CS443: Digital Imaging and Multimedia
Color in Digital Images

Spring 2008

Ahmed Elgammal

Dept. of Computer Science

Rutgers University

Outlines

- Color Perception
- RGB color space
- HSV and HLS
- Color Models for TV and Video
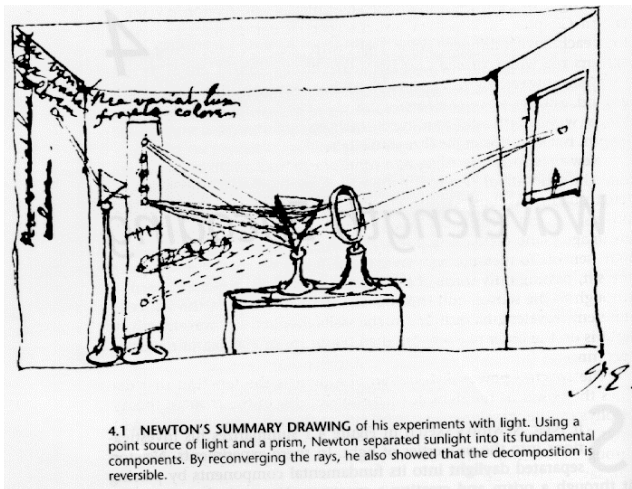- Color Models for Printing
- Colorimetric Color Spaces

- Sources:
  - Burger and Burge "Digital Image Processing" Chapter 12

Color Perception

- Color perception is a fascinating and complicated phenomenon that has occupied the interest of scientist, psychologists, philosophers, and artists for hundreds of years.
- Color plays an important role in object recognition
- What is the best way to represent colors in the digital domain?
- Challenging problem: color constancy.

Complications of color

- Spectral composition of light
  - Newton's original prism experiment
  - light decomposed into its spectral components

4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

## Complications of color

- Why does the prism separate the light into its spectral components?
  - prism bends different wavelengths of light by different amounts
    - refractive index is a function of wavelength
    - shorter wavelengths are refracted more strongly than longer wavelengths

Wavelength	Color (*)
700	Red
610	Orange
580	Yellow
540	Green
480	Blue
400	Violet

* - viewed in isolation


Complications of color
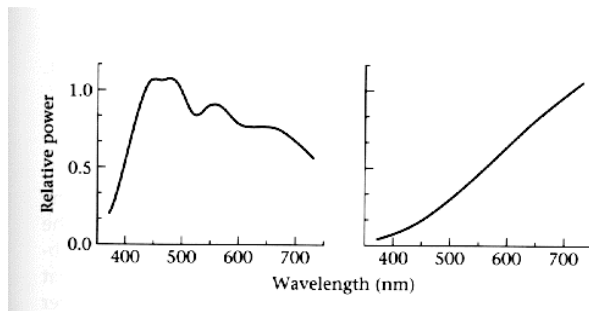
4.4 THE SPECTRAL POWER DISTRIBUTION of two important light sources are shown: (left) blue skylight and (right) a tungsten bulb.

Cones and color - recall

- Three different types of cones
  - they differ in their sensitivity to different wavelengths of light (blue-violet, green, yellow-red)

3.3 SPECTRAL SENSITIVITIES OF THE L-, M-, AND S-CONES in the human eye. The measurements are based on a light source at the cornea, so that the wavelength loss due to the cornea, lens, and other inert pigments of the eye plays a role in determining the sensitivity. Source: Stockman and MacLeod, 1993.
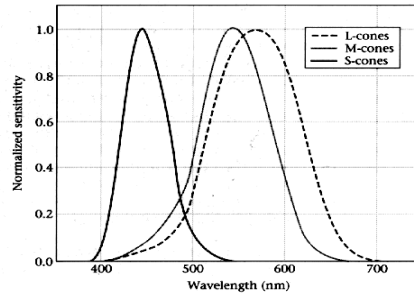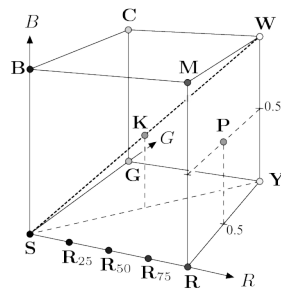
RGB color images

- Three primary colors: Red, Green, blue
- Widely used in transmission, representation, storage of color images.
- RGB is additive color system: add primary colored-light to form different colors
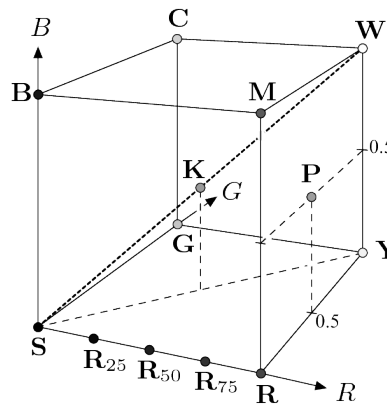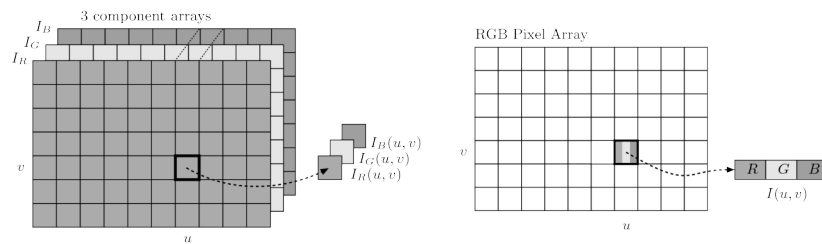
$$\mathbf{C}_i = (R_i, G_i, B_i)$$

	RGB Value			
Point	Color	R	G	B
S	Black	0.00	0.00	0.00
R	Red	1.00	0.00	0.00
Y	Yellow	1.00	1.00	0.00
G	Green	0.00	1.00	0.00
C	Cyan	0.00	1.00	1.00
B	Blue	0.00	0.00	1.00
M	Magenta	1.00	0.00	1.00
W	White	1.00	1.00	1.00
K	50% Gray	0.50	0.50	0.50
$\mathbf{R}_{75}$	75% Red	0.75	0.00	0.00
$\mathbf{R}_{50}$	50% Red	0.50	0.00	0.00
$\mathbf{R}_{25}$	25% Red	0.25	0.00	0.00
P	Pink	1.00	0.50	0.50

- It is hard to determine the color of a pixel from knowing it's R,G,B components
- RGB is not a perceptually uniform representation: measured distance in the RGB color space doesn't correspond to our perception of color.

