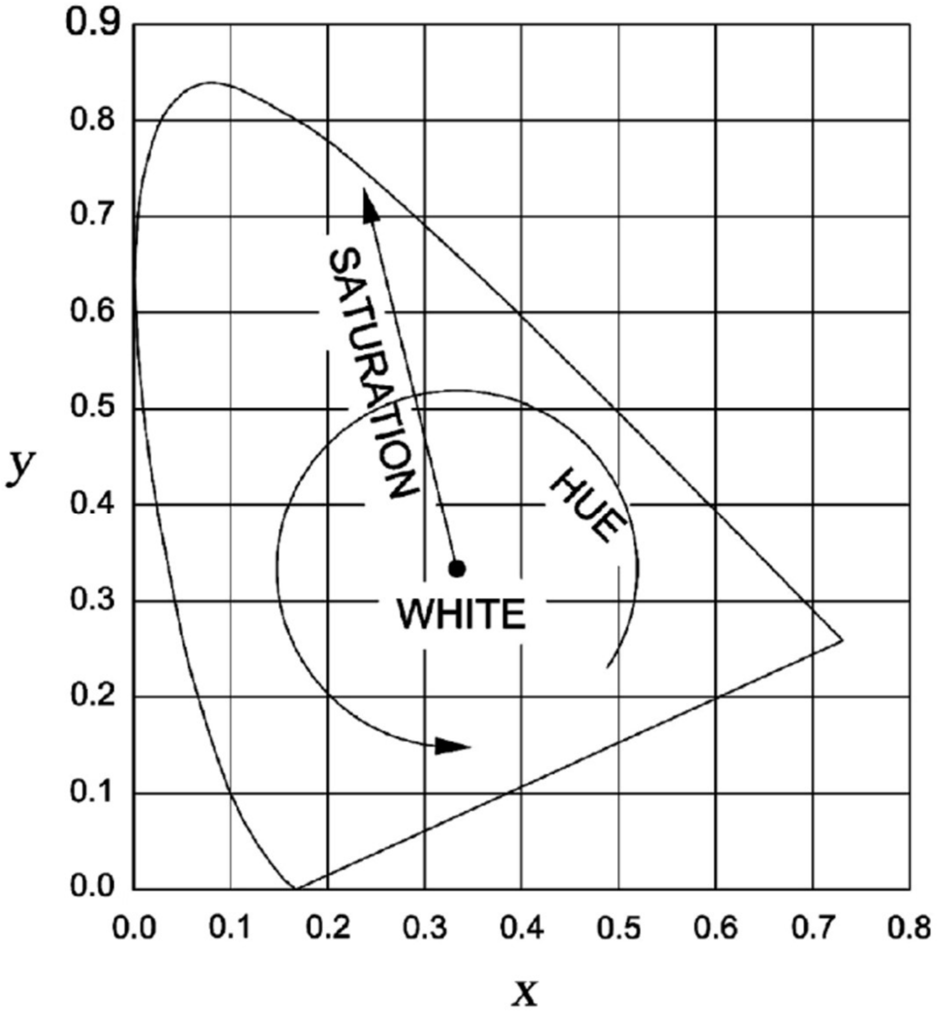
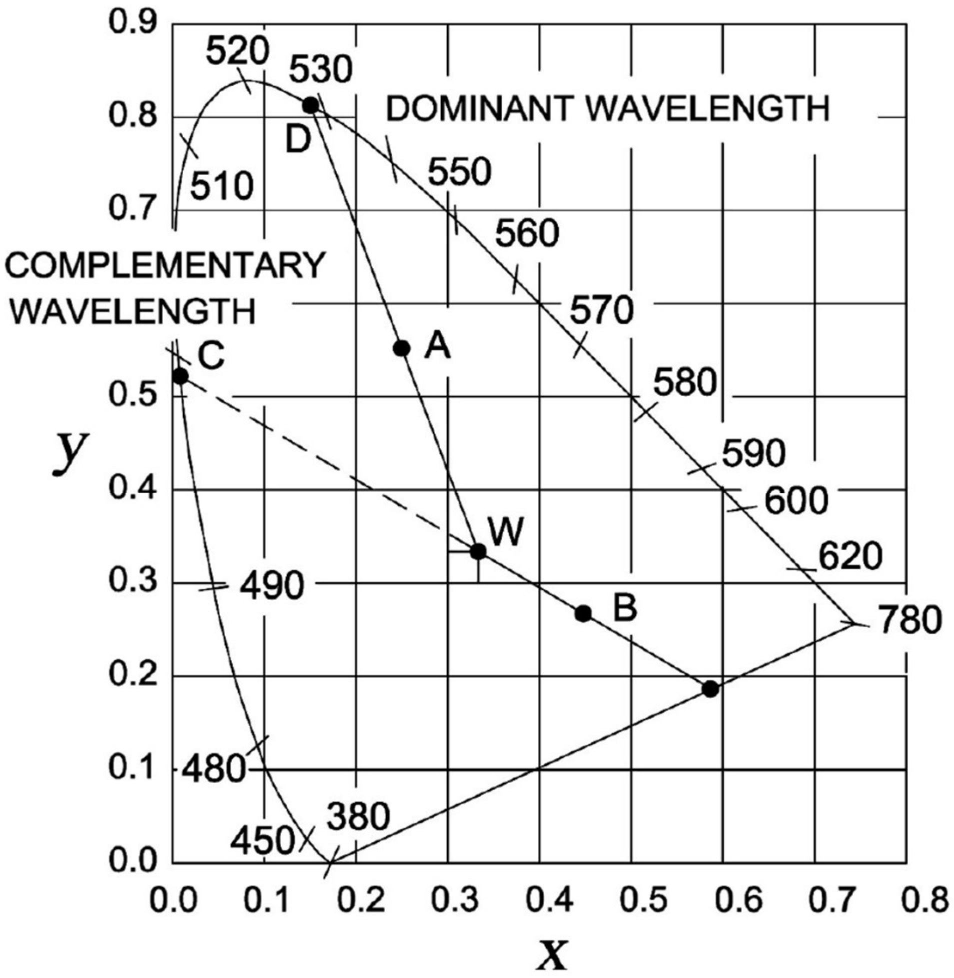


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 87

Standardization of colors

The CIE chromaticity diagram



Purity of the color:

$$p = \frac{\overline{WA}}{\overline{WD}}$$

$$p = \frac{\overline{WB}}{\overline{WC}}$$

Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 88

Standardization of colors

The CIE chromaticity diagram

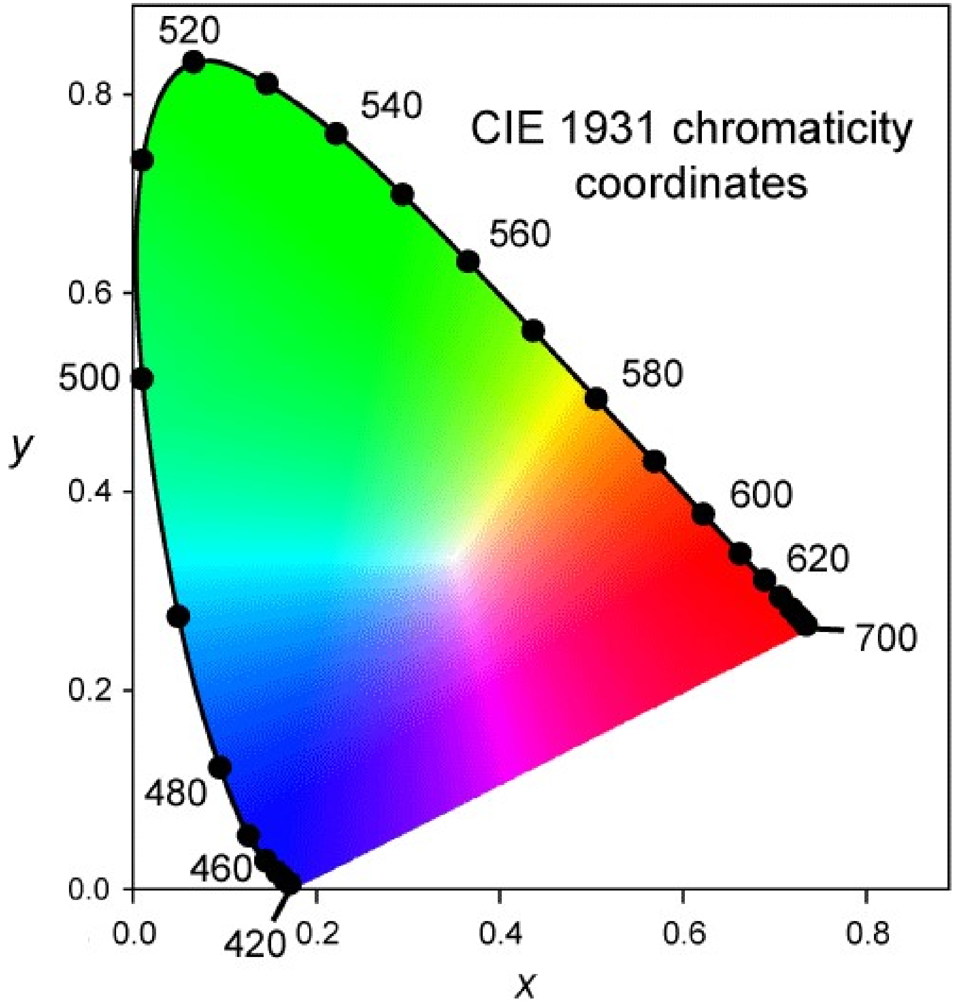


Fig. from: Colour & Vision Research Laboratory, Institute of Ophthalmology at University College London. http://cvrl.ioo.ucl.ac.uk/

Standardization of colors

The CIE chromaticity diagram

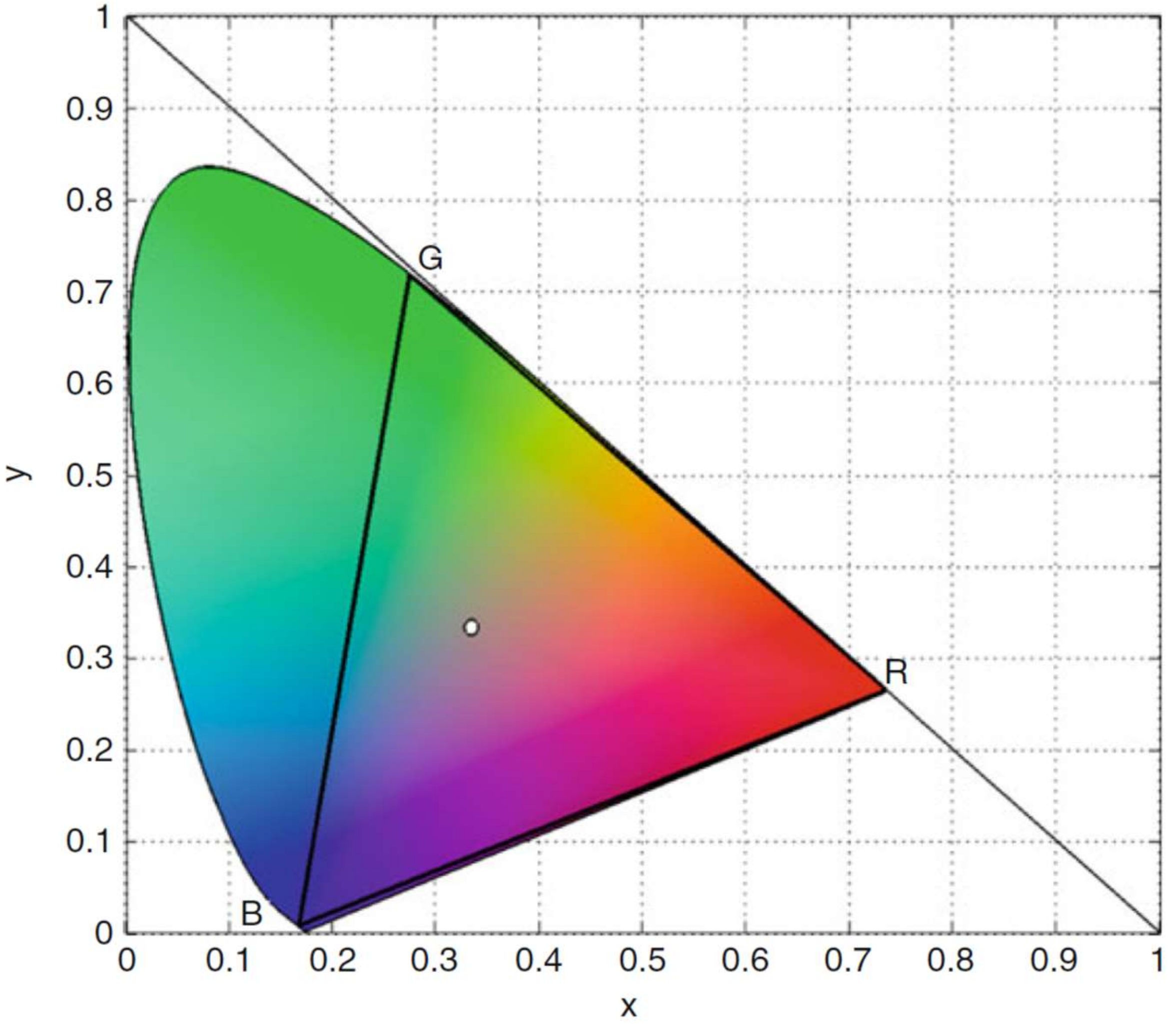


Fig. from: Luo, Encyclopedia of Color Science and Technology, Springer (2016), p. 138.

