Modely farieb

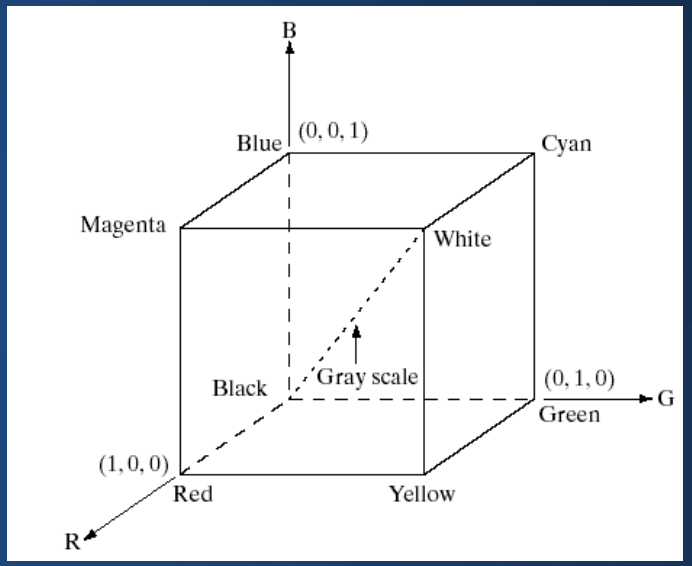
MODELY FARIEB

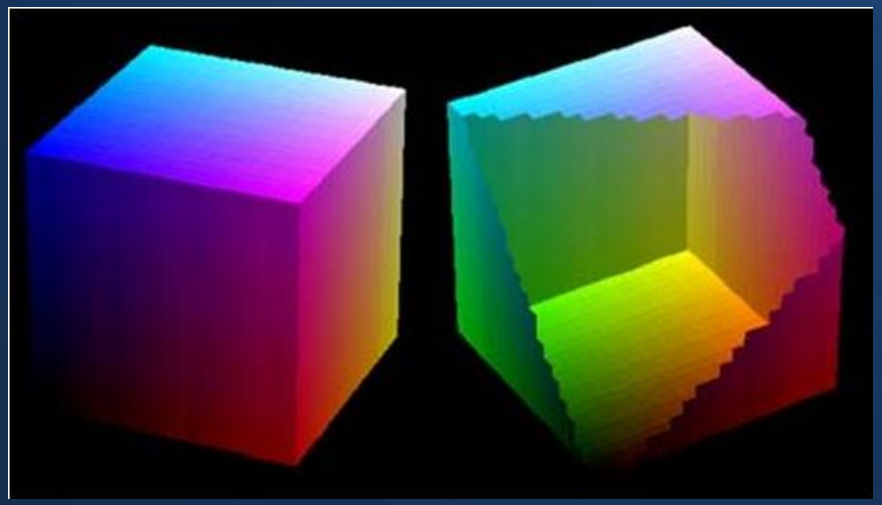
- *HW orientované:*
- *RGB, CMYK, televízne normy*
- *Užívateľsky orientované:*
- *HLS, HSV, HSI*
- *Vnemovo rovnomerné (perceptually uniform) :*
- *CIE Lab, Luv, WUV*
- *Iné:*
- *XYZ, oponent, TSV, LUX, YES, ...*

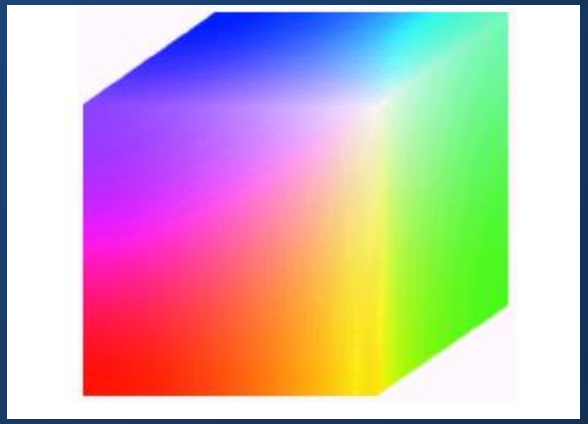
RGB

Najznámejší model
Používaný v monitoroch
Farebné svetlá

Hodnoty R,G,B $\in \langle 0, 1 \rangle$
Kocka

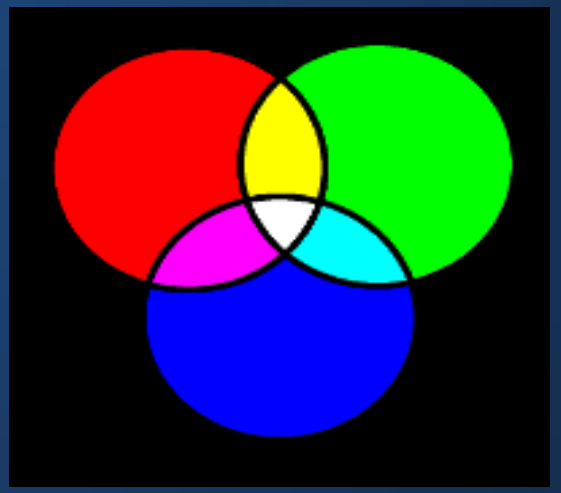






RGB

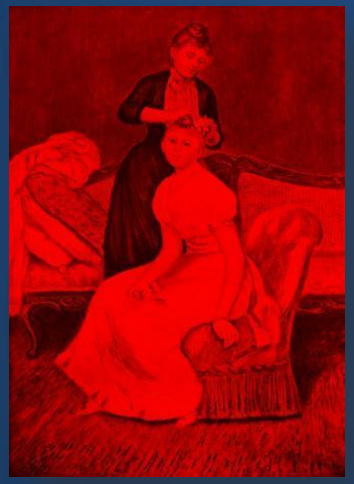
Aditívne skladanie farieb: čím viac farieb zložíme, tým je výsledok svetlejší (spočítava sa ich intenzita).