R	G	B
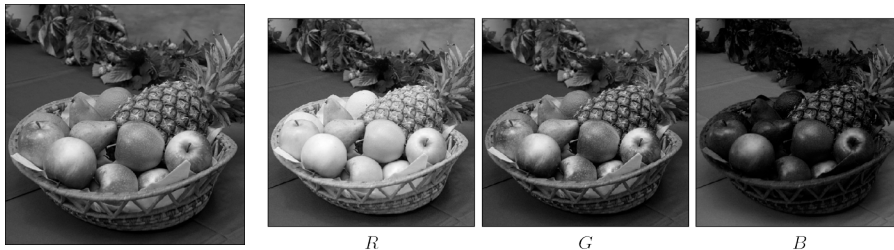
RGB representation

- True color images: represent each pixel with its R,G,B values.
  - Component ordering
  - Packed ordering

3 component arrays

I_B
I_G
I_R

$I_B(u,v)$
$I_G(u,v)$
$I_R(u,v)$

v

u

RGB Pixel Array

v

u

| R | G | B |

$I(u,v)$

RGB representation

- Alternative representation: Indexed images:
  - make a color table
  - each pixel's color is represented by its color's index in the table
- Advantages?
- Limitations?

Image $I_{idx(u,v)}$

v

k

u

Index	P_R	P_G	P_B
0	r_0	g_0	b_0
1	r_1	g_1	b_1
2	r_2	g_2	b_2
⋮	⋮		
k	r_k	g_k	b_k
⋮	⋮		
$N-1$	r_{N-1}	g_{N-1}	b_{N-1}

Color Table P

<table>
<tr><td>(a)</td><td>(b)</td><td>(c)</td></tr>
</table>

- RGB Limitations:
- It is hard to determine the color of a pixel from knowing it's R,G,B components
- RGB is not a perceptually uniform representation: measured distance in the RGB color space doesn't correspond to our perception of color.
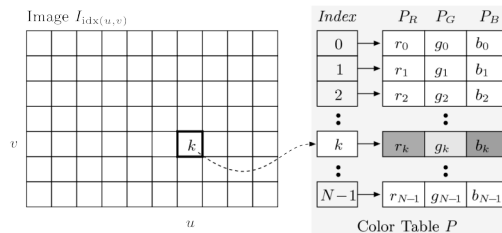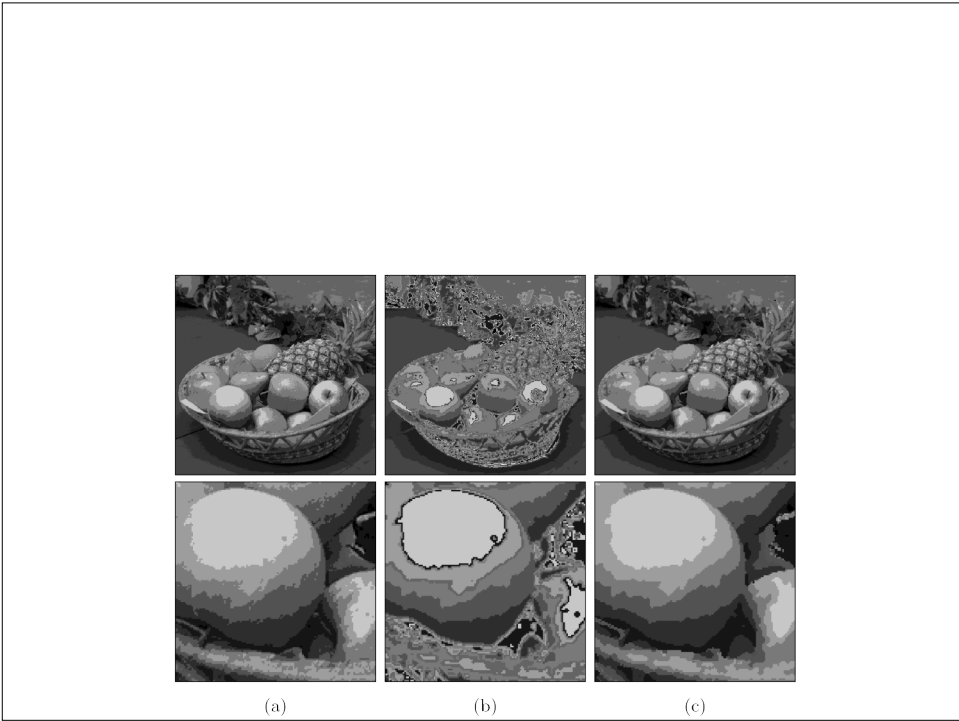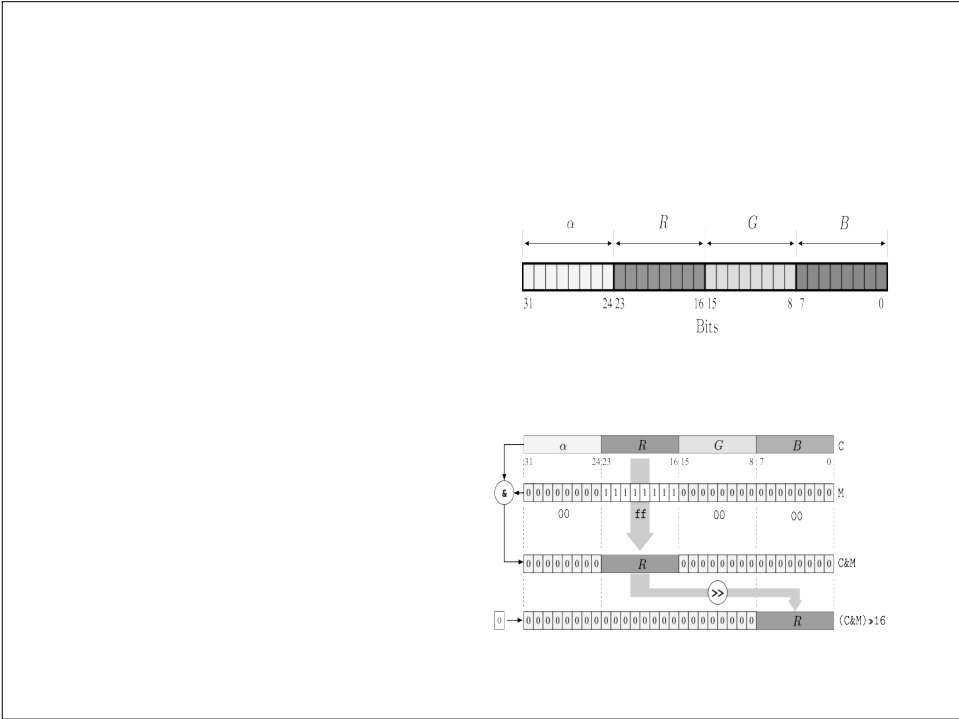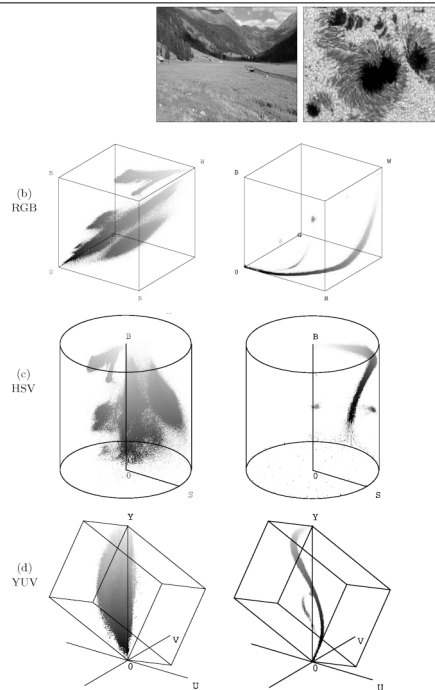- Brightness changes in the RGB color space are not perceived linearly.