Standardization of colors

The CIE chromaticity diagram

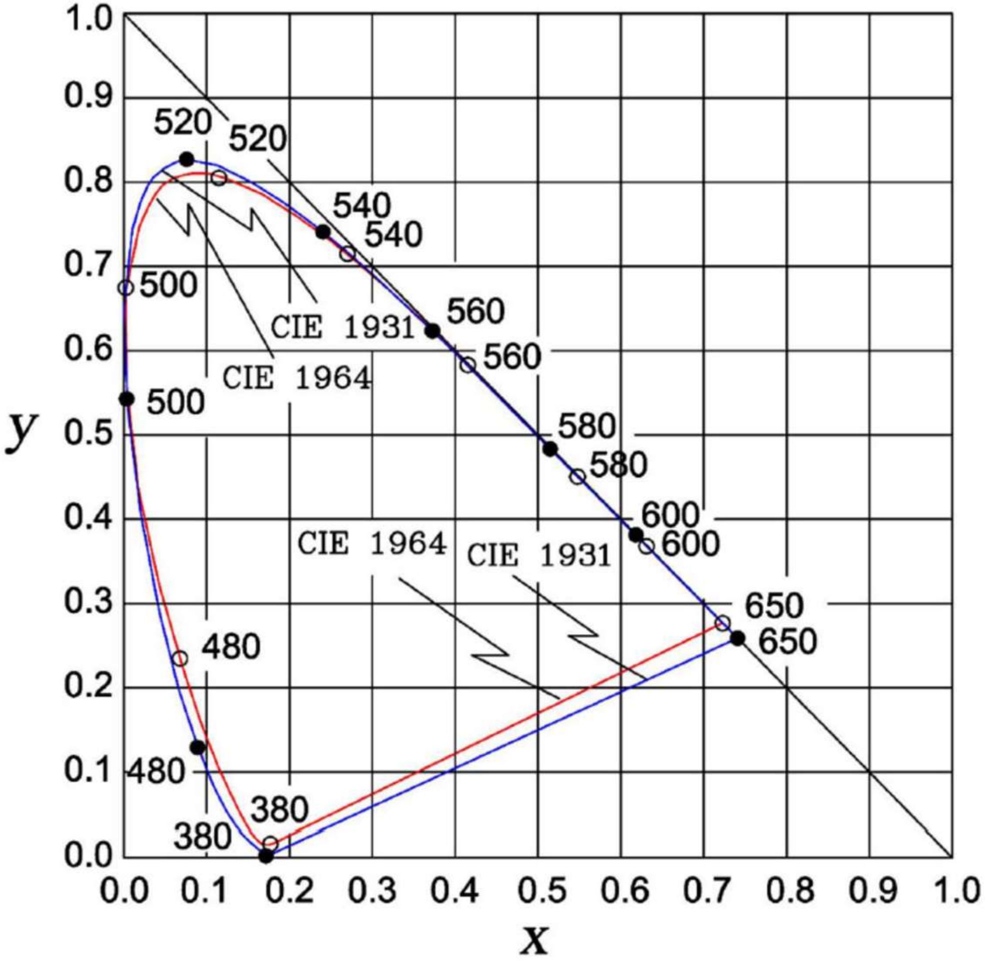


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 91

Standardization of colors

Disadvantages of the CIE chromaticity diagram

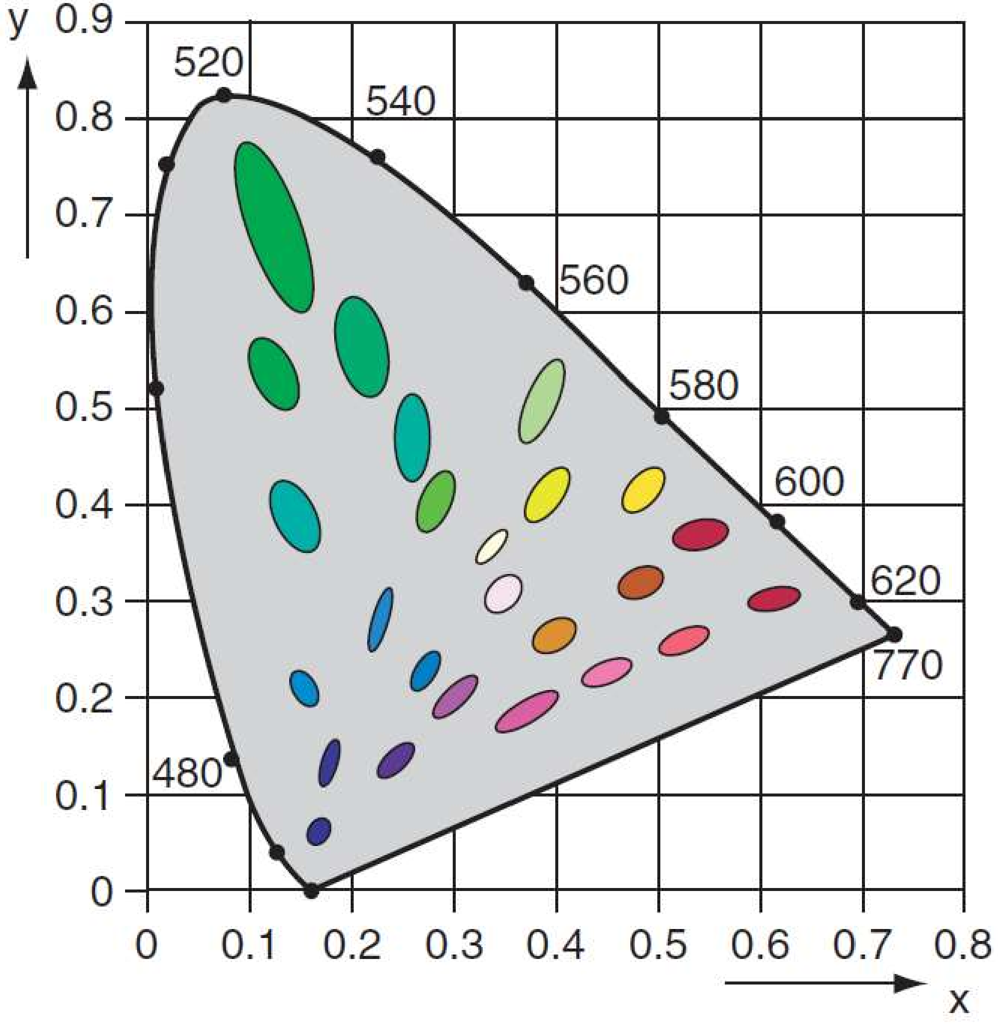


Fig. from: Sharma, Understanding color management, Wiley (2018), p. 76

Standardization of colors

CIE chromaticity coordinates

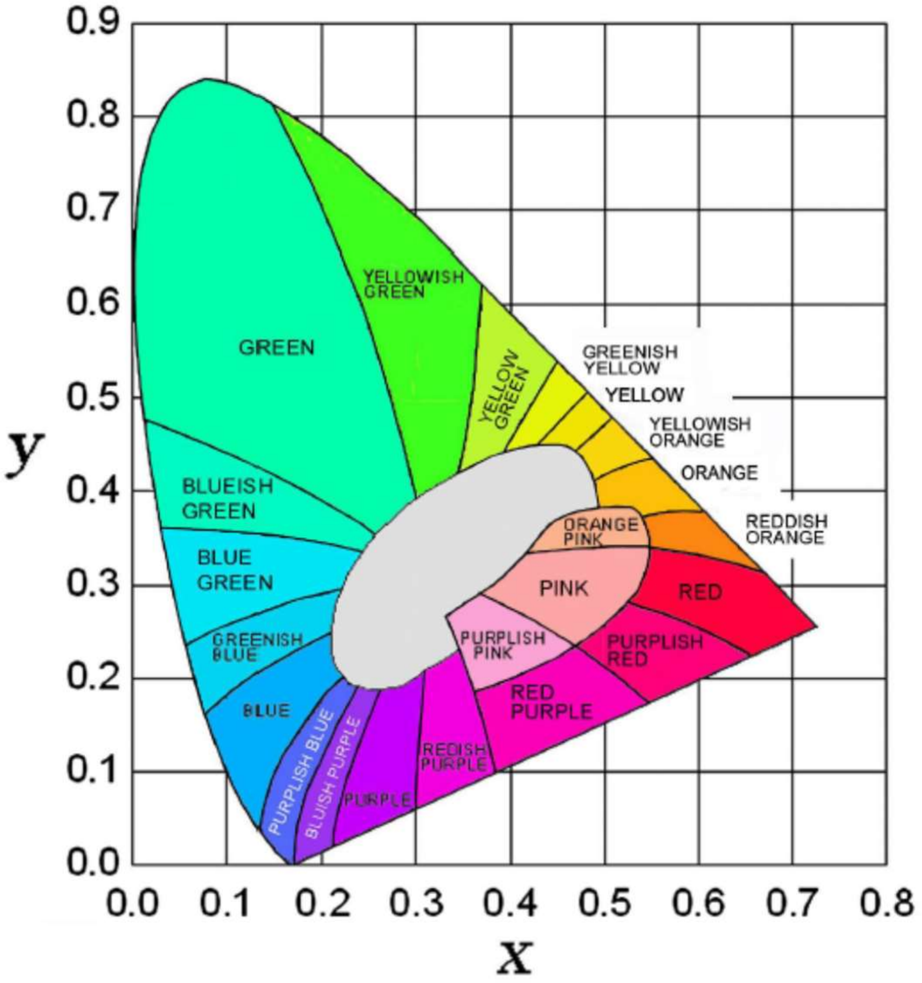


Fig. from: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 104
See Kelly, J Opt Soc Am 33,627-632 (1943) for suggested definitions of color designations for self-luminous sources

Standardization of colors

CIE chromaticity coordinates

The CIE XYZ values are obtained by integration of the product of three spectra:

$$X = k \int E(\lambda) O(\lambda) x(\lambda) d\lambda$$

$$Y = k \int E(\lambda) O(\lambda) y(\lambda) d\lambda$$

$$Z = k \int E(\lambda) O(\lambda) z(\lambda) d\lambda$$

$E(\lambda)$ = spectral power distribution of the illuminant
$O(\lambda)$ = object spectrum, i.e. reflectance or transmittance
$x(\lambda)$, $y(\lambda)$, $z(\lambda)$ = color matching function (CMF)
k = scaling factor

Standardization of colors

Testing the color fidelity of monitors and cameras

Test pattern generated in MATLAB

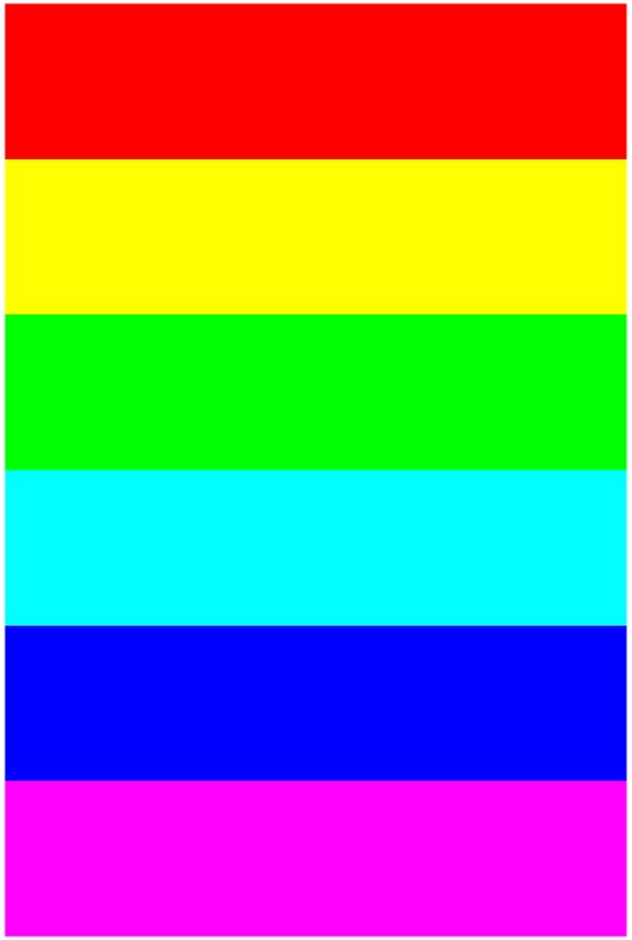
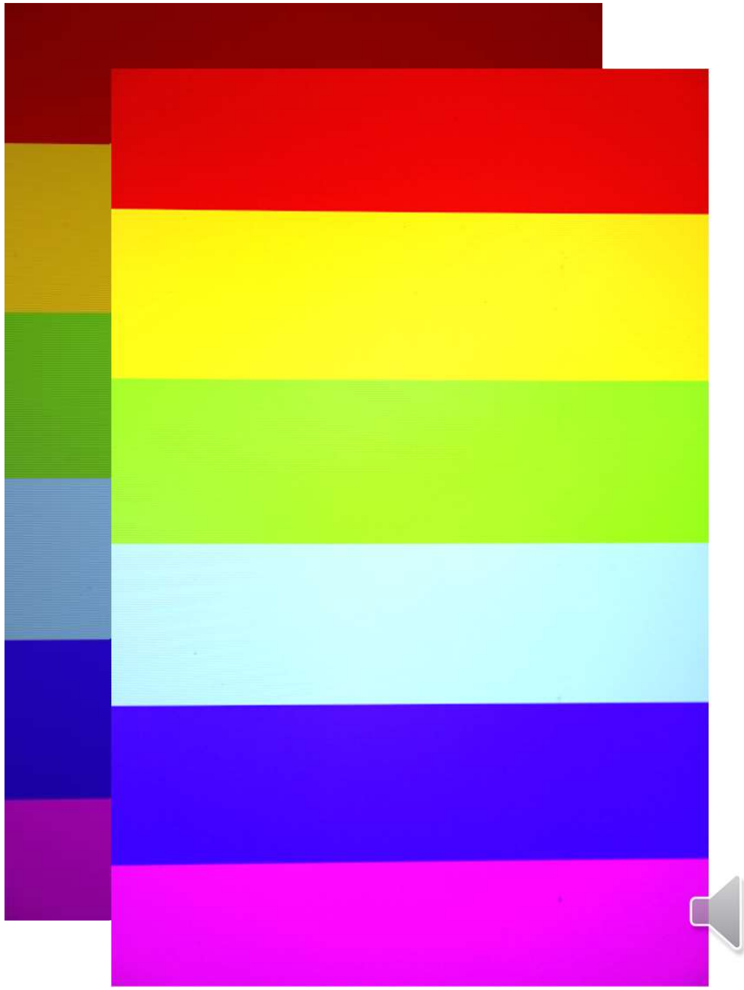