- Veľa rôznych modelov RGB
- Každý ma iné hodnoty základných farieb užívateľovi obvykle nedostupné
- TV spoločnosti si určili hodnoty základných farieb RGB podľa použitých technológií

RGB PRÍKLAD

Original

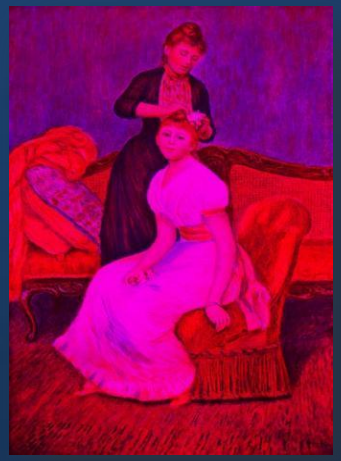


Red Band

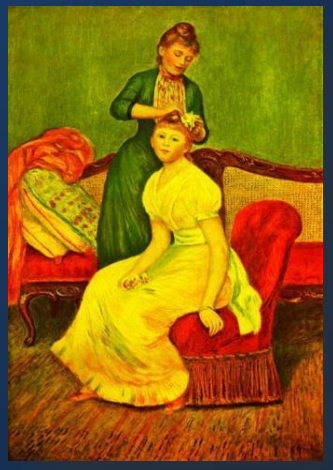
Green Band

Blue Band

No Red



No Green



No Blue

MODELY RGB

CIE RGB – E

NTSC – pôvodne C, teraz D65

EBU (European Broadcast Union) – C alebo D65

CCIR (Comité Consultatif International des Radiocommunications) – D65
ITU-R BT.709 standard

SMPTE (Society of Motion Picture and Television Engineers) – D65

Medzinárodná dohoda pre HDTV
ITU-R BT.709 standard

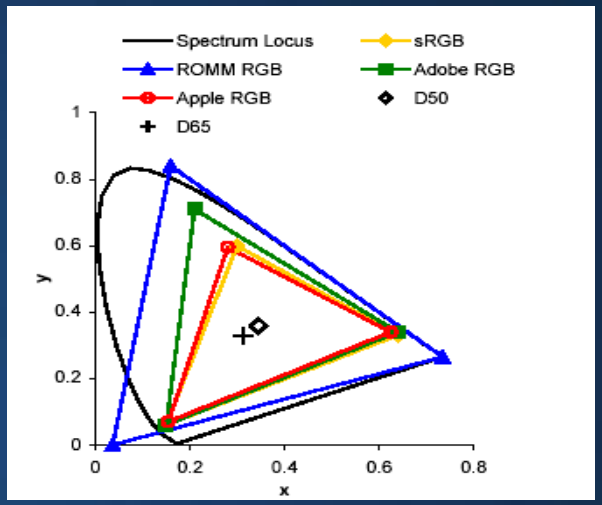


TABLE 3.5-2. *XYZ* Chromaticity Coordinates of Standard Primaries

Standard		*x*	*y*	*z*
CIE	R_C	0.640000	0.330000	0.030000
	G_C	0.300000	0.600000	0.100000
	B_C	0.150000	0.06000	0.790000
NTSC	R_N	0.670000	0.330000	0.000000
	G_N	0.210000	0.710000	0.080000
	B_N	0.140000	0.080000	0.780000
SMPTE	R_S	0.630000	0.340000	0.030000
	G_S	0.310000	0.595000	0.095000
	B_S	0.155000	0.070000	0.775000
EBU	R_E	0.640000	0.330000	0.030000
	G_E	0.290000	0.60000	0.110000
	B_E	0.150000	0.060000	0.790000
CCIR	R_R	0.640000	0.330000	0.030000
	G_R	0.30000	0.600000	0.100000
	B_R	0.150000	0.060000	0.790000

RGB → XYZ

Lineárna transformácia

Súradnice základných farieb

Súradnice bieleho bodu

$$\begin{bmatrix} a(1) \\ a(2) \\ a(3) \end{bmatrix} = \begin{bmatrix} x_R & x_G & x_B \\ y_R & y_G & y_B \\ z_R & z_G & z_B \end{bmatrix}^{-1} \begin{bmatrix} x_W/y_W \\ 1 \\ z_W/y_W \end{bmatrix}$$

$$\begin{bmatrix} M(1,1) & M(1,2) & M(1,3) \\ M(2,1) & M(2,2) & M(2,3) \\ M(3,1) & M(3,2) & M(3,3) \end{bmatrix} = \begin{bmatrix} x_R & x_G & x_B \\ y_R & y_G & y_B \\ z_R & z_G & z_B \end{bmatrix} \begin{bmatrix} a(1) & 0 & 0 \\ 0 & a(2) & 0 \\ 0 & 0 & a(3) \end{bmatrix}$$

RGB-to-*XYZ*

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} M_{1,1} & M_{1,2} & M_{1,3} \\ M_{2,1} & M_{2,2} & M_{2,3} \\ M_{3,1} & M_{3,2} & M_{3,3} \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

RGB

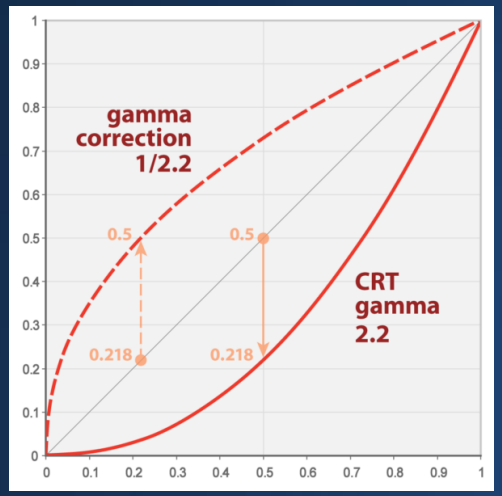
R

G

B

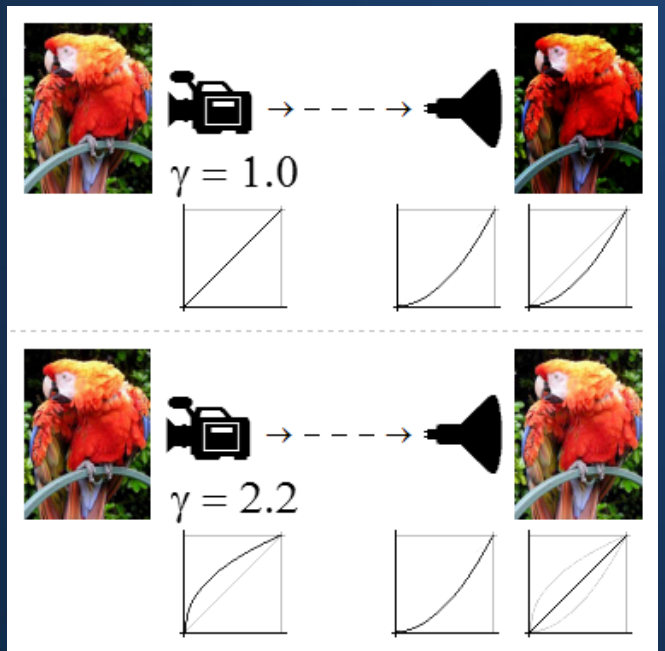
- *Lineárne RGB*
    - *lineárna transformácia z XYZ*
    - *vnemovo neuniformný*
    - *Device independent*
- *Nelineárne RGB*
    - *lineárne RGB pomocou **gamma korekcie** -> nelineárne RGB*
    - *Obrazovky CRT*
    - *Device dependent*

GAMA KOREKCIA



- *γ reprezentuje numerický parameter vyjadrujúci nelinearitu reprodukcie intenzity svetla*
- *CRT nelineárne*
  - *Intenzita svetla reprodukovaného na monitore je nelineárna funkcia napätia*

NTSC γ = 2.2



RGBA

RGBA- α kanál, informácia o priehľadnosti, akým pomerom sa farba mieša s pozadím.