Other Color Spaces

- HSV/HSB and HLS
- TV Color Spaces:
  - YUV, YIQ, YC_bC_r
- Color spaces for printing:
  - CMY, CMYK
- Colorimetric Color Spaces:
  - CIE XYZ
  - CIE L*a*b*

- **Three important concepts:**
  - Hue
  - Saturation
  - Luminance

From RGB to Grayscale

- **How to compute luminance value Y from RGB**
$$Y = \mathrm{Avg}(R, G, B) = \frac{R + G + B}{3}$$
- **We perceive red and green as being brighter than blue**
$$Y = \mathrm{Lum}(R, G, B) = w_R \cdot R + w_G \cdot G + w_B \cdot B$$
- **For analog color TV signal**
$$w_R = 0.299 \qquad w_G = 0.587 \qquad w_B = 0.114$$
- **For digital color encoding ITY-BT.709**
$$w_R = 0.2125 \qquad w_G = 0.7154 \qquad w_B = 0.072$$

$R \qquad\qquad G \qquad\qquad B$

Desaturating Color Images

$$\begin{pmatrix} R_d \\ G_d \\ B_d \end{pmatrix} \leftarrow \begin{pmatrix} Y \\ Y \\ Y \end{pmatrix} + s_{\text{col}} \cdot \begin{pmatrix} R - Y \\ G - Y \\ B - Y \end{pmatrix}$$
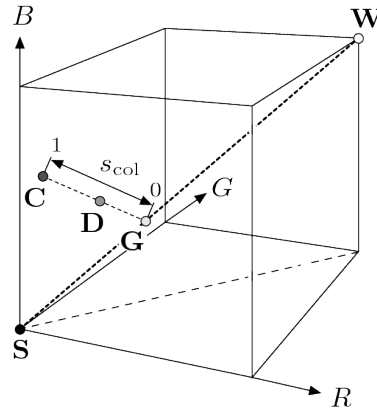
HSV color space

- **Represent three components:**
    - Hue
    - Saturation
    - Value (brightness)
- **Also called HSB or HIS**
- **Upside-down six-sided pyramid**
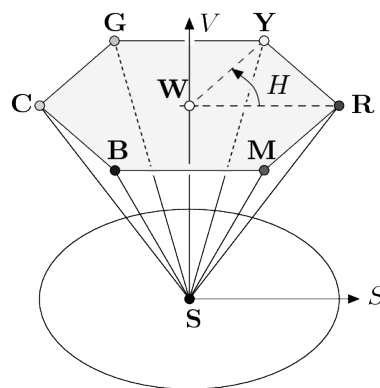
(a) HSV

HLS color space

- Similar to HSV:
  - Hue
  - Luminance
  - Saturation
- Also called HSL
- Double pyramid representation (like a diamond)