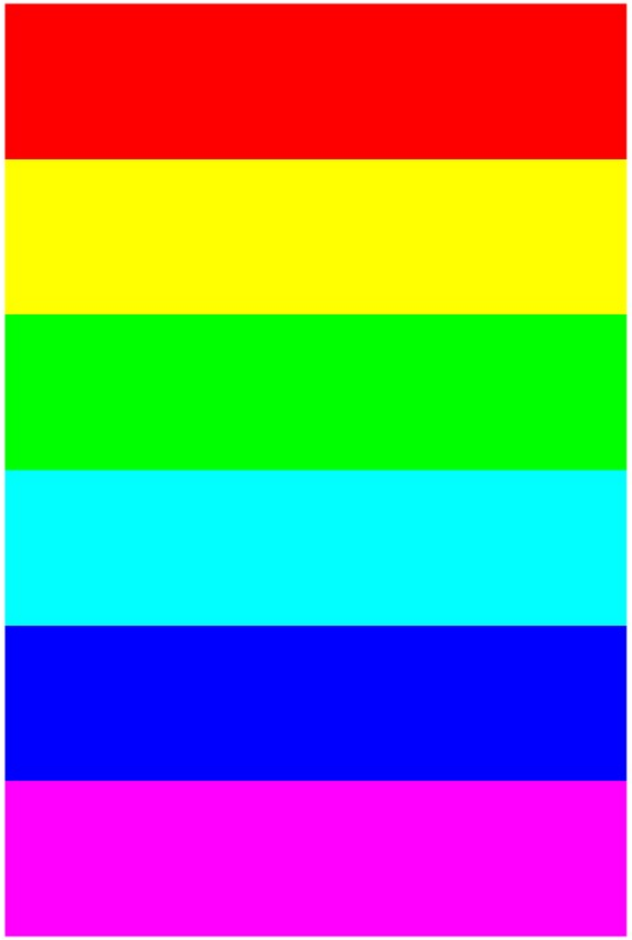
Photo of the computer screen



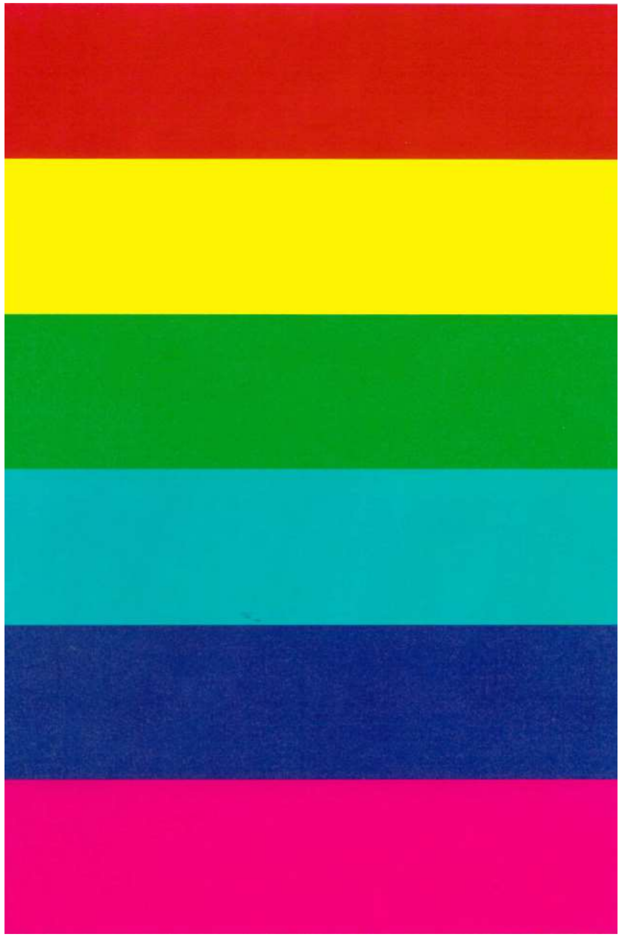
Standardization of colors

Testing the color fidelity of monitors, printers and scanners

Test pattern generated in MATLAB



Scanned print



Standardization of colors

Color variations in microscopic images

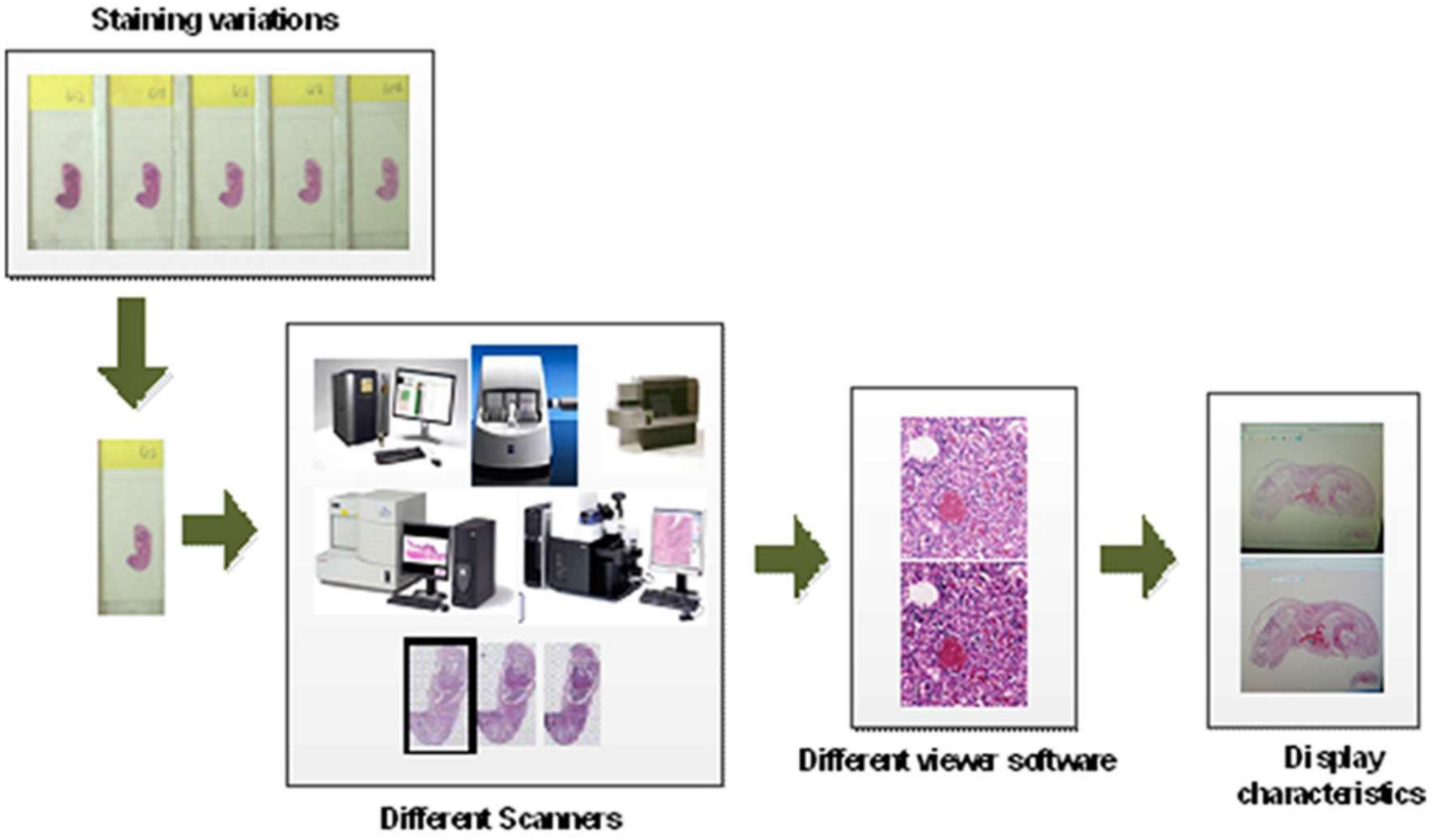


Fig. from: Bautista, J Pathol Inform 514, (2014)

Standardization of colors

Color variations in microscopic images

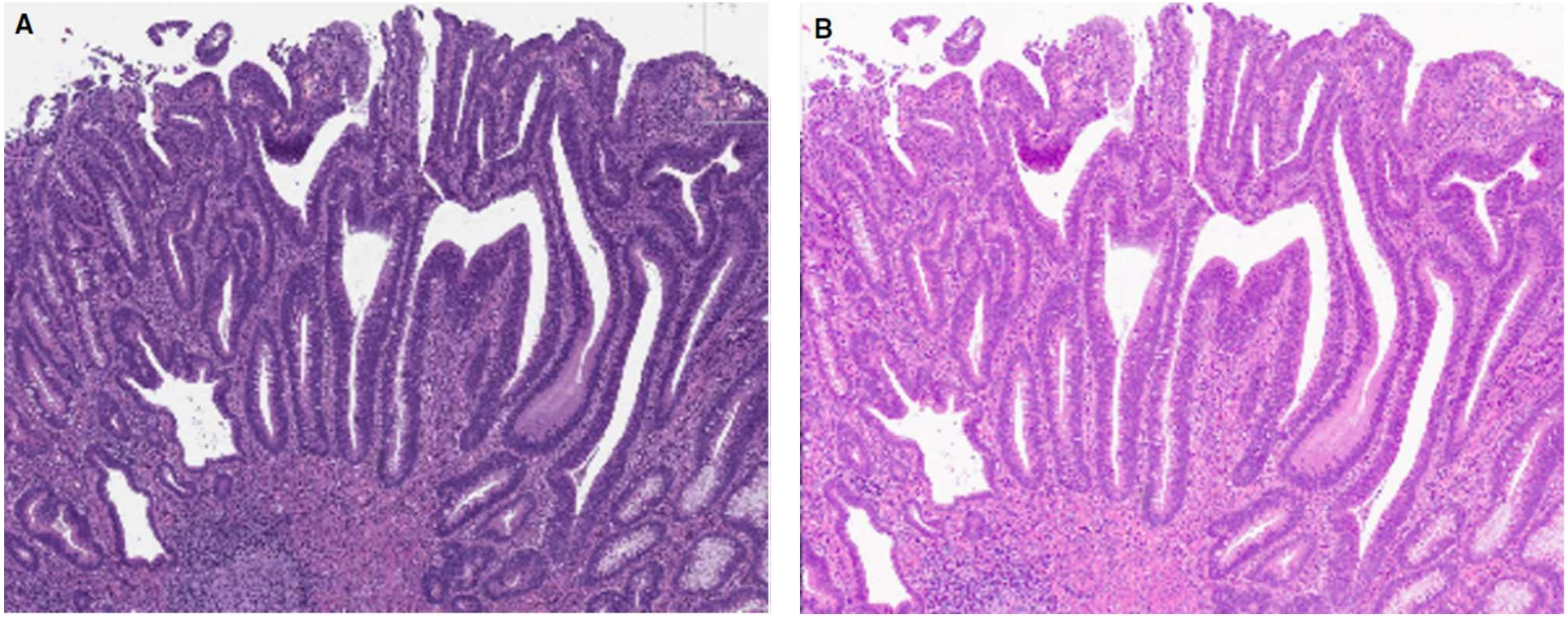


Fig. from: Clarke, Histopathology 70, 153-163 (2017)

Standardization of colors

Digital Color Management

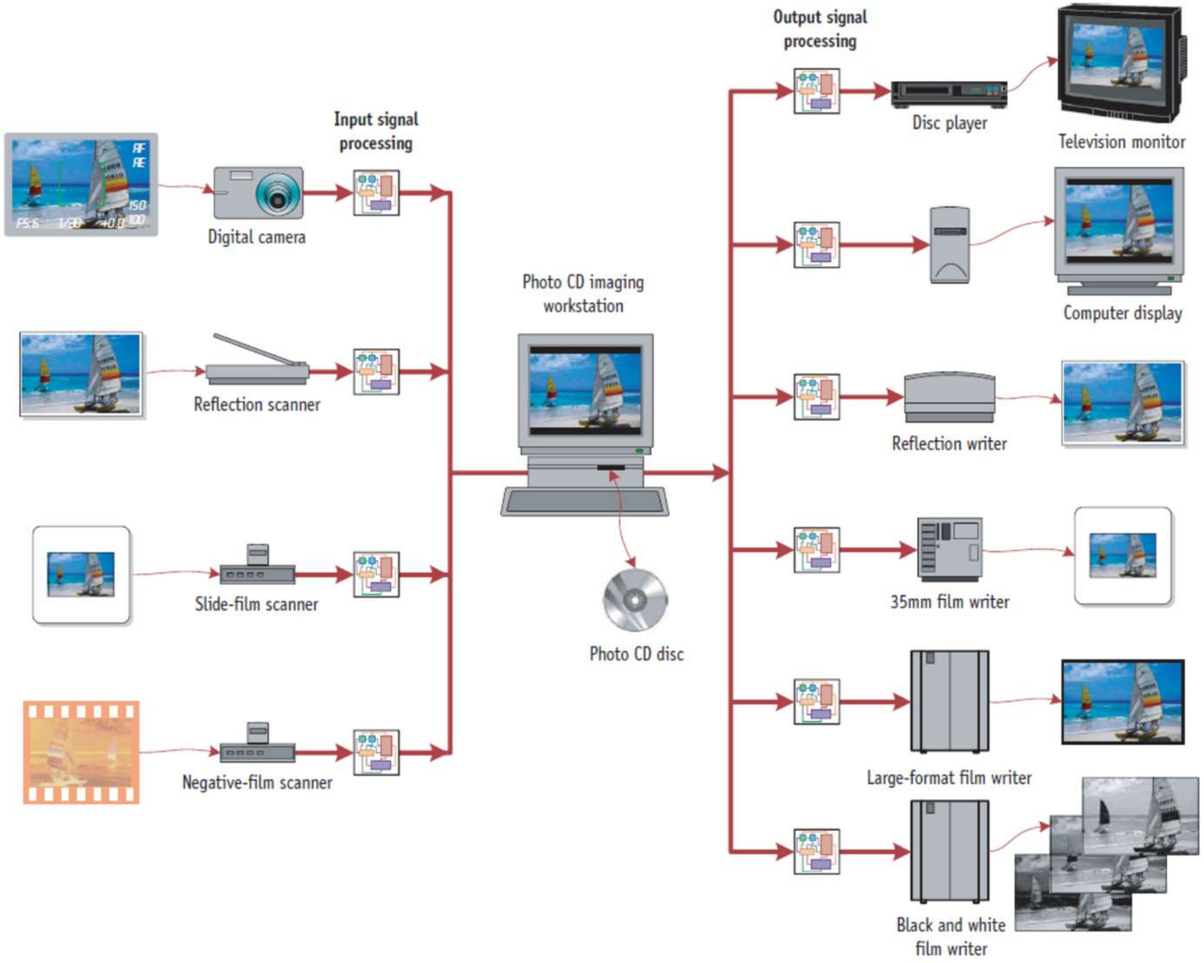


Fig. from: Giorgianni, Madden, Kriss, Digital Color Management-Encoding Solutions, Wiley (2009), p. 154

Color Spaces

Overview

Hardware dependent models

Additive color models

- ○ RGB (red, green, blue) models
  - sRGB (1996)
  - Adobe RGB (1998)
- ○ HSI (hue, saturation, intensity) models
  - HSI (hue, saturation, intensity)
  - HSV (hue, saturation, value) (1983)
  - NTSC (luminance (Y), hue (I), saturation (Q)

Subtractive color models

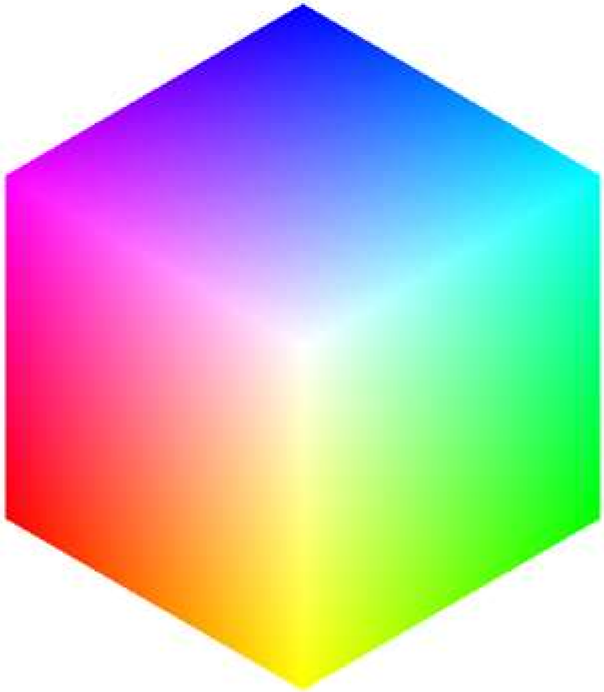
- ○ CMY (cyan, magenta, yellow) (1983)
- ○ CMYK (cyan, magenta, yellow, black) (1983)