Používa sa napríklad v OpenGL

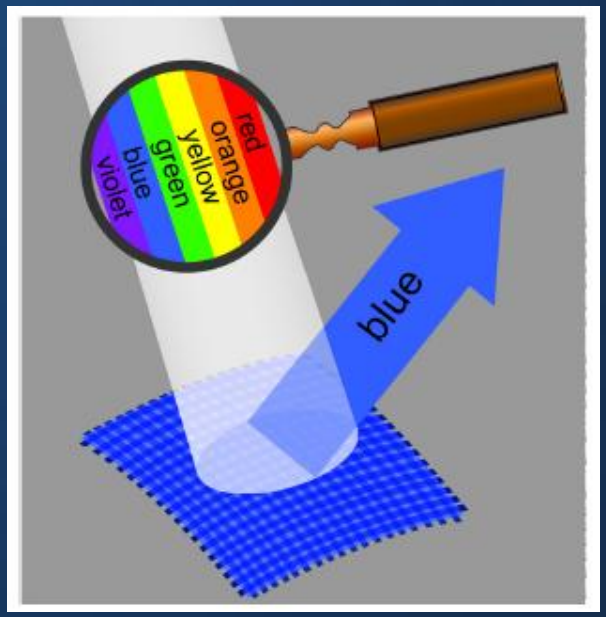
$\alpha = 1$ perfektne nepriesvitné
$\alpha = 0$ úplne priehľadné
$0 < \alpha < 1$ rôzne úrovne priesvitnosti

Blending je miešanie rôznych farieb: zdroja a miesta určenia

Priesvitný – čiastočne prepúšťajúci svetlo

CMY

Farebné filtre
Farba telies - farby sa ukladajú na seba, svetlo musí prejsť vrstvami (filtrami) a odraziť sa od podkladu



Komplementárny model k RGB:
C = 1 - R
M = 1 - G
Y = 1 - B

Subtraktívne skladanie farieb
pridávaním pigmentu tvorí tmavšiu farbu

CMYK

Pri tlači sa používa CMYK (blacK)
Nemusia sa tlačiť 3 farby na seba - ušetrí sa na drahých farebných náplniach
Čierna sa tlačí samostatne

CMYK (K, blacK)
K* = min(1-R,1-G,1-B)
C = 1 - R - uK*
M = 1 - G - uK*
Y = 1 - B - uK*
K = bK*
0 ≤ u,b ≤ 1

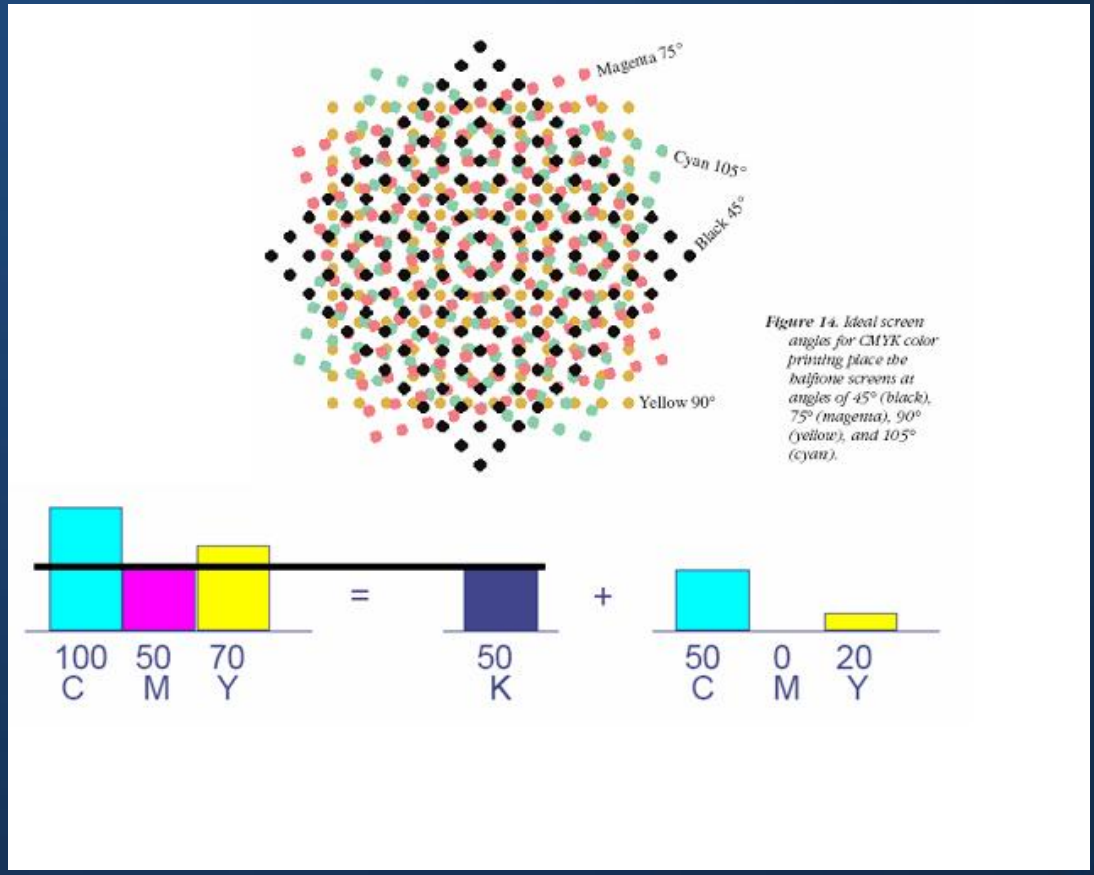
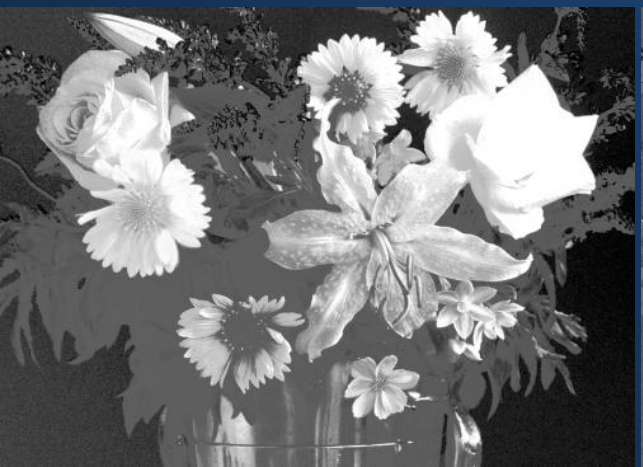
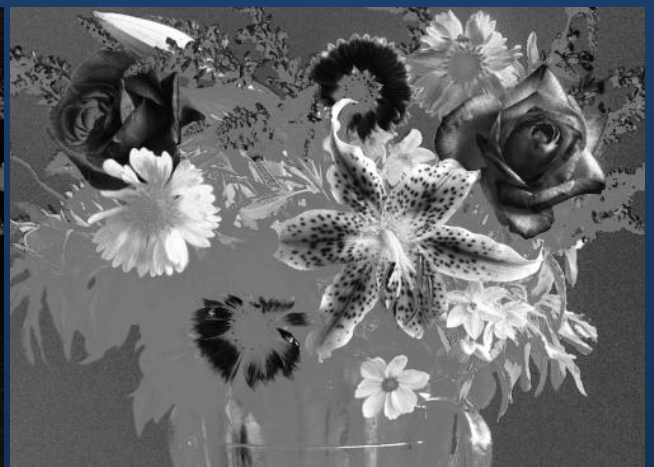