(a) HSV

(b) HLS

H_{HSV} S_{HSV} V_{HSV}

RGB to HSV

- **Easier represented as a cylinder.**

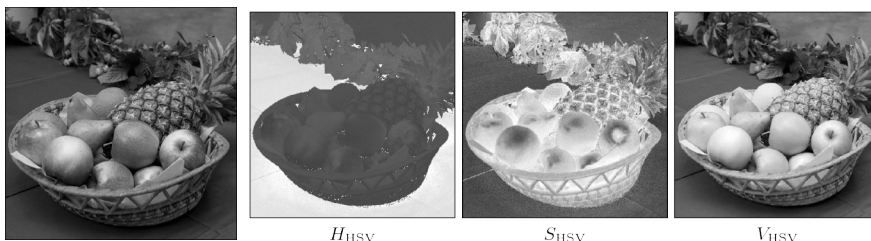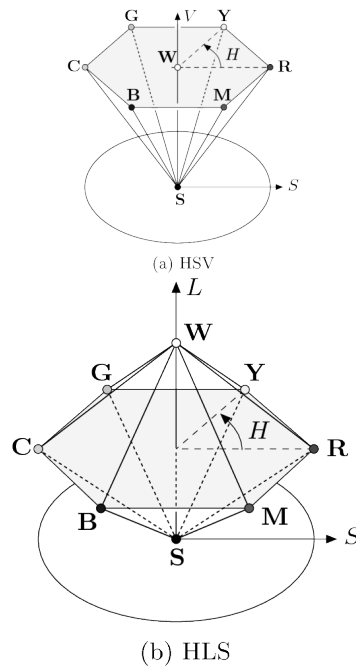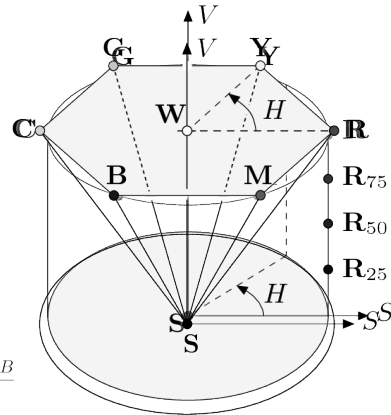$$S_{\mathrm{HSV}} = \begin{cases} \frac{C_{\mathrm{rng}}}{C_{\mathrm{high}}} & \text{for } C_{\mathrm{high}} > 0 \\ 0 & \text{otherwise} \end{cases}$$

$$V_{\mathrm{HSV}} = \frac{C_{\mathrm{high}}}{C_{\mathrm{max}}}$$

$$R' = \frac{C_{\mathrm{high}} - R}{C_{\mathrm{rng}}} \qquad G' = \frac{C_{\mathrm{high}} - G}{C_{\mathrm{rng}}} \qquad B' = \frac{C_{\mathrm{high}} - B}{C_{\mathrm{rng}}}$$

$$H' = \begin{cases} B' - G' & \text{if } R = C_{\mathrm{high}} \\ R' - B' + 2 & \text{if } G = C_{\mathrm{high}} \\ G' - R' + 4 & \text{if } B = C_{\mathrm{high}} \end{cases}$$

$$H_{\mathrm{HSV}} = \frac{1}{6} \cdot \begin{cases} (H' + 6) & \text{for } H' < 0 \\ H' & \text{otherwise} \end{cases}$$

(a) HSV

RGB to HSV

RGB/HSV Values

Pt.	Color	R	G	B	H	S	V
S	Black	0.00	0.00	0.00	—	0.00	0.00
R	Red	1.00	0.00	0.00	0	1.00	1.00
Y	Yellow	1.00	1.00	0.00	1/6	1.00	1.00
G	Green	0.00	1.00	0.00	2/6	1.00	1.00
C	Cyan	0.00	1.00	1.00	3/6	1.00	1.00
B	Blue	0.00	0.00	1.00	4/6	1.00	1.00
M	Magenta	1.00	0.00	1.00	5/6	1.00	1.00
W	White	1.00	1.00	1.00	—	0.00	1.00
R$_{75}$	75% Red	0.75	0.00	0.00	0	1.00	0.75
R$_{50}$	50% Red	0.50	0.00	0.00	0	1.00	0.50
R$_{25}$	25% Red	0.25	0.00	0.00	0	1.00	0.25
P	Pink	1.00	0.50	0.50	0	0.5	1.00

RGB to HLS

$$H_{\mathrm{HLS}} = H_{\mathrm{HSV}}$$

$$S_{\mathrm{HLS}} = \begin{cases} 0 & \text{for } L_{\mathrm{HLS}} = 0 \\ 0.5 \cdot \dfrac{C_{\mathrm{rng}}}{L_{\mathrm{HLS}}} & \text{for } 0 < L_{\mathrm{HLS}} \le 0.5 \\ 0.5 \cdot \dfrac{C_{\mathrm{rng}}}{1 - L_{\mathrm{HLS}}} & \text{for } 0.5 < L_{\mathrm{HLS}} < 1 \\ 0 & \text{for } L_{\mathrm{HLS}} = 1 \end{cases}$$

$$L_{\mathrm{HLS}} = \frac{C_{\mathrm{high}} + C_{\mathrm{low}}}{2}$$
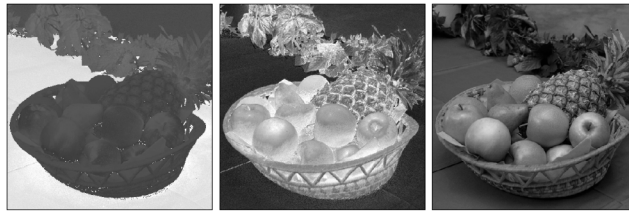
H_{HLS} S_{HLS} L_{HLS}

RGB/HLS Values

Pt.	Color	R	G	B	H	S	L
S	Black	0.00	0.00	0.00	—	0.00	0.00
R	Red	1.00	0.00	0.00	0	1.00	0.50
Y	Yellow	1.00	1.00	0.00	1/6	1.00	0.50
G	Green	0.00	1.00	0.00	2/6	1.00	0.50
C	Cyan	0.00	1.00	1.00	3/6	1.00	0.50
B	Blue	0.00	0.00	1.00	4/6	1.00	0.50
M	Magenta	1.00	0.00	1.00	5/6	1.00	0.50
W	White	1.00	1.00	1.00	—	0.00	1.00
R_{75}	75% Red	0.75	0.00	0.00	0	1.00	0.375
R_{50}	50% Red	0.50	0.00	0.00	0	1.00	0.250
R_{25}	25% Red	0.25	0.00	0.00	0	1.00	0.125
P	Pink	1.00	0.50	0.50	0/6	1.00	0.75

RGB/HSV Values

Pt.	Color	R	G	B	H	S	V
S	Black	0.00	0.00	0.00	—	0.00	0.00
R	Red	1.00	0.00	0.00	0	1.00	1.00
Y	Yellow	1.00	1.00	0.00	1/6	1.00	1.00
G	Green	0.00	1.00	0.00	2/6	1.00	1.00
C	Cyan	0.00	1.00	1.00	3/6	1.00	1.00
B	Blue	0.00	0.00	1.00	4/6	1.00	1.00
M	Magenta	1.00	0.00	1.00	5/6	1.00	1.00
W	White	1.00	1.00	1.00	—	0.00	1.00
$\mathbf{R}_{75}$	75% Red	0.75	0.00	0.00	0	1.00	0.75
$\mathbf{R}_{50}$	50% Red	0.50	0.00	0.00	0	1.00	0.50
$\mathbf{R}_{25}$	25% Red	0.25	0.00	0.00	0	1.00	0.25
P	Pink	1.00	0.50	0.50	0	0.5	1.00