Hardware independent models

- ○ CIE XYZ (1931), CIE (1964)
- ○ CIE L*a*b (1976)
- ○ CIE L*C*h

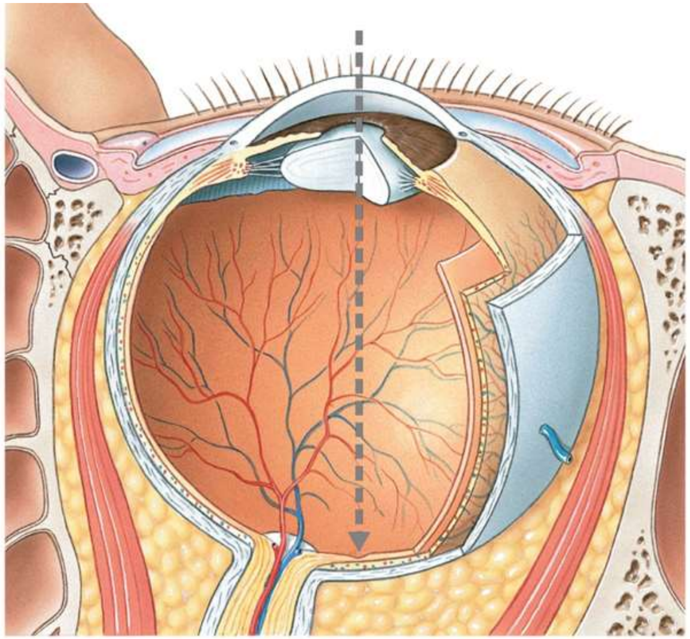
Color Spaces

The RGB space

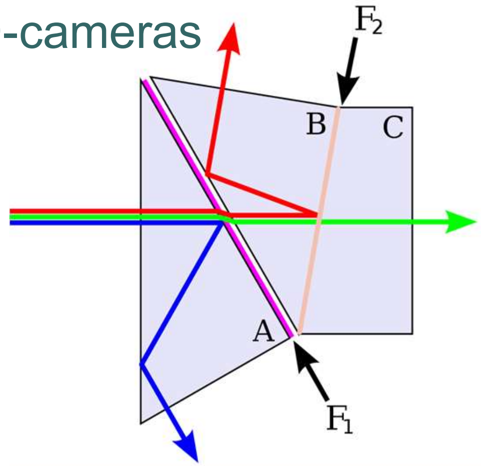


Color Spaces

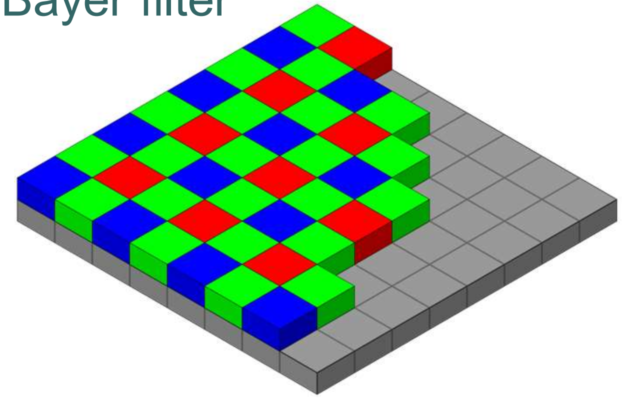
RGB input devices



3CCD-cameras

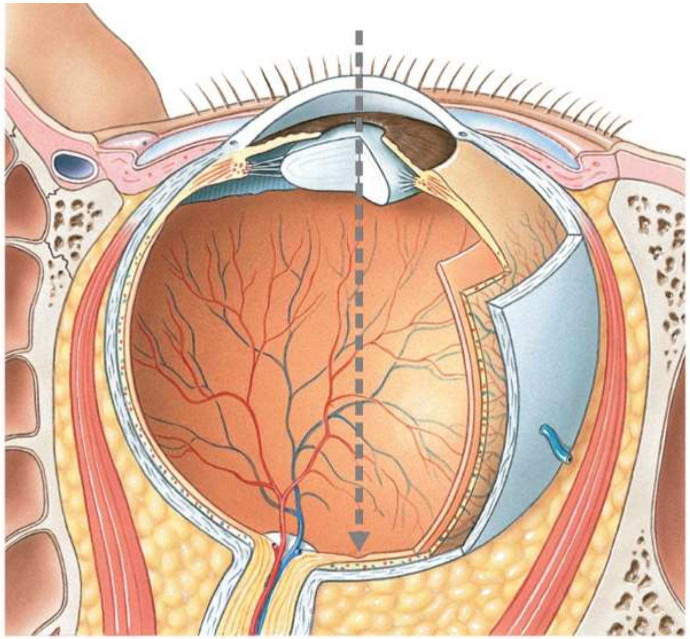


Bayer filter

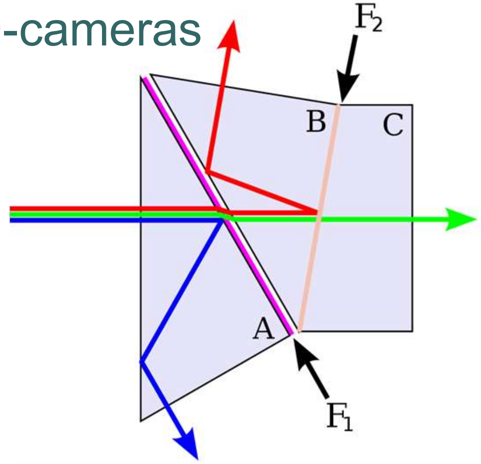


Color Spaces

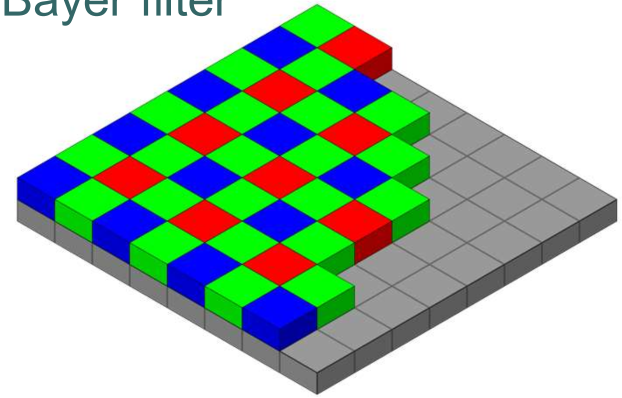
RGB input devices



3CCD-cameras



Bayer filter



Color Spaces

The “classic” RGB input “device”: The eye

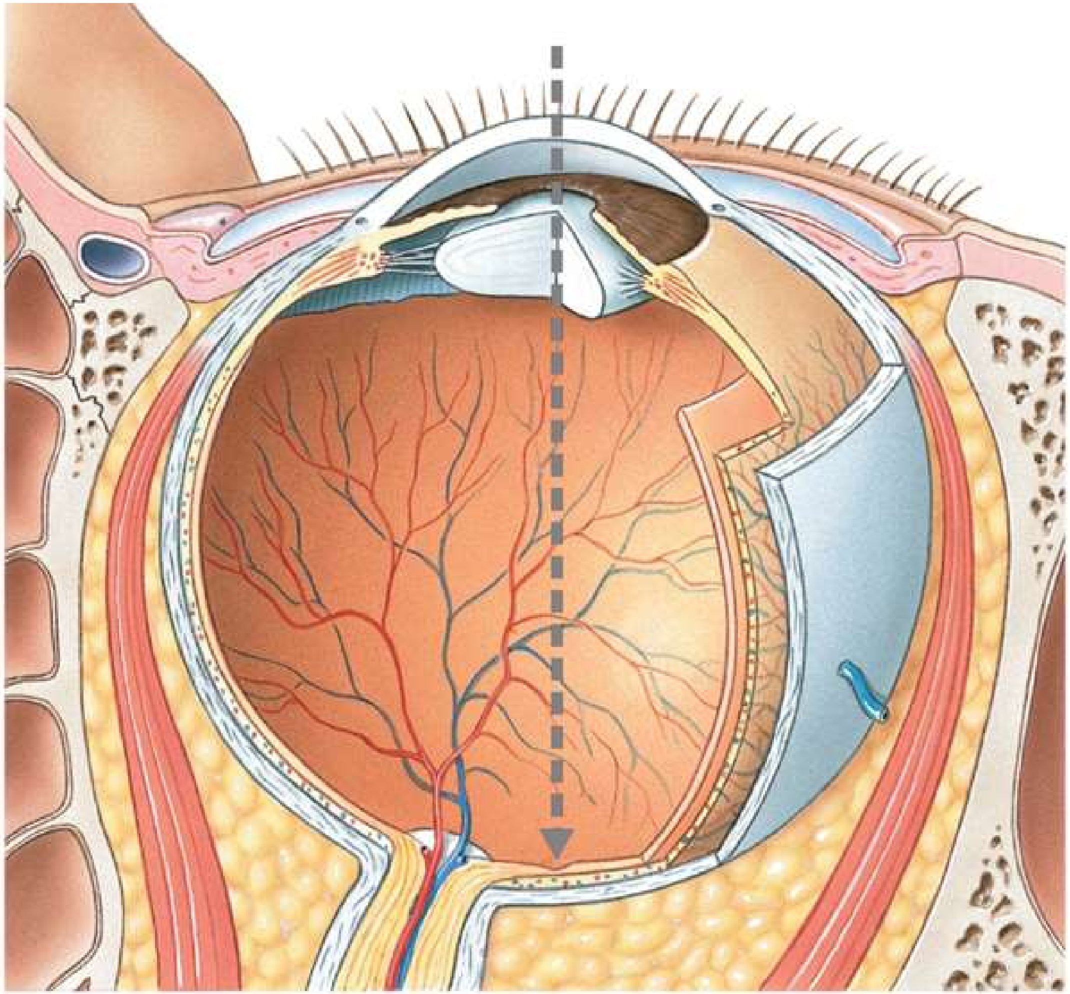


Fig. from: Martini, Nath, Bartholomew, Fundamentals of Anatomy & Physiology, 10th ed, Pearson (2015), p. 572.

Color Spaces

RGB input device: Bayer filter for digital image sensors

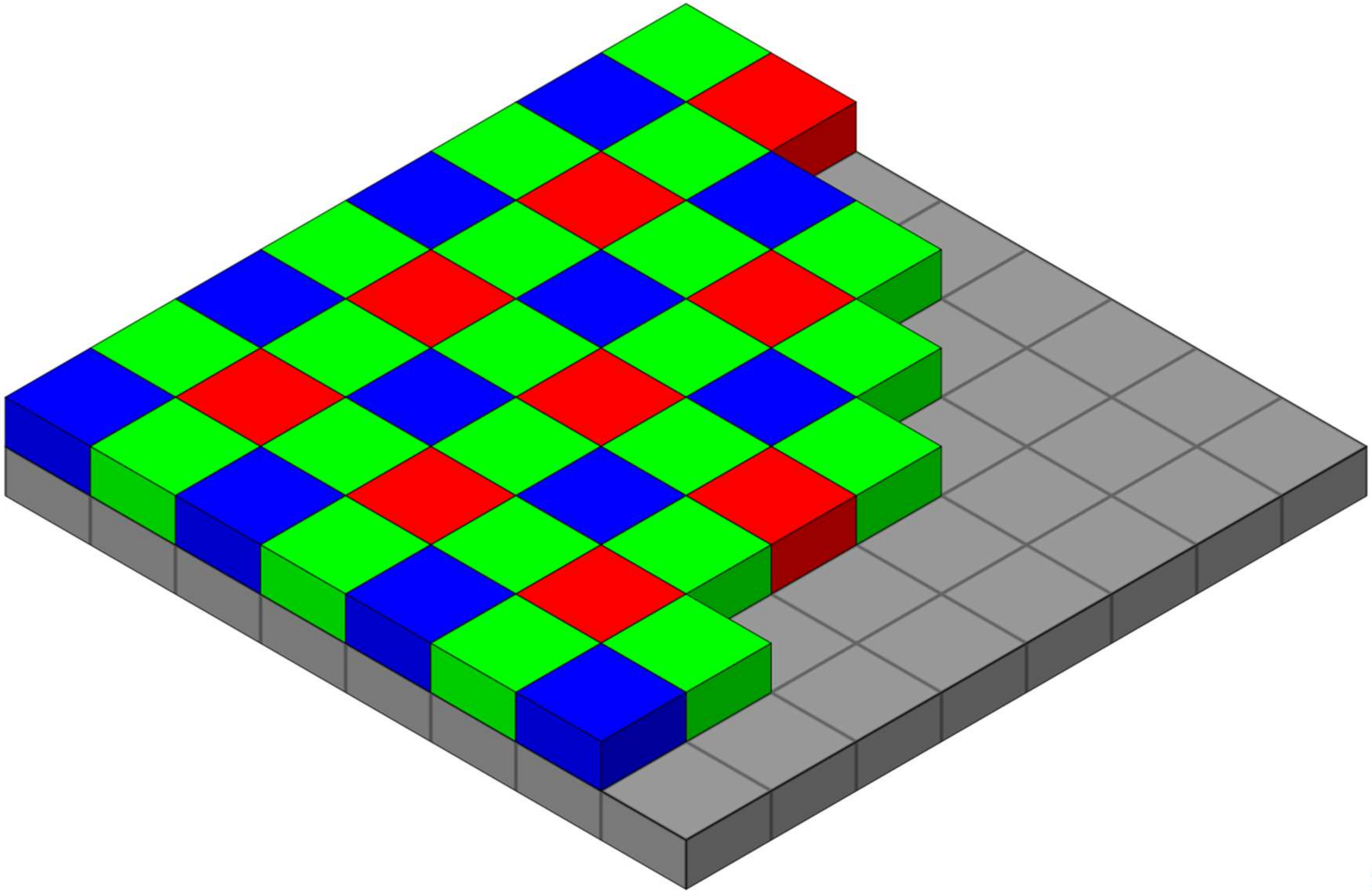
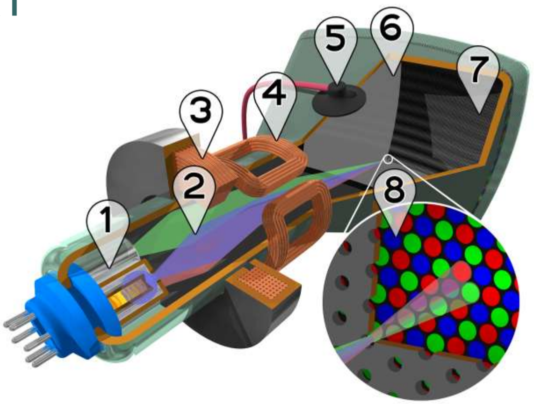


Fig. from: Wikipedia (https://en.wikipedia.org/wiki/Bayer_filter#/media/File:Bayer_pattern_on_sensor.svg)

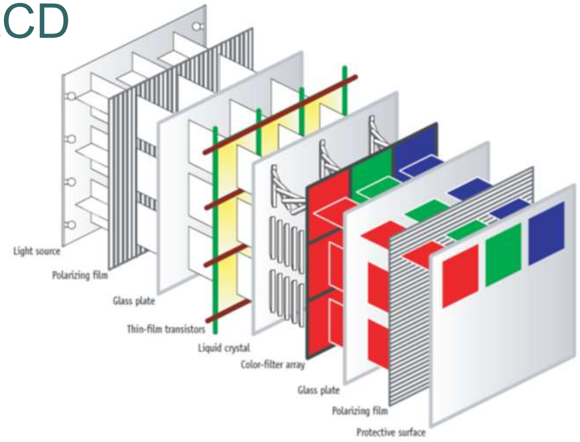
Color Spaces

RGB output devices

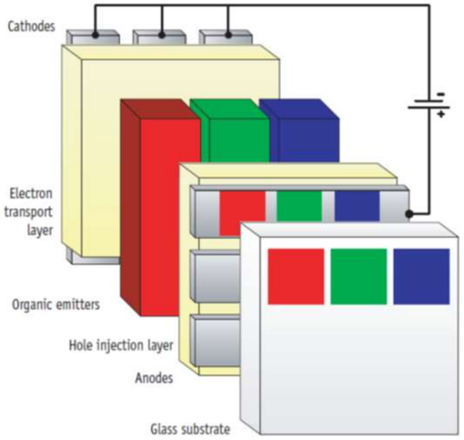
CRT



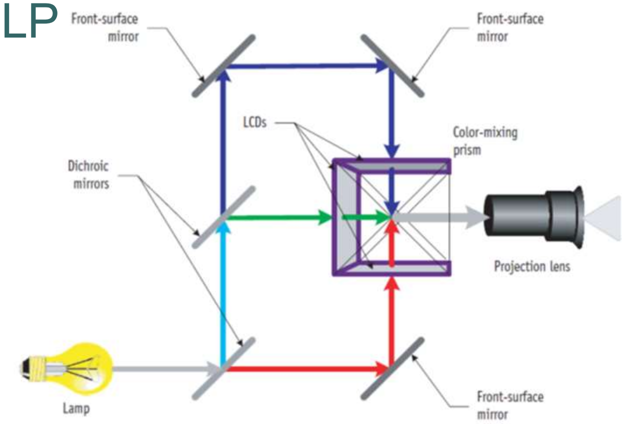
LCD



OLED



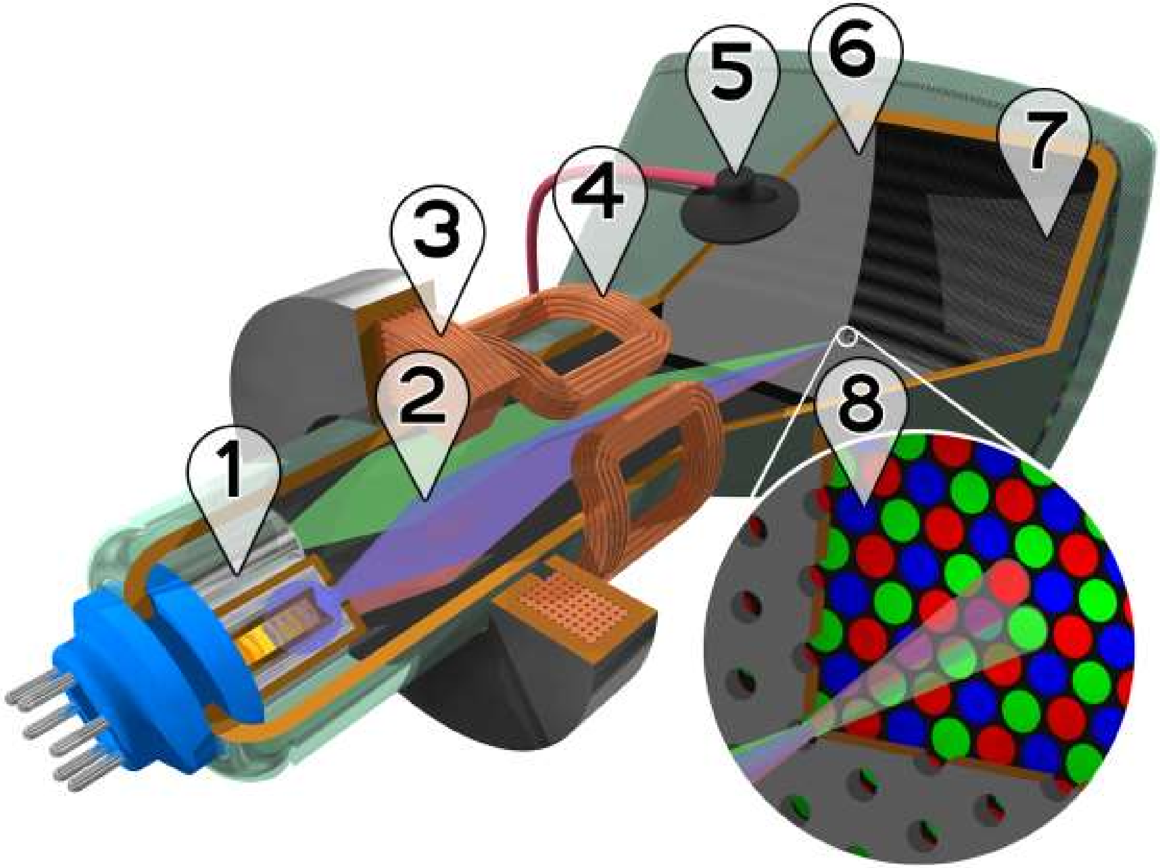
DLP



Figures from: Wikipedia and Giorgianni, Madden, Kriss, Digital Color Management-Encoding Solutions, Wiley (2009).