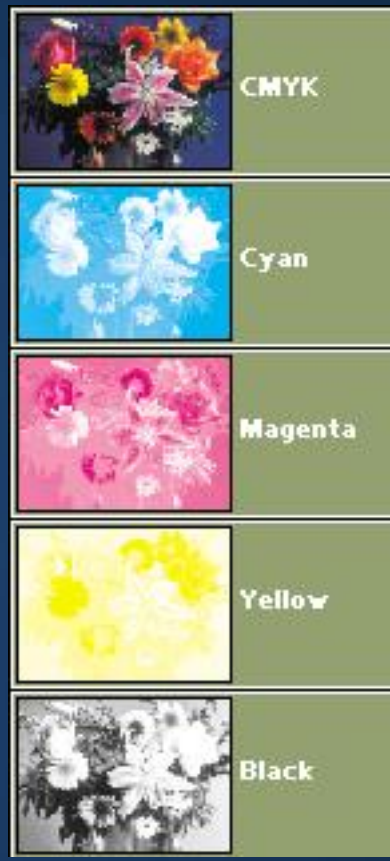
Figure 14. Ideal screen angles for CMYK color printing place the halftone screens at angles of 45° (black), 75° (magenta), 90° (yellow), and 105° (cyan).

K

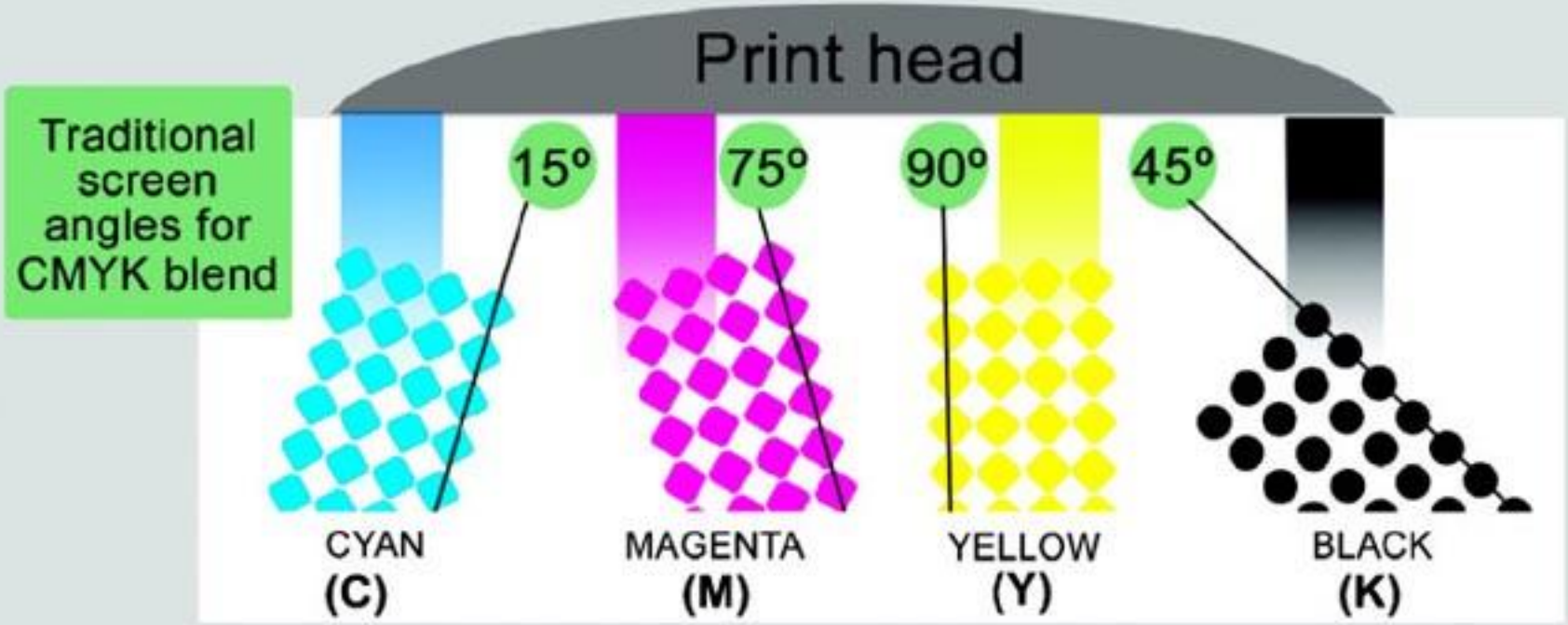
C M Y





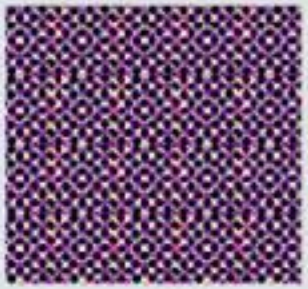


Four color process printing



CMYK combined to create a blend

Reduced



Reduced further

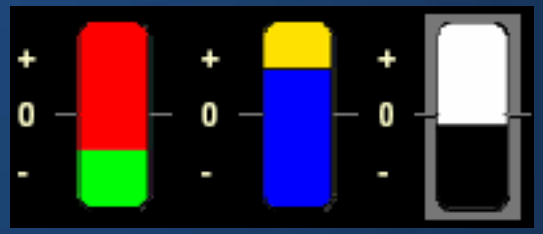
section of final image

Four color process separations

Separating an image into the four process colors

MODELY FARIEB “TRIEDY Y”