RGB/HLS Values

Pt.	Color	R	G	B	H	S	L
S	Black	0.00	0.00	0.00	—	0.00	0.00
R	Red	1.00	0.00	0.00	0	1.00	0.50
Y	Yellow	1.00	1.00	0.00	1/6	1.00	0.50
G	Green	0.00	1.00	0.00	2/6	1.00	0.50
C	Cyan	0.00	1.00	1.00	3/6	1.00	0.50
B	Blue	0.00	0.00	1.00	4/6	1.00	0.50
M	Magenta	1.00	0.00	1.00	5/6	1.00	0.50
W	White	1.00	1.00	1.00	—	0.00	1.00
$\mathbf{R}_{75}$	75% Red	0.75	0.00	0.00	0	1.00	0.375
$\mathbf{R}_{50}$	50% Red	0.50	0.00	0.00	0	1.00	0.250
$\mathbf{R}_{25}$	25% Red	0.25	0.00	0.00	0	1.00	0.125
P	Pink	1.00	0.50	0.50	0/6	1.00	0.75

HSV	HLS	Difference
S_{HSV}	S_{HLS}	$S_{\mathrm{HSV}} - S_{\mathrm{HLS}}$
V_{HSV}	L_{HLS}	$V_{\mathrm{HSV}} - L_{\mathrm{HLS}}$

Color Models in TV and Video

- Part of the standards for recording, storage, transmission, and display of TV signals
- YIQ: used in analog NTSC systems. Also in VHS videotape coding. (N. America and Japan
- YUV: used in European TV standard (SECAM)
- YCbCr: a variation of YUV that is used in digital video and digital TV. Also in JPEG
- Common ideas:
  - A separate luminance component Y
  - Two chroma components
  - Encode color difference instead of absolute colors
  - More bandwidth for luminance than chroma components.
  - Linear transformation from RGB (a matrix multiplication for conversion.

YUV

- Luminance component:

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

- Chroma components: based on differences between the luminance and the blue and red components:

$$U = 0.492 \cdot (B - Y) \qquad \text{and} \qquad V = 0.877 \cdot (R - Y)$$

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.000 & 0.000 & 1.140 \\ 1.000 & -0.395 & -0.581 \\ 1.000 & 2.032 & 0.000 \end{pmatrix} \cdot \begin{pmatrix} Y \\ U \\ V \end{pmatrix}$$
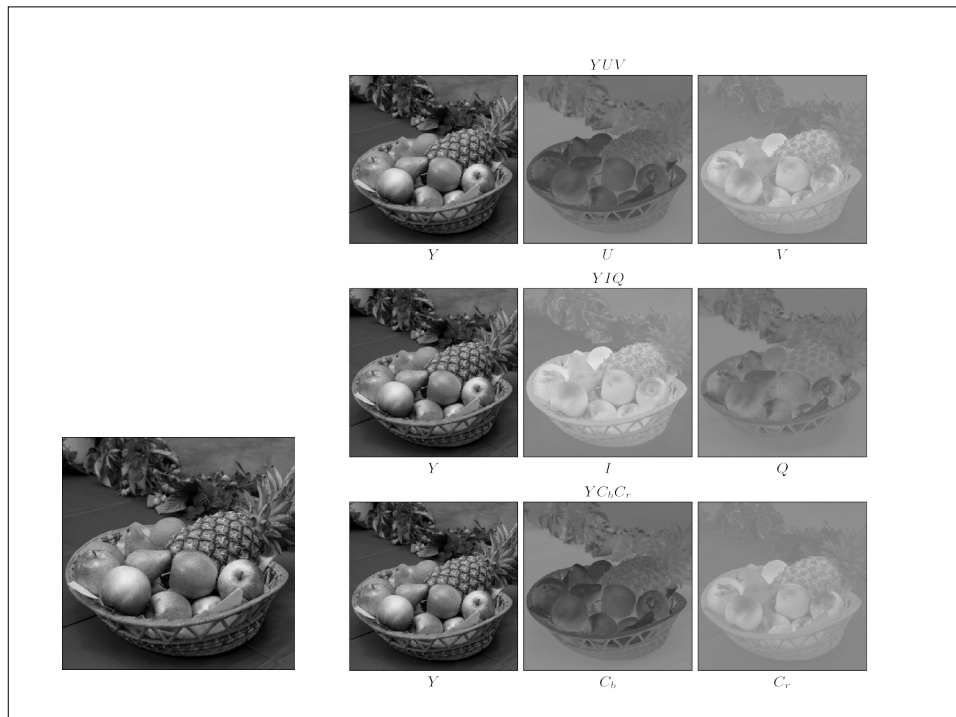
YIQ and YCbCr

- YIQ: similar to YUV (rotate and mirror the UV)

$$\begin{pmatrix} I \\ Q \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \cdot \begin{pmatrix} U \\ V \end{pmatrix}$$

- YC_bC_r:

$$Y = w_R \cdot R + (1 - w_B - w_R) \cdot G + w_B \cdot B$$

$$C_b = \frac{0.5}{1 - w_B} \cdot (B - Y)$$

$$C_r = \frac{0.5}{1 - w_R} \cdot (R - Y)$$

- Setting the weights to w_B=0.299 and w_R=0.114

$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Color Models for Printing

- Subtractive color models: CMY and CMYK
- Color printing requires a minimum of three primary colors: traditionally: Cyan, Magenta, and Yello
- White: C=M=Y=0 (no ink)
- Black: C=M=Y=1 (complete subtraction of light)
- CMY from RGB (simplified):

$$C = 1 - R$$

$$M = 1 - G$$

$$Y = 1 - B$$

CMYK

- In actual printing, CMY is not sufficient, we need a black ink as well. K component
- How to determine the amount of black ink?
$$K = \min(C, M, Y)$$
- The more the black the less the C, M, Y ink should be
- If C=M=Y, we only need black ink
- Different conversions are possible.
- Very complicated task in reality, which depends on the printer used