Color Spaces

RGB output device: color cathode ray tube



1. Electron emitters (for red, green, and blue phosphor dots)
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Connection for anodes
6. Mask for separating beams for red, green, and blue part of the displayed image
7. Phosphor layer (screen) with red, green, and blue zones
8. Close-up of the phosphor-coated inner side of the screen

Fig. from: Wikipedia (https://commons.wikimedia.org/w/index.php?curid=756581). Basic design of the image by Søren Peo Pedersen

Color Spaces

RGB output device: color cathode ray tube

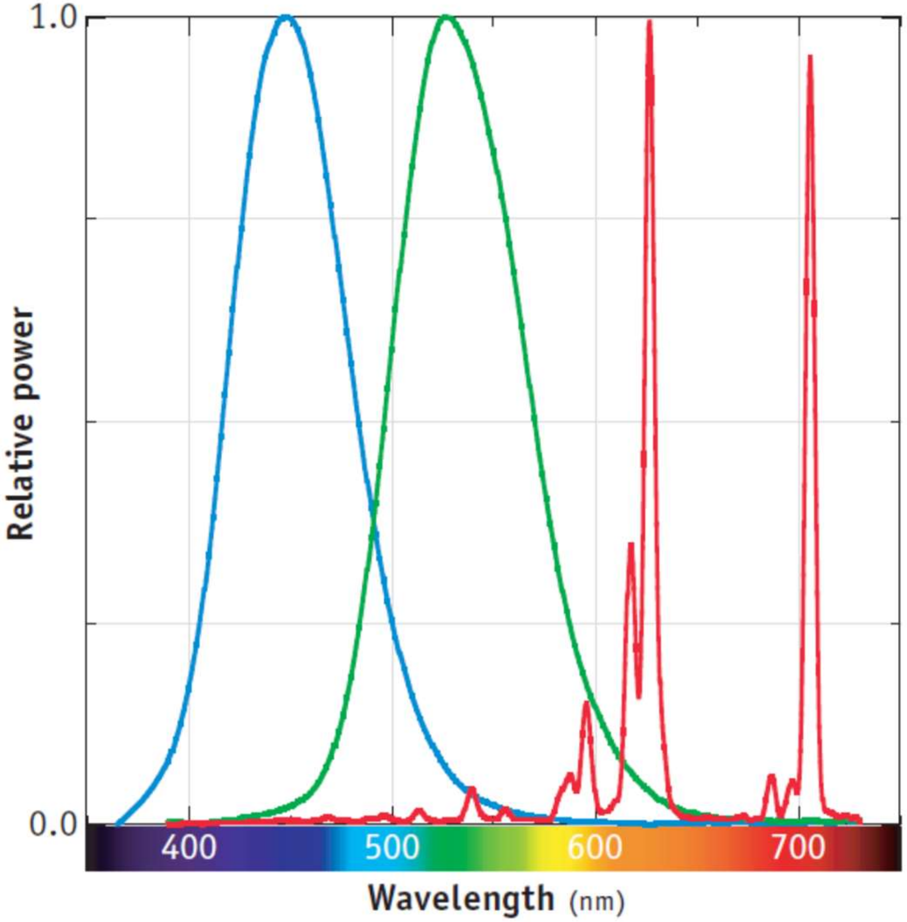


Fig. from: Giorgianni, Madden, Kriss, Digital Color Management-Encoding Solutions, Wiley (2009), p. 32

Color Spaces

RGB output devices: LCD

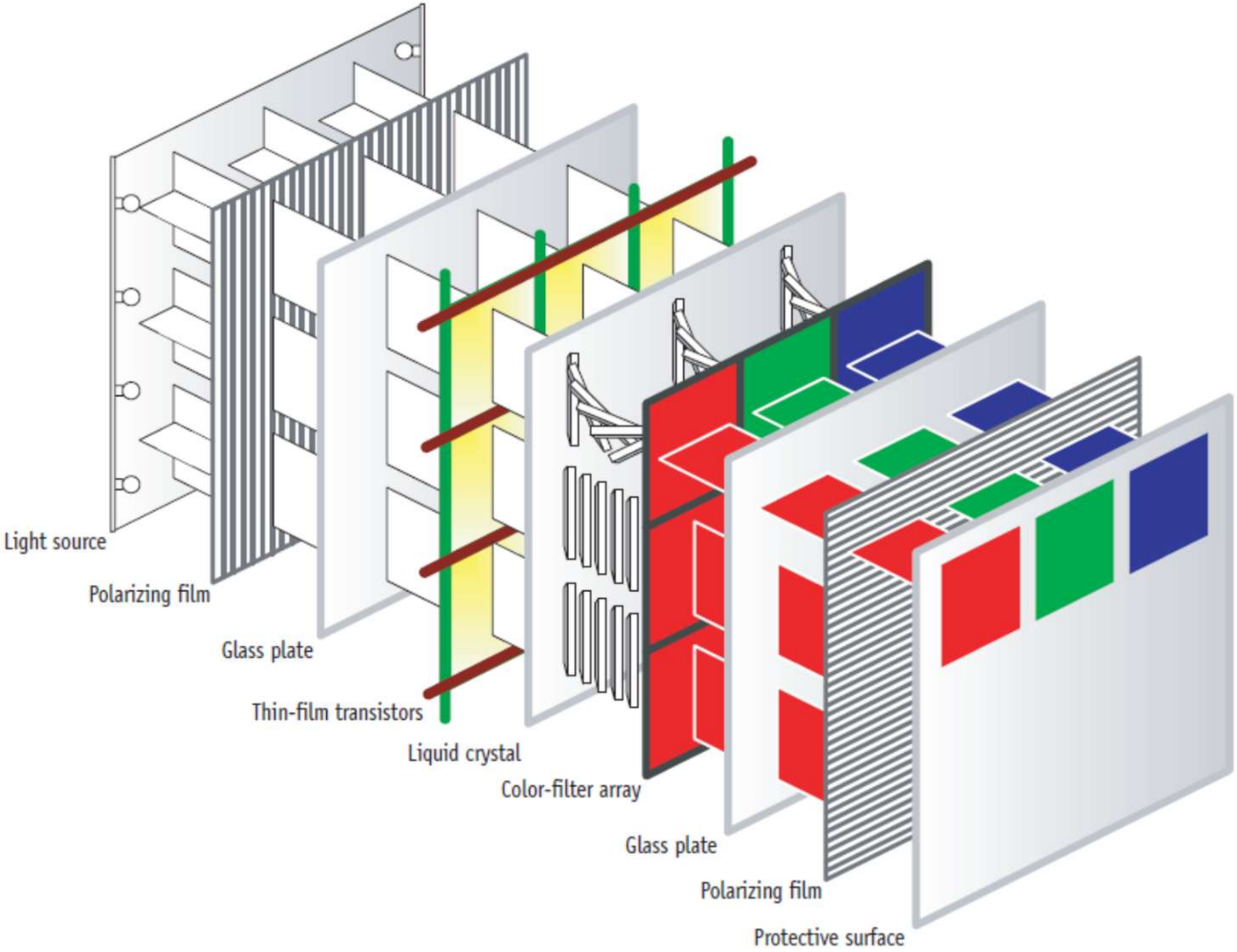
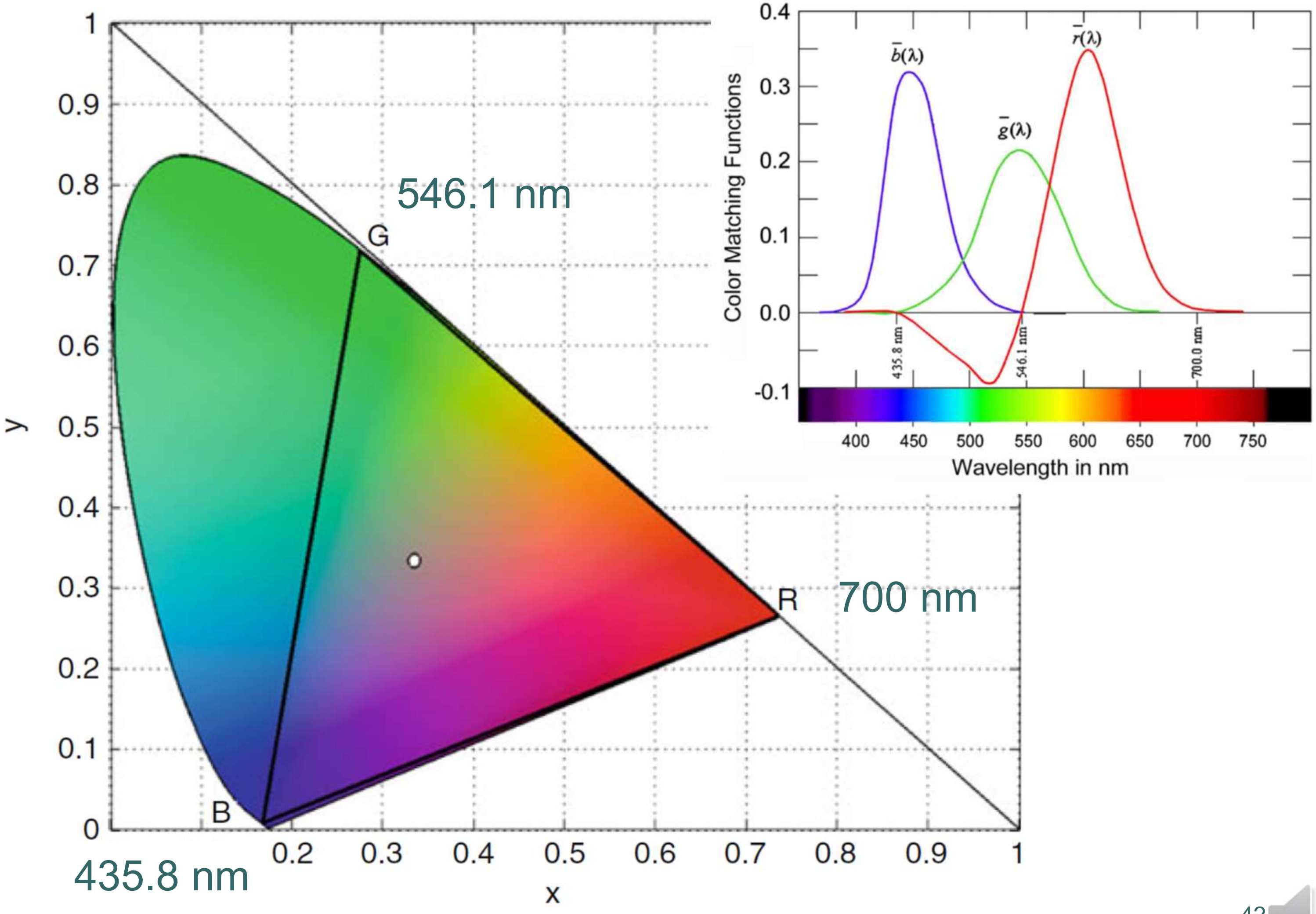


Fig. from: Giorgianni, Madden, Kriss, Digital Color Management-Encoding Solutions, Wiley (2009), p. 36

Standardization of colors

The gamut of the CIE primaries



546.1 nm

700 nm

435.8 nm

Fig. from: Luo, Encyclopedia of Color Science and Technology, Springer (2016), p. 138.

Standardization of colors

The gamut of sRGB and other RGB systems

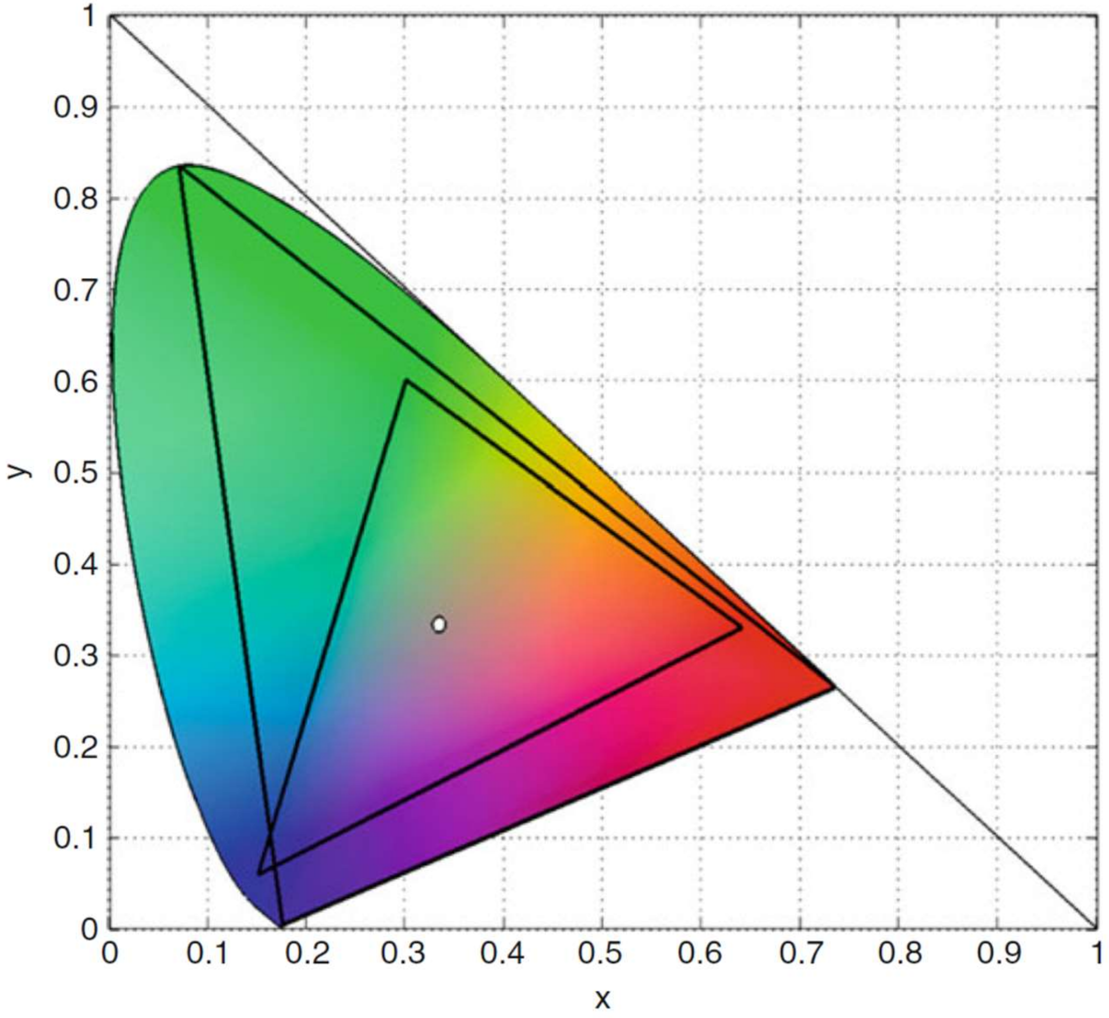


Fig. from: Luo, Encyclopedia of Color Science and Technology, Springer (2016), p. 139.