Televízne a video štandardy
YIQ – NTSC
YUV – PAL
YCbCr – digital video
YPbPr – analógová TV
YCC – Kodak

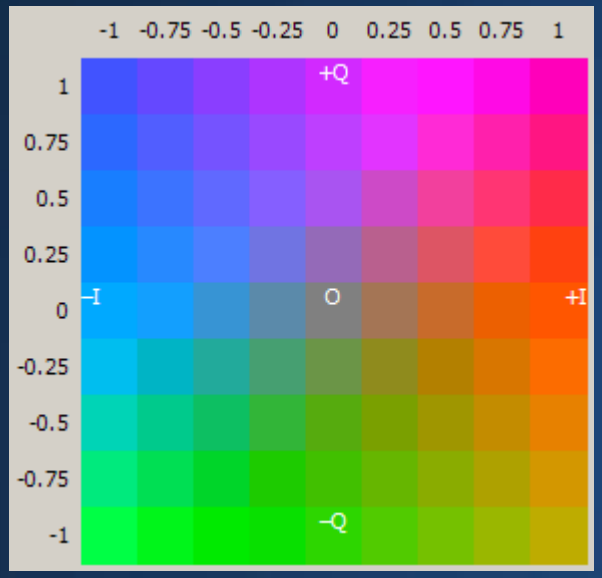


Farebná zložka oddelená od jasovej (Y)
Farebná zložka: zeleno/červený kanál
modro/žltý kanál

Vo všeobecnosti:

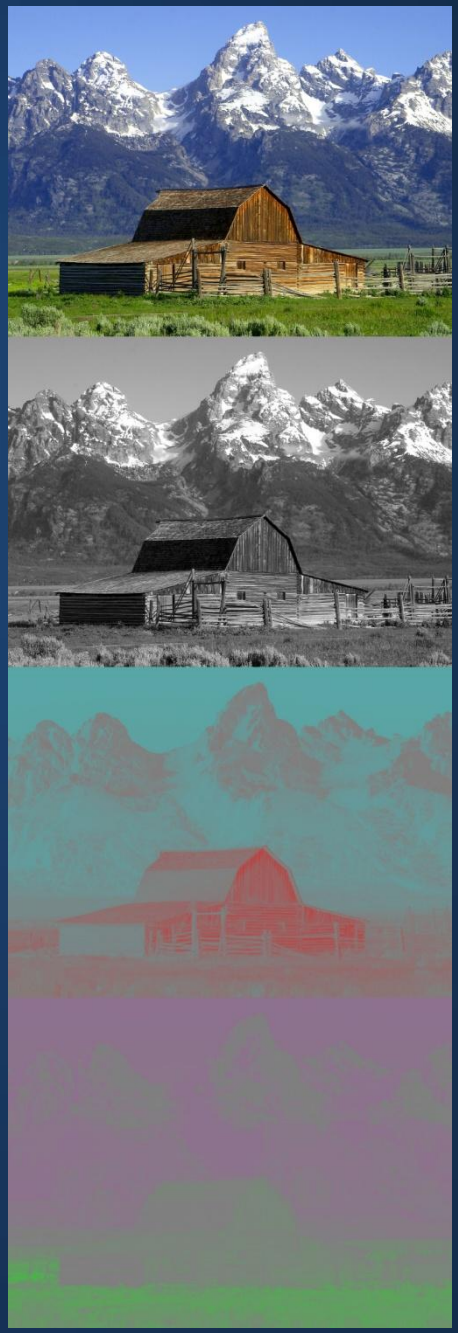
$$\begin{aligned} Y' &= 0.299R' + 0.587G' + 0.114B' \\ C_1 &= a_1(R' - Y') + b_1(B' - Y') \\ C_2 &= a_2(R' - Y') + b_2(B' - Y'), \end{aligned}$$

$$\begin{bmatrix} Y' \\ C_1 \\ C_2 \end{bmatrix} = M * \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$



YIQ

Y – luma
I - in-phase, (orange-blue range)
Q – quadrature (purple-green range)



- 1950 NTSC štandard
- kompatibilita s jednofarebným TV
- väčšia šírka pásma pre Y ako pre I Q.
- oddelená jasová zložka – manipulácia bez ovplyvnenia farebnej zložky (histogram equalization)
- vnemovo neuniformné – Euklidovská vzdialenosť nefunguje
- Gama korekcia aplikovaná na lineárny RGB, vážený súčet nelineárnych komponentov RGB -> luma Y