CMY to CMYK

- **Version 1**

$$\begin{pmatrix} C' \\ M' \\ Y' \\ K' \end{pmatrix} = \begin{pmatrix} C - K \\ M - K \\ Y - K \\ K \end{pmatrix}$$
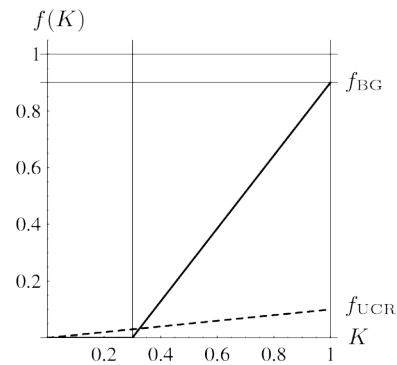
- **Version 2**

$$\begin{pmatrix} C' \\ M' \\ Y' \end{pmatrix} = \begin{pmatrix} C - K \\ M - K \\ Y - K \end{pmatrix} \cdot \begin{cases} \frac{1}{1-K} & \text{for } K < 1 \\ 1 & \text{otherwise} \end{cases}$$
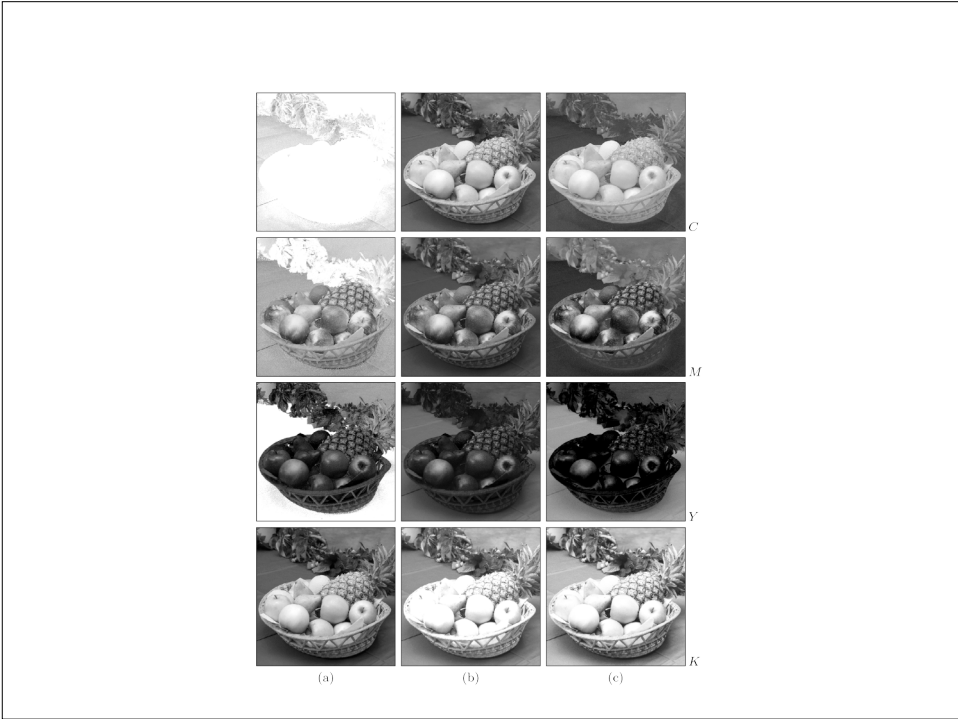$$K' = K$$

- **Version 3**

$$\begin{pmatrix} C' \\ M' \\ Y' \\ K' \end{pmatrix} = \begin{pmatrix} C - f_{\mathrm{UCR}}(K) \\ M - f_{\mathrm{UCR}}(K) \\ Y - f_{\mathrm{UCR}}(K) \\ f_{\mathrm{BG}}(K) \end{pmatrix}$$
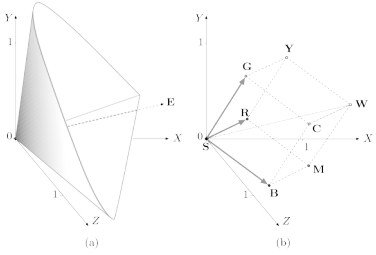

$$f_{\mathrm{UCR}}(K) = s_K \cdot K$$

$$f_{\mathrm{BG}}(K) = \begin{cases} 0 & \text{for } K < K_0 \\ K_{\max} \cdot \frac{K - K_0}{1 - K_0} & \text{for } K \geq K_0 \end{cases}$$

(a)   (b)   (c)

Colorimetric Color Spaces

- Goal: measure colors independent of devices
- A calibrated device-independent color system
- CIE color spaces: CIE (Commission Inernationale d'Eclairge - International commission on Illumination.
- CIE XYZ, CIE x,y, CIE L*a*b*

CIE XYZ

- Three imaginary primary colors X, Y, Z
- All the visible colors are summations of positive components.
- All visible colors lie inside a cone-shaped region, which doesn't include the X,Y, Z
- Y corresponds to the luminosity of the color (lightness)
- RGB cube is a distorted cube in the XYZ space.
- Linear transformation between RGB and XYZ
- Similar to RGB, the space is nonlinear wrt human color perception

(a) (b)

CIE - XYZ

(a) (b)