Color Spaces

The sRGB color space

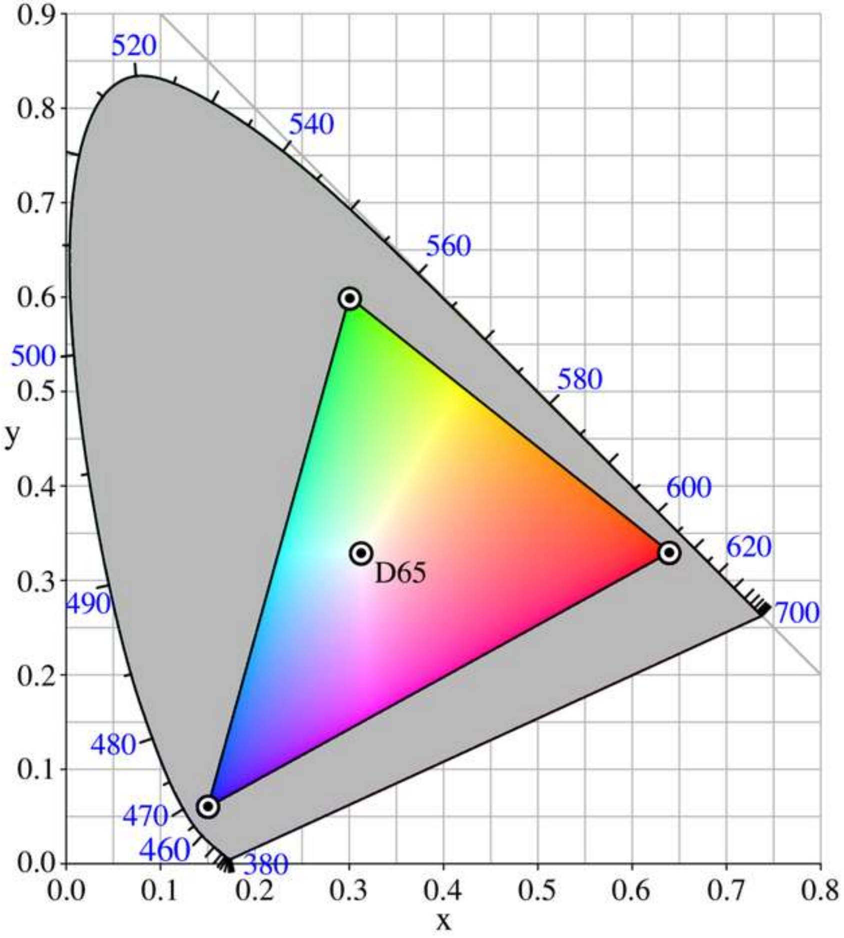


Fig. from: Wikipedia

Color Spaces

The RGB color space

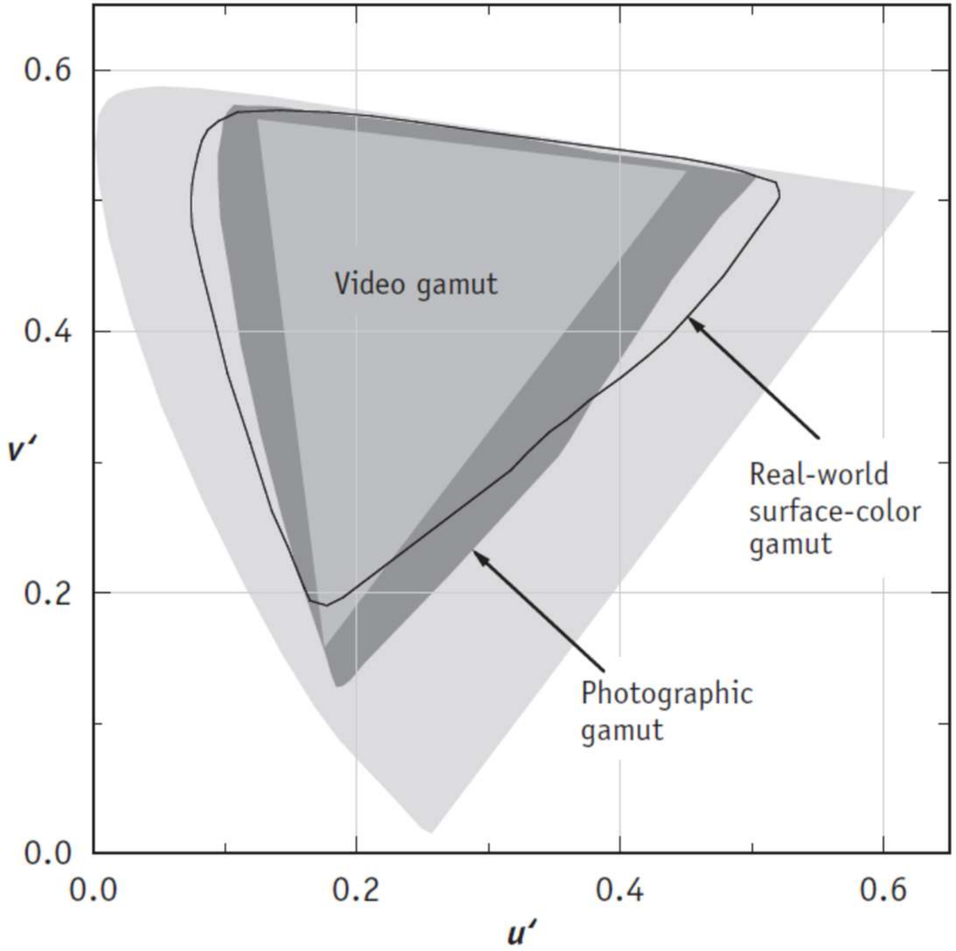


Fig. from: Giorgianni, Madden, Kriss, Digital Color Management-Encoding Solutions, Wiley (2009), p. 169

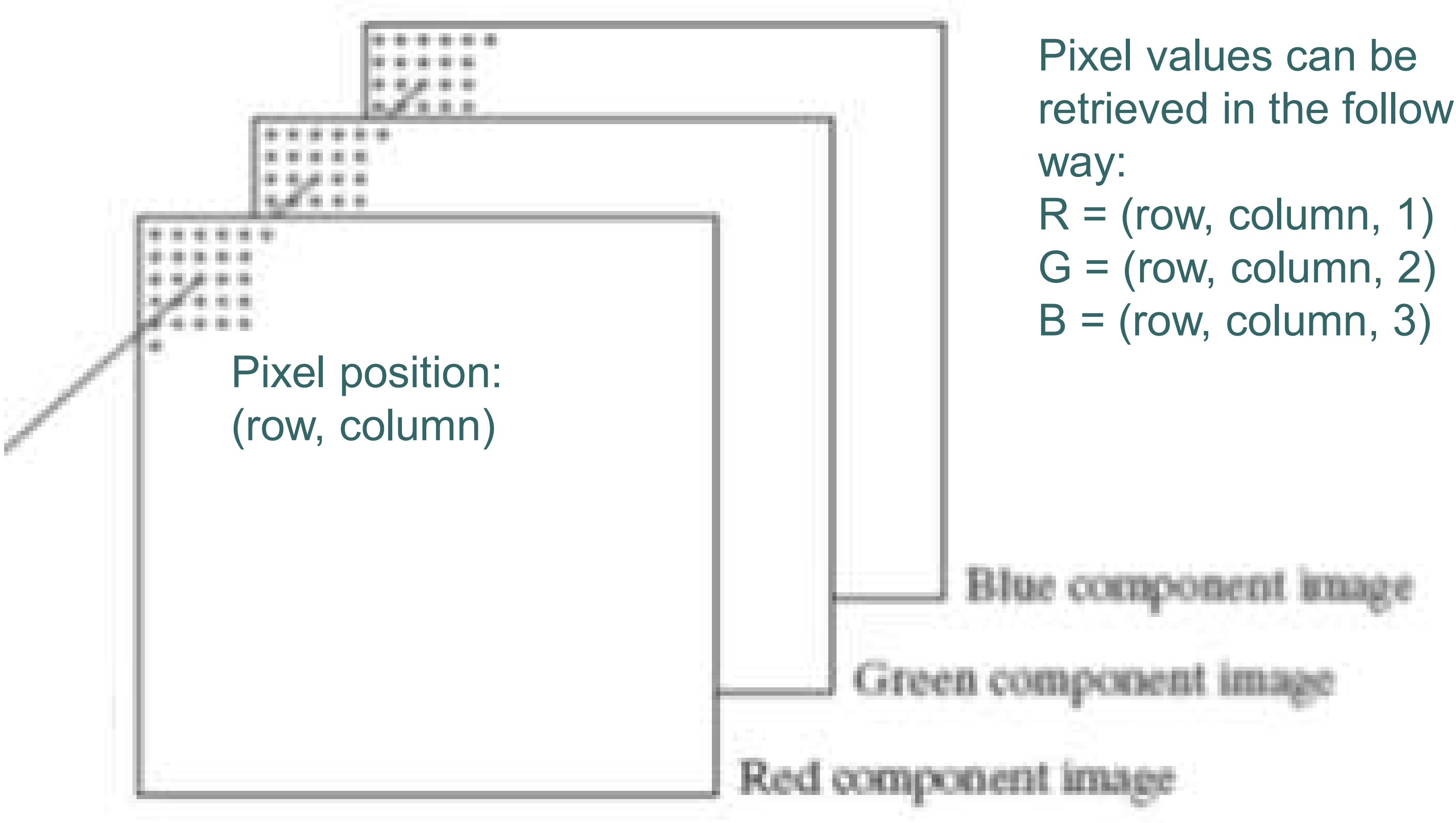
Color Image Processing in MATLAB

Review: Image types in MATLAB

Image Type	**Description**
Binary Image	Image data are stored as an *m*-by-*n* logical array. Array values of 0 and 1 are interpreted as black and white, respectively.
Grayscale / intensity	Image data are stored as an *m*-by-*n* numeric array whose elements specify intensity values. • For single or double arrays, values range from [0, 1]. • For uint8 arrays, values range from [0,255]. • For uint16, values range from [0, 65535]. • For int16, values range from [-32768, 32767].
RGB Image	Image data are stored as an *m*-by-*n*-by-3 numeric array whose elements specify the intensity values of one of the three color channels. For RGB images, the three channels represent the red, green, and blue signals of the image. • For single or double arrays, RGB values range from [0, 1]. • For uint8 arrays, RGB values range from [0,255]. • For uint16, RGB values range from [0, 65535].
Indexed Image	Image data are stored as an *m*-by-*n* numeric matrix whose elements are direct indices into a color map. Each row of the color map specifies the red, green, and blue components of a single color. • For single or double arrays, integer values range from [1, *p*]. • For logical, uint8, or uint16 arrays, values range from [0, *p*-1]. The colormap is a *c*-by-3 array of class double.

Color Image Processing in MATLAB

RGB image format



Pixel position:
(row, column)

Pixel values can be retrieved in the following way:
R = (row, column, 1)
G = (row, column, 2)
B = (row, column, 3)

Fig. from: Gonzales, Woods, Eddins, Digital Image Processing using MATLAB, 2nd ed, Mac Graw Hill, Chennai (2010)

Color Spaces

RGB images in MATLAB

A layer can be extracted by indexing the array:

```
redLayer   = rgbImage(:,:,1);
greenLayer = rgbImage(:,:,2);
blueLayer  = rgbImage(:,:,3);
```

Individual layers can be merged to an RGB image by using the concatenate command:

```
rgbImage = cat(3,redLayer,greenLayer,blueLayer);
```

Color Spaces

Displaying images in MATLAB

Syntax	Description
`image(img);`	Displays the image stored in the variable `img`. If `img` is a vector or a matrix, the elements of `img` are displayed in a color which is defined in the colormap of the associated axes. If `img` is a 3-D array of RGB triplets, the image is displayed as an rgb image.
`imshow(img)`	displays the image `img` in a figure. `imshow` handles binary, grayscale, rgb and indexed images. `imshow` uses the default display range for the image data type and optimizes figure, axes, and image object properties for image display.
	See MATLAB help page for further information

Color Spaces

Loading and saving images in MATLAB

Syntax	Description
Loading images	
`img = imread(filename);`	reads the image from the file specified by `filename`, guessing the format of the file from its contents. If filename is a multi-image file, then `imread` reads the first image in the file
`img = imread(filename,fmt);`	specifies the format of the file with the standard file extension indicated by `fmt`
`img = imread(filename,idx);`	reads the specified image or images from a multi-image file (GIF, CUR, ICO, TIF, and HDF4)
	See MATLAB help page for further information

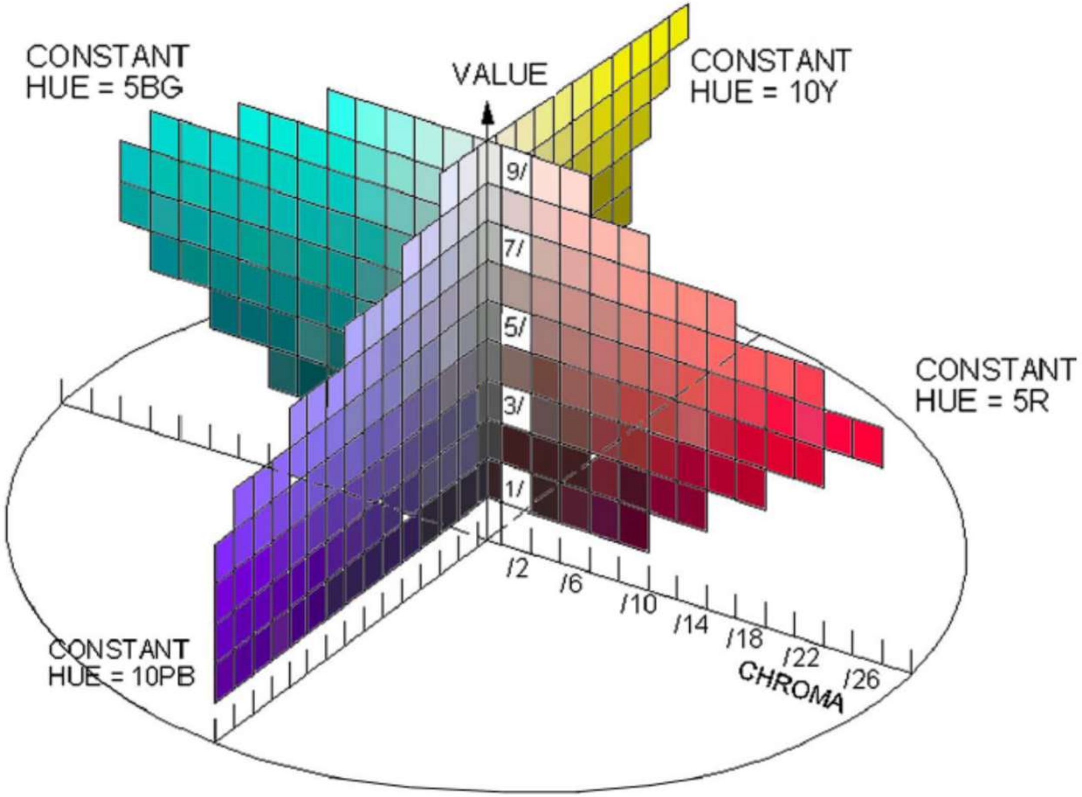
Color Spaces

Loading and saving images in MATLAB

Syntax	**Description**
imwrite(img, filename)	writes image data stored in the variable `img` to the file specified by `filename`, inferring the file format from the extension. `imwrite` creates the new file in your current folder. The bit depth of the output image depends on the data type of `img` and the file format. For most formats: If `img` is of data type uint8, then `imwrite` outputs 8-bit values. If `img` of data type uint16 and the output file format supports 16 bit data (JPEG, PNG, and TIFF), then `imwrite` outputs 16 bit values. If the output file format does not support 16-bit data, then `imwrite` returns an error. If `img` is a grayscale or RGB color image of data type double or single, then `imwrite` assumes that the dynamic range is [0,1] and automatically scales the data by 255 before writing it to the file as 8-bit values. If the data in `img` is single, then the user has to convert `img` to double before writing to a GIF or TIFF file. If `img` is of data type logical, then `imwrite` assumes that the data is a binary image and writes it to the file with a bit depth of 1, if the format allows it. Valid formats are BMP, PNG, or TIFF
	See MATLAB help page for further information