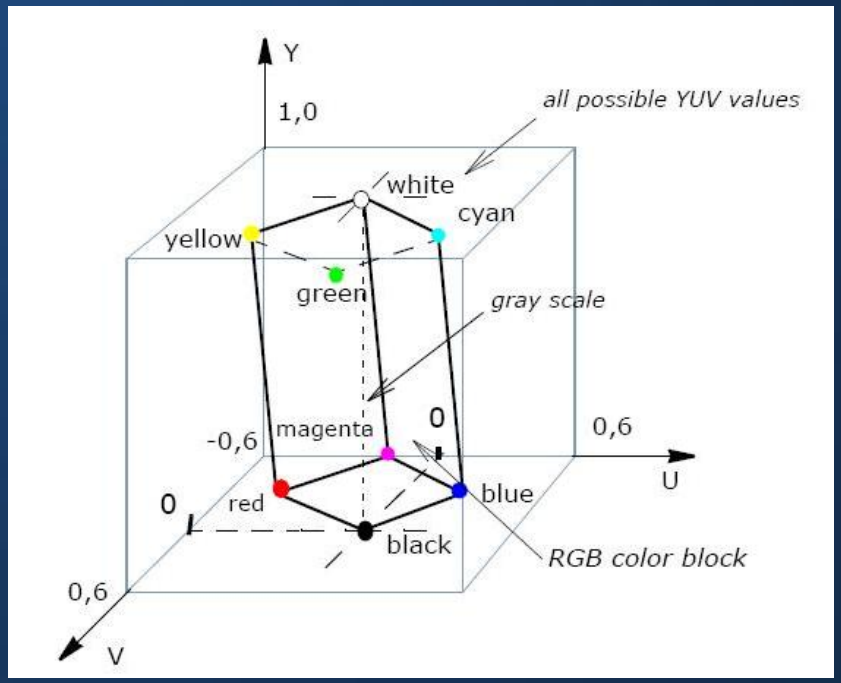
YUV - PAL

Podobne ako YIQ
YUV vzorkovacie formáty 4:4:4, 4:2:2, and 4:2:0

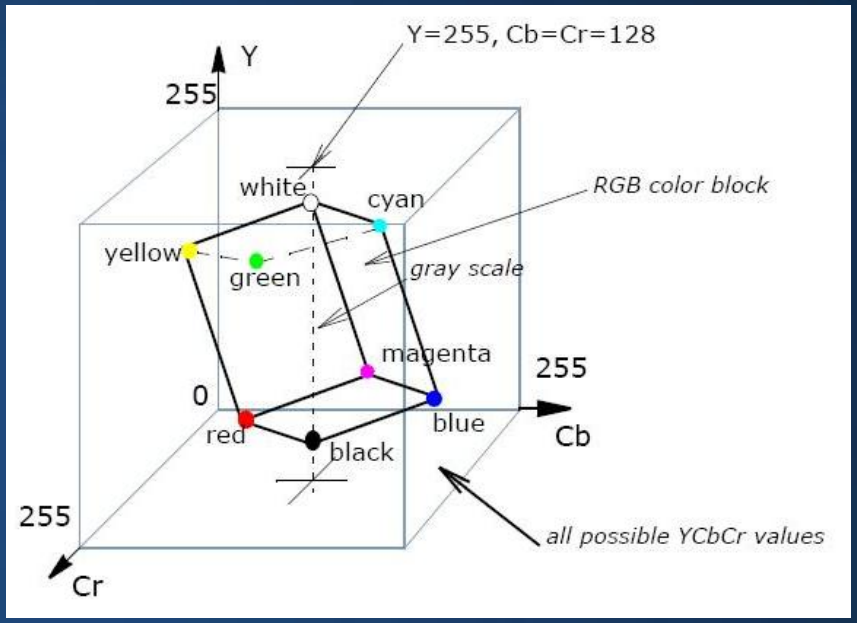
Y U V – vypočítané z RGB s gama korekciou (R G B)

Y'= 0.299*R' + 0.587*G' + 0.114*B'
U'= 0.492*(B'- Y')
V'= 0.877*(R'- Y')

R' = Y' + 1.140*V'
G' = Y' - 0.394*U' - 0.581*V'
B' = Y' + 2.032*U'



YC_bC_r a YCCK



- **YCbCr** component digital video
- Popísané v štandarde ITU-R BT.601
- YCbCr je škálovaná a posunutá verzia YUV
- Y'Cb'Cr' vypočítané z RGB s gama korekciou (R G B)

- **YCCK** – špeciálne pre JPEG kompresiu obrazu
- Je variáciou YCrCb modelu s pridaným K (black) kanálom

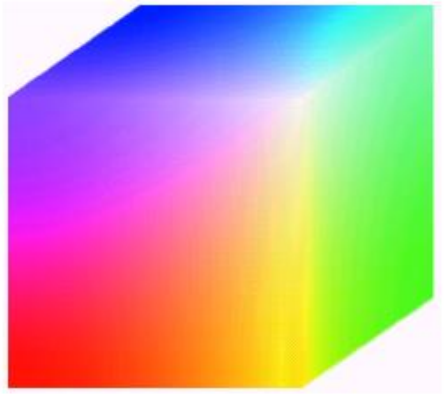
LINEÁRNE VZŤAHY

Color space	Matrix/cefficients
YC_bC_r	$\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.168736 & -0.331264 & 0.5 \\ 0.5 & -0.418668 & -0.081312 \end{bmatrix}$
YCC	$\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.299 & -0.587 & 0.886 \\ 0.701 & -0.587 & -0.114 \end{bmatrix}$
YIQ	$\begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.59597799 & -0.27417610 & -0.32180189 \\ 0.21147017 & -0.52261711 & 0.31114694 \end{bmatrix}$
YUV	$a_1 = 0 \quad b_1 = 1/2.03$ $a_2 = 1/1.14 \quad b_2 = 0$

Polárne súradnice

$$Hue = \tan^{-1}\left(\frac{C_2}{C_1}\right)$$

$$Saturation = \sqrt{C_1^2 + C_2^2}.$$



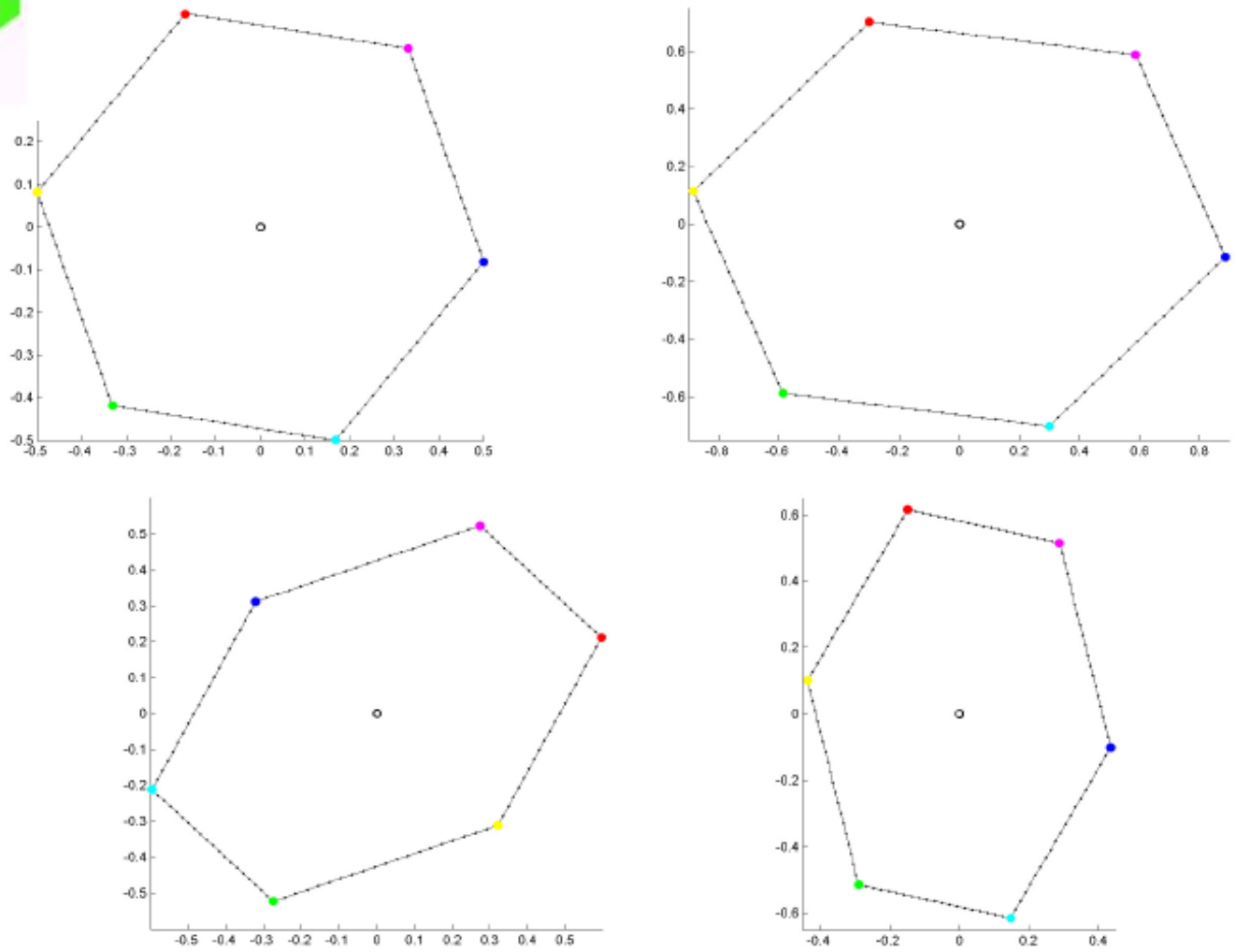


Figure 1.18: Class Y' color spaces. Projection along the Y' axis. a) YC_bC_r, b) YCC, c) YIQ, d) YUV.