20
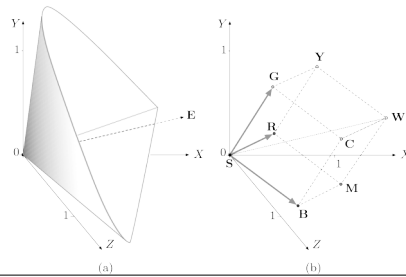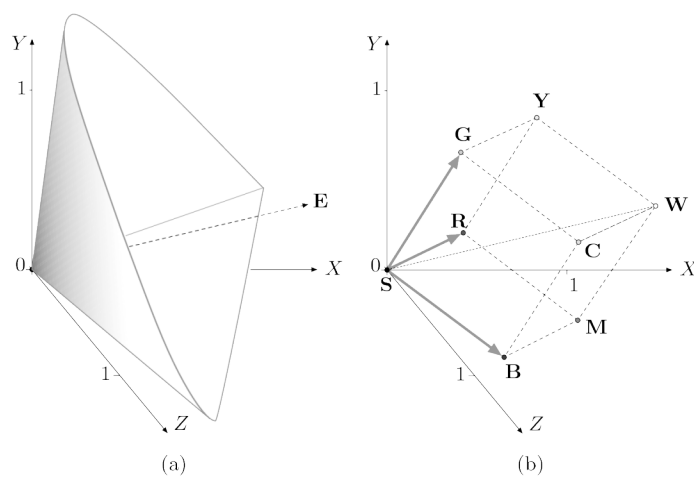
RGB to CIE XYZ - a linear transformation

Pt.	Color	R	G	B	X	Y	Z	x	y
S	black	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.3127	0.3290
R	red	1.00	0.00	0.00	0.4125	0.2127	0.0193	0.6400	0.3300
Y	yellow	1.00	1.00	0.00	0.7700	0.9278	0.1385	0.4193	0.5052
G	green	0.00	1.00	0.00	0.3576	0.7152	0.1192	0.3000	0.6000
C	cyan	0.00	1.00	1.00	0.5380	0.7873	1.0694	0.2247	0.3288
B	blue	0.00	0.00	1.00	0.1804	0.0722	0.9502	0.1500	0.0600
M	magenta	1.00	0.00	1.00	0.5929	0.2848	0.9696	0.3209	0.1542
W	white	1.00	1.00	1.00	0.9505	1.0000	1.0888	0.3127	0.3290

CIE x,y chromaticity

- How to separate the color hue from the luminance
- A central projection (through S) to the plane $X + Y + Z = 1$

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

- Then, project to the XY plane (use only the *x,y* - drop *z*)

(a)   (b)

$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z} \qquad z = \frac{Z}{X + Y + Z}$$

(a)   (b)
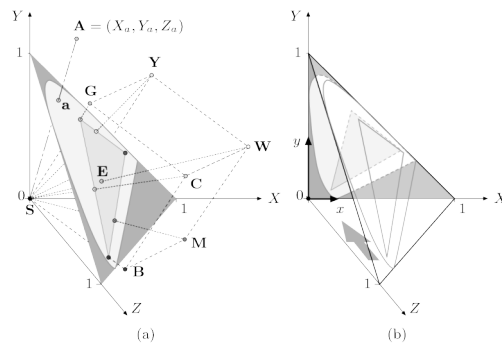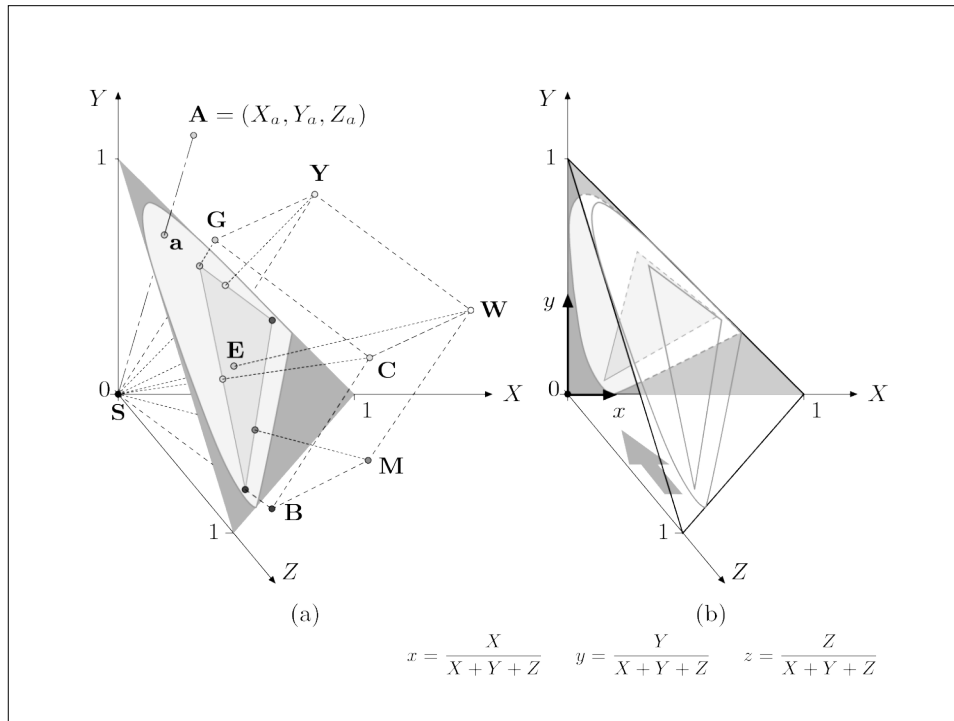
CIE-xy chromaticity diagram

- Horseshoe-shaped
- The outer boundary represents monochromatic (spectrally pure), maximally saturated colors.
- Neutral point (E) where x=y=1/3, (X=Y=Z=1)
- Saturation falls off towards E
- Complementary colors?
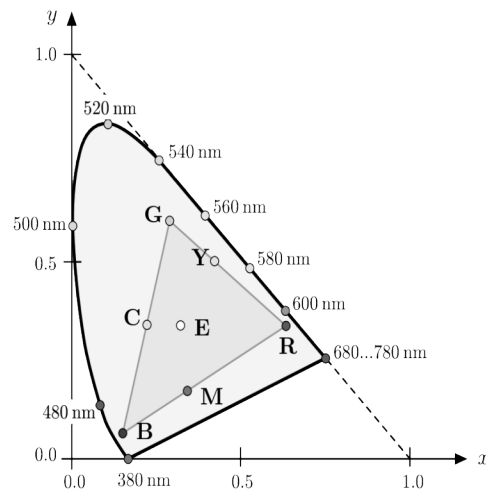
- We cannot reconstruct the XYZ from xy only
- We can reconstruct the XYZ if we know x,y, and Y