Color Spaces

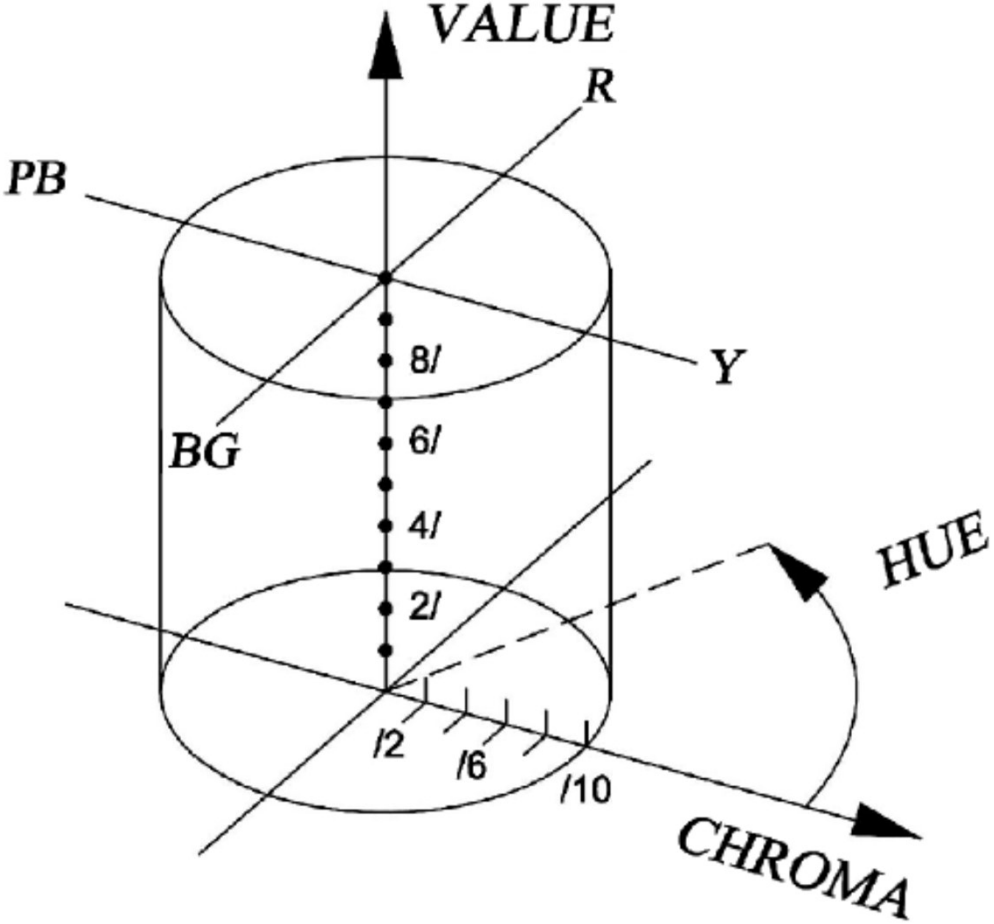
Munsell color space

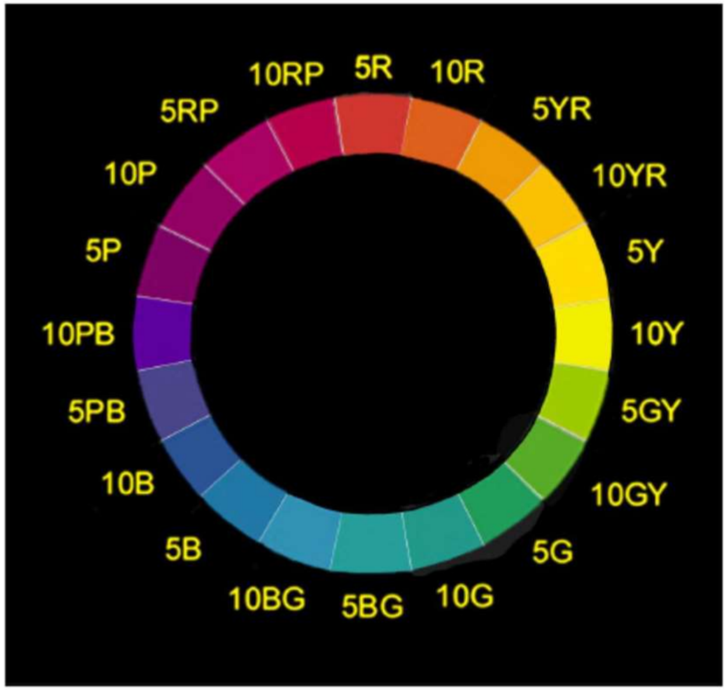


Source: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 108

Color Spaces

Munsell color space





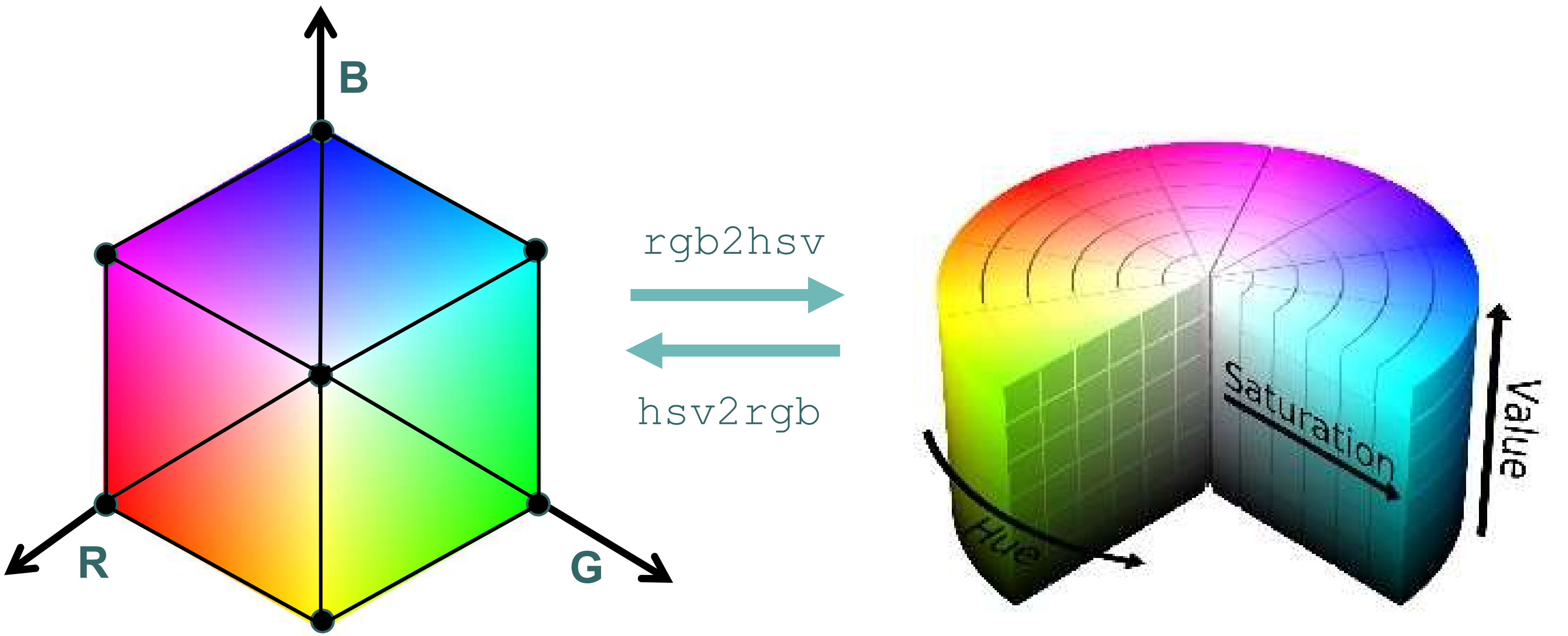
Source: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 106/108

Color Spaces

The HSV color space

RGB color space

HSV color space

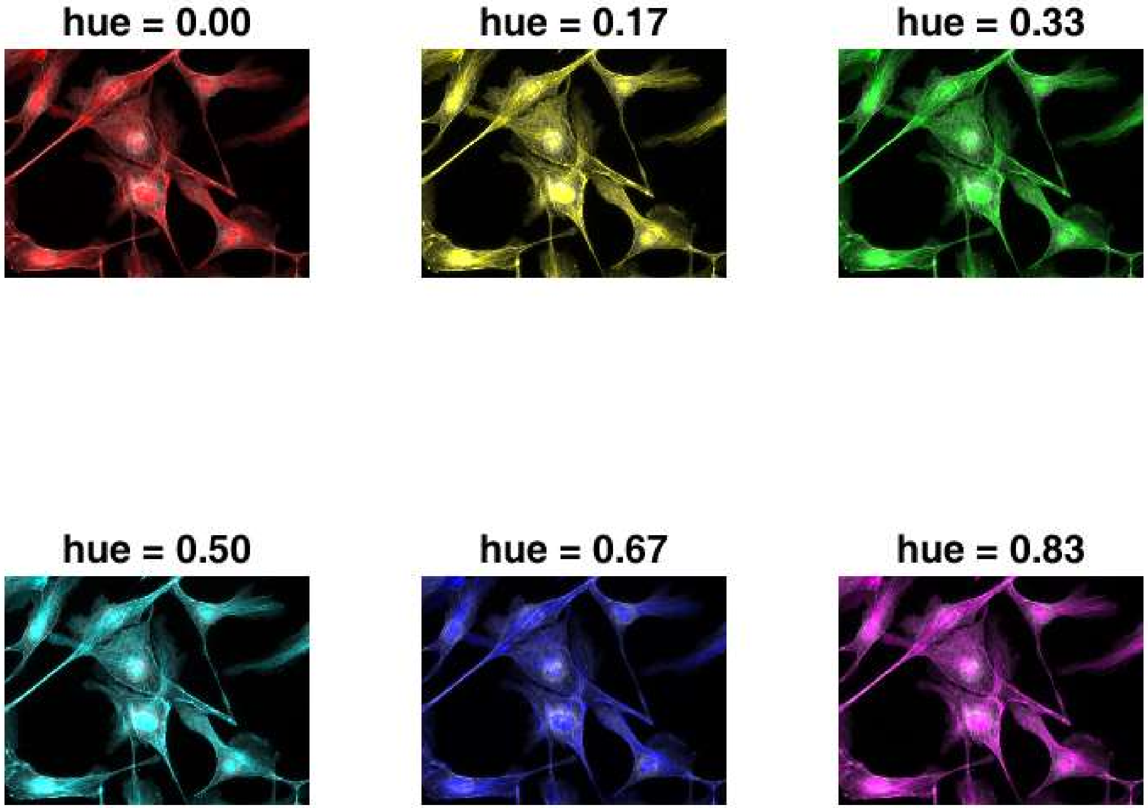


`rgb2hsv`

`hsv2rgb`

Color Image Processing in MATLAB

Effect of varying the hue in the HSV color space



hue = 0.00

hue = 0.17

hue = 0.33

hue = 0.50

hue = 0.67

hue = 0.83

Color Spaces

The YIQ color space

The YIQ color system was established for color television sets by the National Television Systems Committee (NTSC) in the United States.
Color image data consist of three components:

- luminance (Y),
- hue (I) and
- saturation (Q).

The YIQ components can be obtained from the RGB components of an image using the following linear transformation:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

`rgb2ntsc`

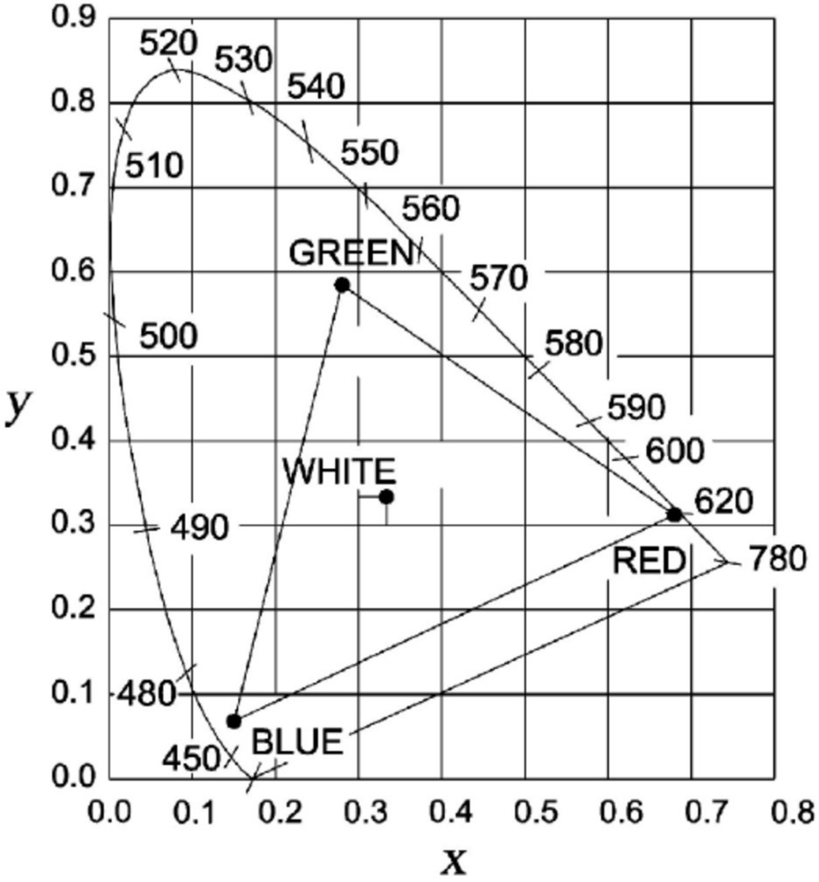
Similarly, the RGB components can be obtained from the YIQ components by multiplication with the inverse matrix:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.956 & 0.621 \\ 1 & -0.272 & -0.647 \\ 1 & -1.106 & 1.703 \end{bmatrix} * \begin{bmatrix} Y \\ I \\ Q \end{bmatrix}$$