YIQ

Y

I

Q

Color space	Color mixing	Primary parameters	Used for	Pros and cons
RGB	Additive	Red, Green, Blue		Easy but wasting bandwidth
CMYK	Subtractive	Cyan, Magenta, Yellow, Black	Printer	Works in pigment mixing
YCbCr YPbPr	additive	Y(luminance), Cb(blue chroma), Cr(red chroma)	Video encoding, digital camera	Bandwidth efficient
YUV	additive	Y(luminance), U(blue chroma), V(red chroma)	Video encoding for NTSC, PAL, SECAM	Bandwidth efficient
YIQ	additive	Y(luminance), I(rotated from U), Q(rotated from V)	Video encoding for NTSC	Bandwidth efficient

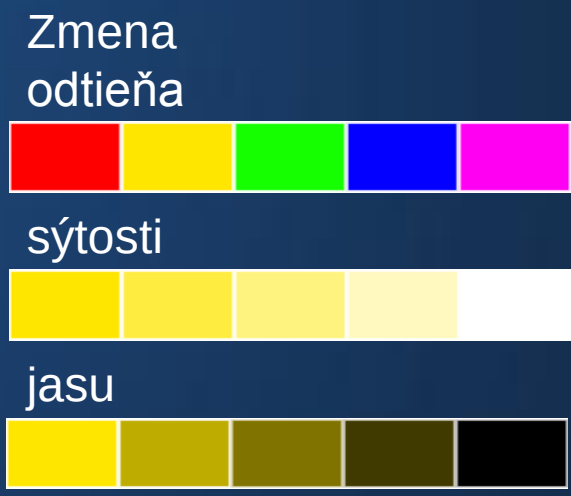
UŽÍVATEĽSKY ORIENTOVANÉ MODELY

Analógia s maliarskym pohľadom (odtieň, sýtosť, jas)

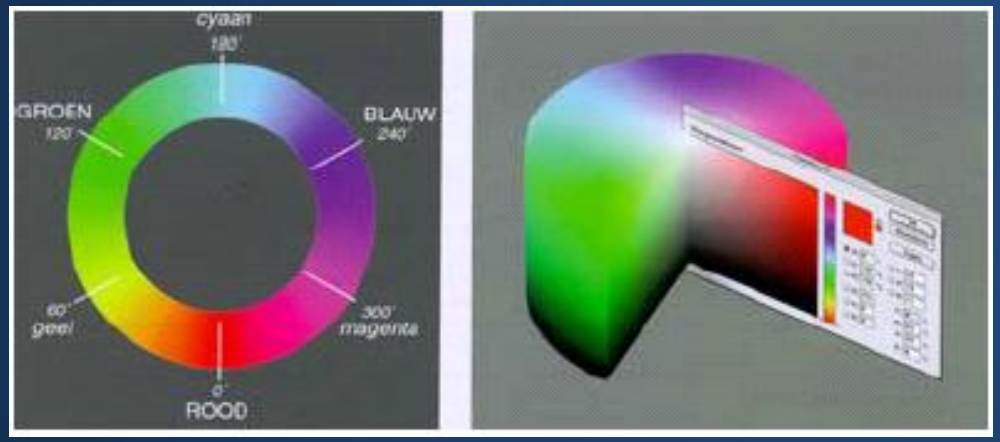
Vhodné pre vizualizáciu (color maps)

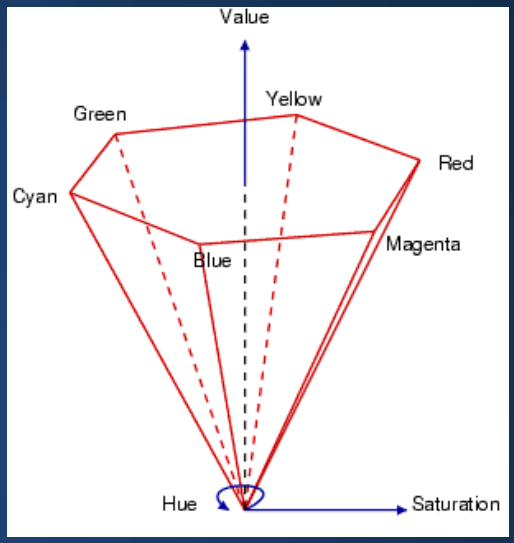
Nelineárny prevod z/do RGB

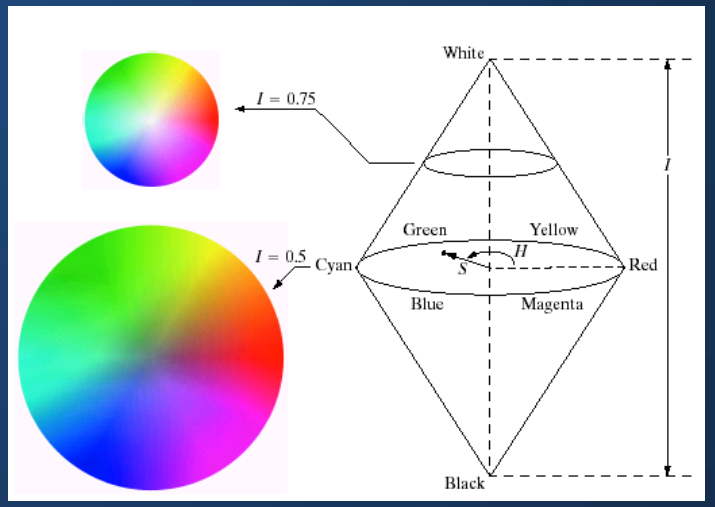
Tvar: kužeľ (aj dvojitý), ihlan, niekedy valec