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

- Standard illuminants
  - D50: emulate direct sunlight illumination
  - D65:emulate overcast daylight illumination
- These are important reference points to transform between color spaces and devices
- Gamut: the set of all colors that can be handled by a certain media device or can be represented by a given color space.
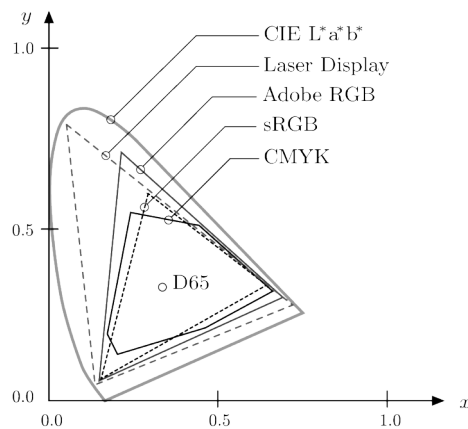
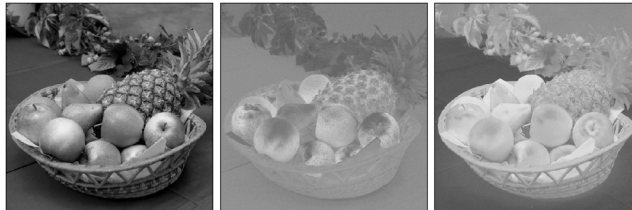| Pt.	Temp.	X	Y	Z	x	y
D50	5000° K	0.964296	1.000000	0.825105	0.3457	0.3585
D65	6500° K	0.950456	1.000000	1.088754	0.3127	0.3290
E	5400° K	1	1	1	1/3	1/3

CIE L*a*b*

- XYZ is not perceptually uniform
- L*a*b* is a similar color space but more uniform
- Green-red, blue-yellow hue axis.

$$L^* = 116 \cdot Y' - 16 \qquad X' = f_1\left(\frac{X}{X_{\text{ref}}}\right) \quad Y' = f_1\left(\frac{Y}{Y_{\text{ref}}}\right) \quad Z' = f_1\left(\frac{Z}{Z_{\text{ref}}}\right)$$

$$a^* = 500 \cdot (X' - Y')$$

$$b^* = 200 \cdot (Y' - Z') \qquad f_1(c) = \begin{cases} c^{\frac{1}{3}} & \text{for } c > 0.008856 \\ 7.787 \cdot c + \frac{16}{116} & \text{for } c \leq 0.008856 \end{cases}$$

L^* \qquad a^* \qquad b^*

sRGB

- Standard RGB: precisely specifying where are the R,G,B colors and the white reference point in the XYZ space.
- Important standard (developed by HP and MS)
- Used in JPEG, PNG, HTML4,…

Pt.	R	G	B	X_{65}	Y_{65}	Z_{65}	x_{65}	y_{65}
R	1.0	0.0	0.0	0.412453	0.212671	0.019334	0.6400	0.3300
G	0.0	1.0	0.0	0.357580	0.715160	0.119193	0.3000	0.6000
B	0.0	0.0	1.0	0.180423	0.072169	0.950227	0.1500	0.0600
W	1.0	1.0	1.0	0.950456	1.000000	1.088754	0.3127	0.3290

$$M_{\mathrm{RGB}} = \begin{pmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{pmatrix} \qquad M_{\mathrm{RGB}}^{-1} = \begin{pmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{pmatrix}$$

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = M_{\mathrm{RGB}} \cdot \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = M_{\mathrm{RGB}}^{-1} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

$$R' = f_\gamma(R) \qquad G' = f_\gamma(G) \qquad B' = f_\gamma(B)$$

$$f_\gamma(c) = \begin{cases} 1.055 \cdot c^{\frac{1}{2.4}} - 0.055 & \text{for } c > 0.0031308 \\ 12.92 \cdot c & \text{for } c \leq 0.0031308 \end{cases}$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \longrightarrow \boxed{\begin{array}{c} \text{linear} \\ \text{mapping} \\ M_{\mathrm{RGB}} \end{array}} \longrightarrow \begin{pmatrix} R \\ G \\ B \end{pmatrix} \longrightarrow \boxed{\begin{array}{c} \text{gamma} \\ \text{correction} \\ f_\gamma() \end{array}} \longrightarrow \begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$$
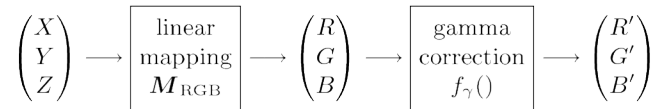
		sRGB nonlinear			sRGB linearized			CIE XYZ		
Pt.	Color	R'	G'	B'	R	G	B	X_{65}	Y_{65}	Z_{65}
S	black	0.00	0.0	0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R	red	1.00	0.0	0.0	1.0000	0.0000	0.0000	0.4125	0.2127	0.0193
Y	yellow	1.00	1.0	0.0	1.0000	1.0000	0.0000	0.7700	0.9278	0.1385
G	green	0.00	1.0	0.0	0.0000	1.0000	0.0000	0.3576	0.7152	0.1192
C	cyan	0.00	1.0	1.0	0.0000	1.0000	1.0000	0.5380	0.7873	1.0694
B	blue	0.00	0.0	1.0	0.0000	0.0000	1.0000	0.1804	0.0722	0.9502
M	magenta	1.00	0.0	1.0	1.0000	0.0000	1.0000	0.5929	0.2848	0.9696
W	white	1.00	1.0	1.0	1.0000	1.0000	1.0000	0.9505	1.0000	1.0888
K	50% gray	0.50	0.5	0.5	0.2140	0.2140	0.2140	0.2034	0.2140	0.2330
R$_{75}$	75% red	0.75	0.0	0.0	0.5225	0.0000	0.0000	0.2155	0.1111	0.0101
R$_{50}$	50% red	0.50	0.0	0.0	0.2140	0.0000	0.0000	0.0883	0.0455	0.0041
R$_{25}$	25% red	0.25	0.0	0.0	0.0509	0.0000	0.0000	0.0210	0.0108	0.0010
P	pink	1.00	0.5	0.5	1.0000	0.2140	0.2140	0.5276	0.3812	0.2482