`ntsc2rgb`

Standardization of colors

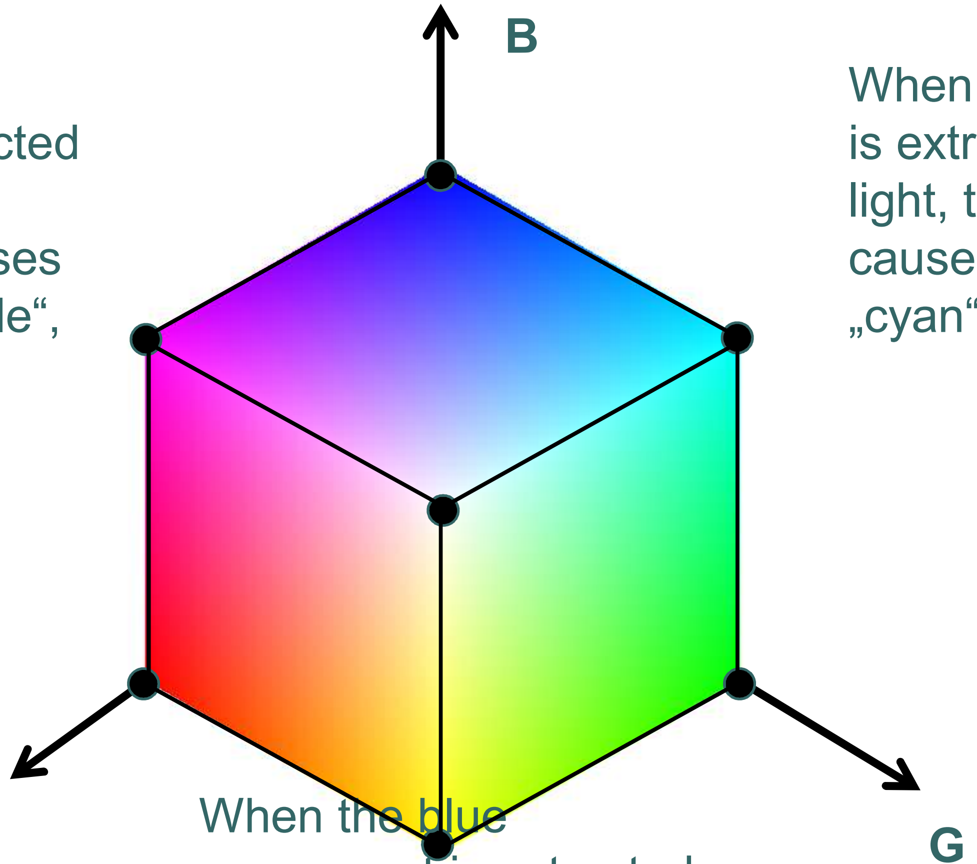
The NTSC system



Source: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 136

Color Fundamentals

Subtractive color mixing and the CMY color space



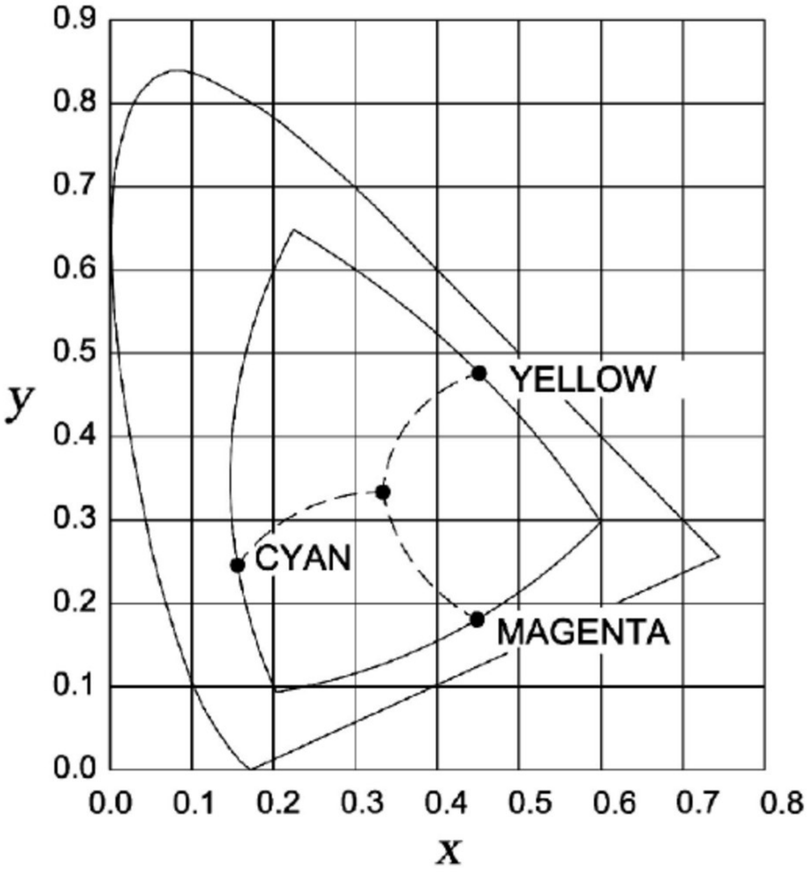
When the green component is extracted from white light, the remaining light causes the sensation „purple“,

When the red component is extracted from white light, the remaining light causes the sensation „cyan“.

When the blue component is extracted from white light, the remaining light causes the sensation „yellow“.

Standardization of colors

The CMY system



Source: Malacara, Color Vision and Colorimetry, SPIE Press (2011), p. 139

Color Spaces

Overview

Hardware dependent models

Additive color models

- RGB (red, green, blue) models
  - sRGB (1996)
  - Adobe RGB (1998)
- HSI (hue, saturation, intensity) models
  - HSI (hue, saturation, intensity)
  - HSV (hue, saturation, value) (1983)
  - NTSC (luminance (Y), hue (I), saturation (Q)

Subtractive color models

- CMY (cyan, magenta, yellow) (1983)
- CMYK (cyan, magenta, yellow, black) (1983)

Hardware independent models

- CIE XYZ (1931), CIE (1964)
- CIE L*a*b (1976)
- CIE L*C*h

Standardization of colors

The CIE L*a*b system

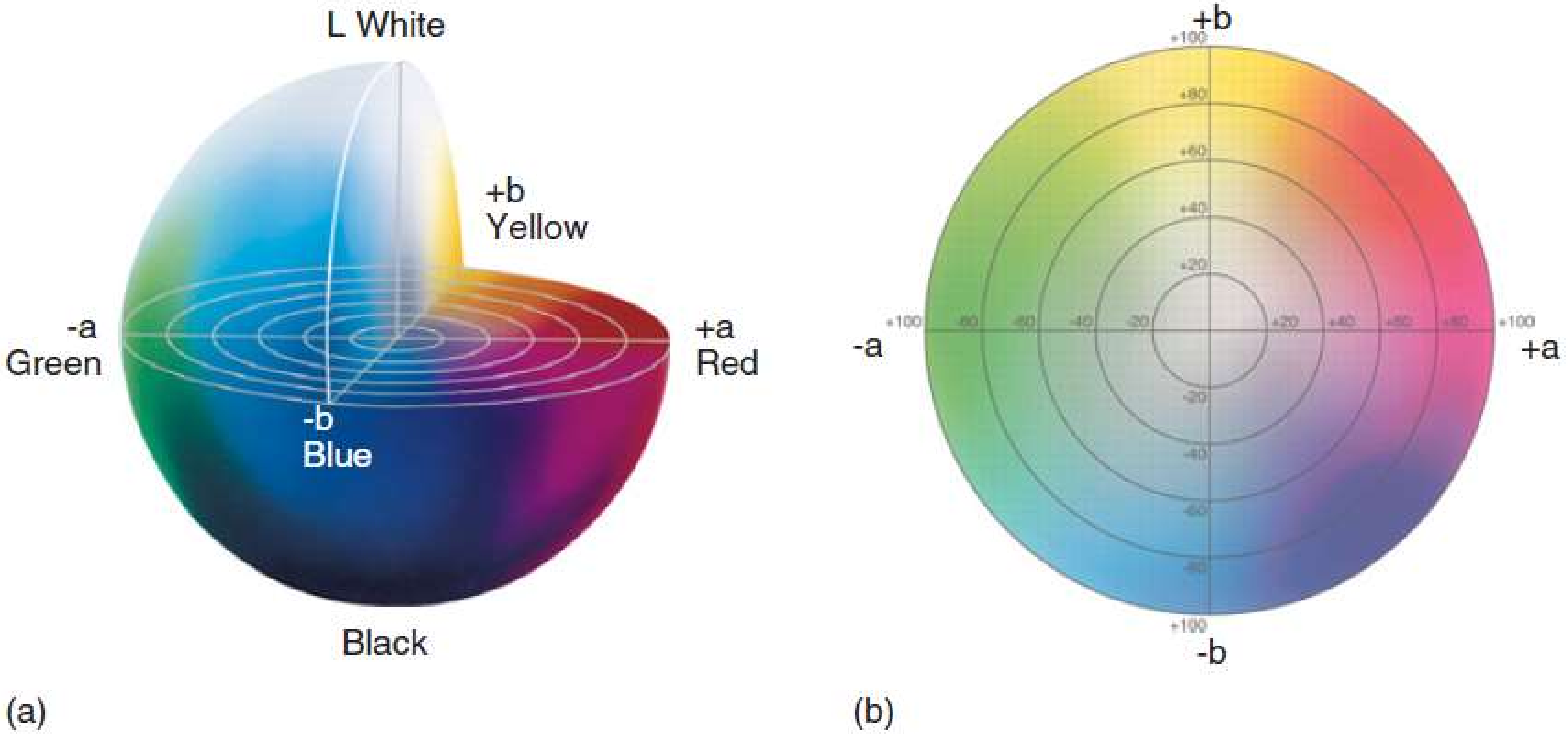


Fig. from: Sharma, Understanding color management, Wiley (2018), p. 79.

Standardization of colors

The CIE L*C*h system

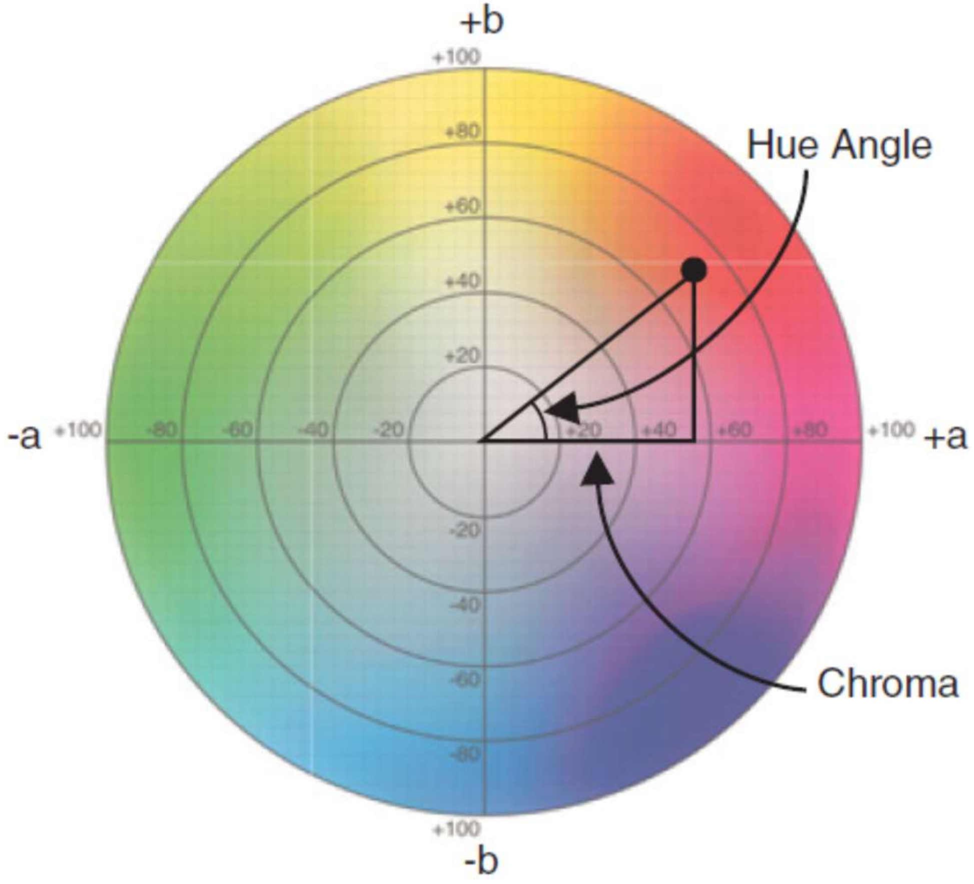


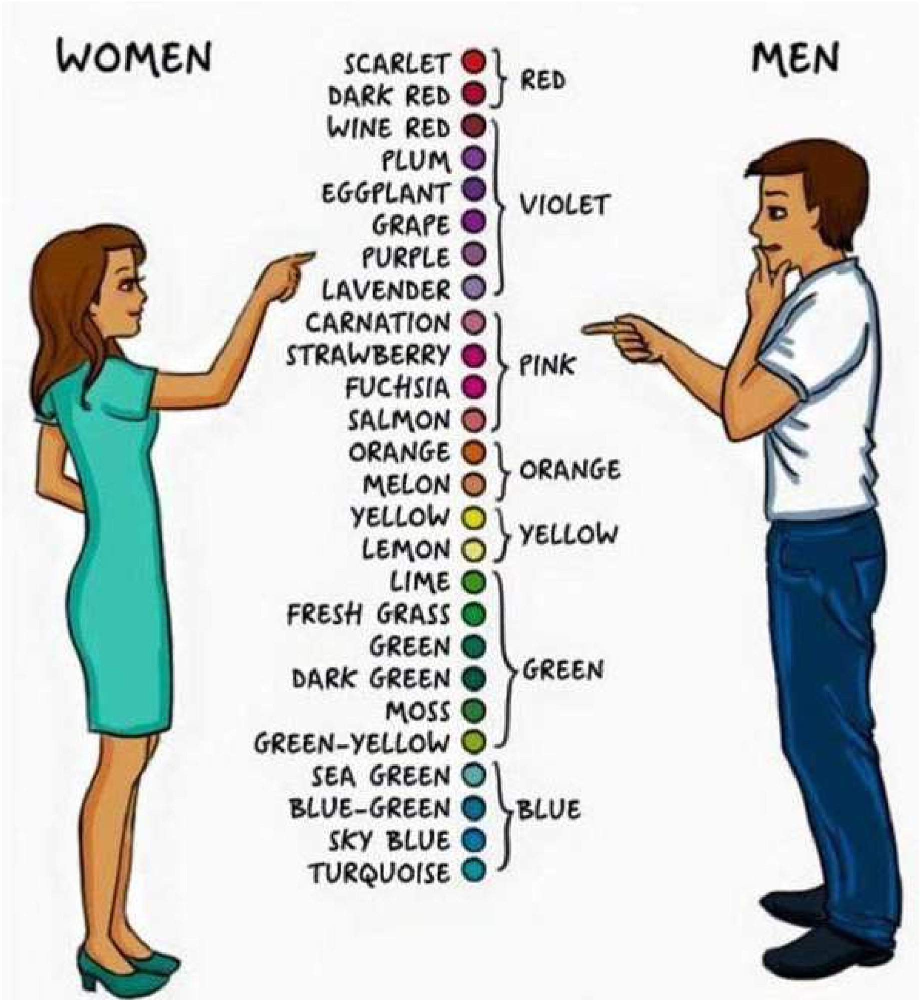
Fig. from: Sharma, Understanding color management, Wiley (2018), p. 84.

Color Image Processing in MATLAB

Conversion between color spaces

Color space	Application	Conversion between color spaces
HSV (hue (H), saturation (S), value (V))	Easy selection of colors	`hsv = rgb2hsv(rgb)` converts RGB images or colormaps to the HSV color space. `rgb = hsv2rgb(hsv)` converts HSV values to the RGB color space.
YIQ (luminance (Y), hue (I), and saturation (Q))	The YIQ color space is used in televisions in the United States. The standard is defined by the National Television Systems Committee (NTSC)	`YIQ = rgb2ntsc(rgb)` converts RGB images or colormaps to the NTSC color space. `rgb = ntsc2rgb(YIQ)` performs the reverse operation.
YCbCr (luminance (Y), chrominance (Cb,Cr)	The YCbCr color space is widely used for digital video. (Cb represents the difference between the blue component and a reference value. Cr represents the difference between the red component and a reference value)	`video = rgb2ycbcr(RGB)` converts RGB images or colormaps to the YCbCr color space. `rgb = ycbcr2rgb(video)` performs the reverse operation.
CIE XYZ	Device independent, widely used color space, created by the CIE in 1931	`XYZ = rgb2xyz(rgb)` converts RGB images to to CIE 1931 XYZ coordinates. `rgb = xyz2rgb(xyz)` performs the reverse operation
CIE L*a*b	Device independent, perceptually uniform color space, created by the CIE in 1976.	`lab = rgb2lab(rgb)` converts RGB values to CIE 1976 L*a*b* values. `rgb = lab2rgb(lab)` converts RGB values to CIE 1976 L*a*b* values. An RGB color is out of gamut when any of its component values are less than 0 or greater than 1.

Colors


WOMEN
MEN
SCARLET
DARK RED
RED
WINE RED
PLUM
EGGPLANT
GRAPE
PURPLE
LAVENDER
VIOLET
CARNATION
STRAWBERRY
FUCHSIA
SALMON
PINK
ORANGE
MELON
ORANGE
YELLOW
LEMON
YELLOW
LIME
FRESH GRASS
GREEN
DARK GREEN
MOSS
GREEN-YELLOW
GREEN
SEA GREEN
BLUE-GREEN
SKY BLUE
TURQUOISE
BLUE