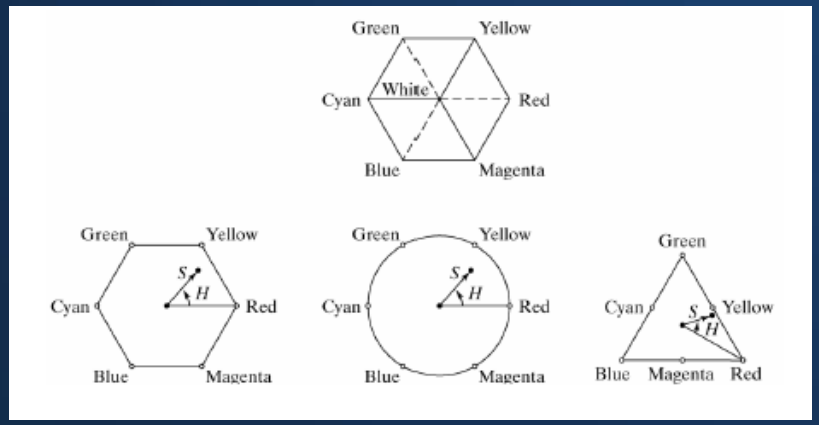


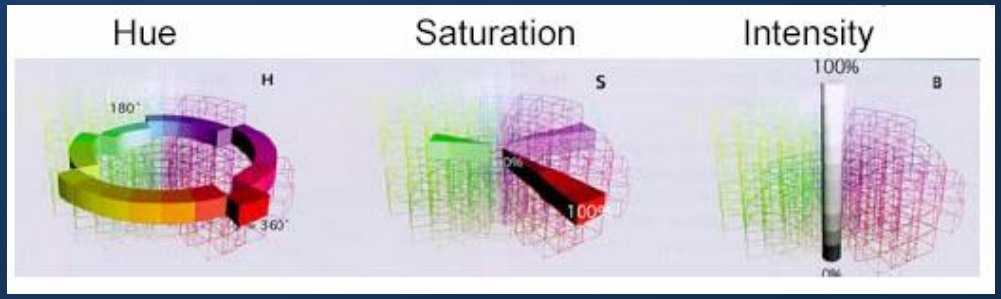
TVARY


cyaan
180°
GROEN
120°
BLAUW
240°
60°
geel
300°
magenta
0°
ROOD

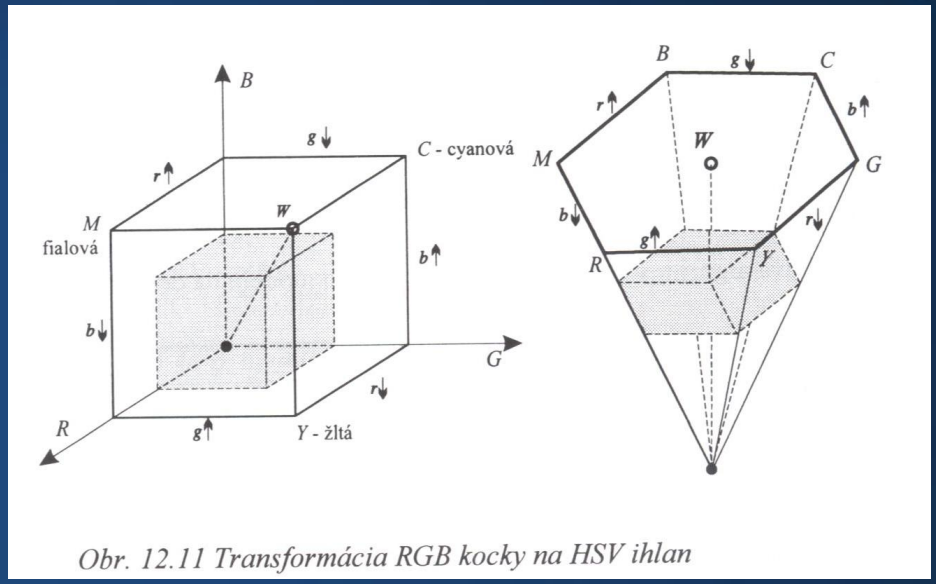

Value
Green
Yellow
Red
Cyan
Magenta
Blue
Hue
Saturation


I = 0.75
I = 0.5
White
Green
Yellow
Cyan
Red
Blue
Magenta
Black
I
H
S


Green
Yellow
Cyan
White
Red
Blue
Magenta
S
H

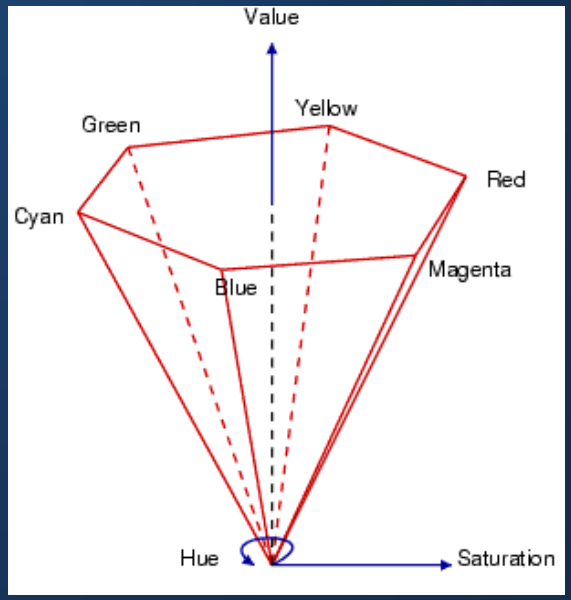

Hue
Saturation
Intensity
H
S
B
180°
360°
100%

RGB → HSV



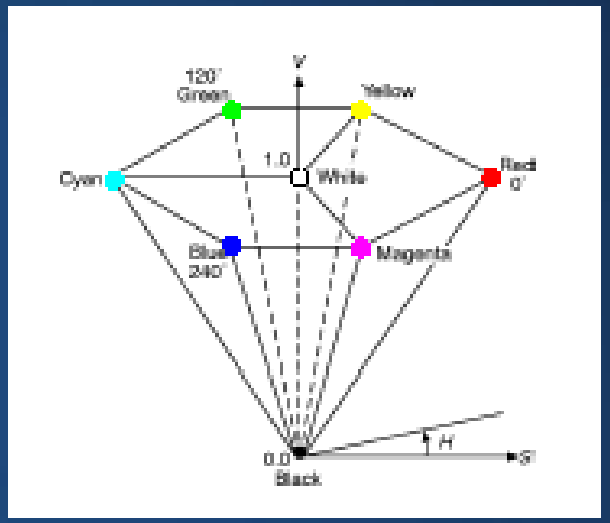
Obr. 12.11 Transformácia RGB kocky na HSV ihlan

max(R,G,B)
min(R,G,B)
V = max
S = (max-min)/max A = π/3(max-min)
H = (G-B)A ak max = R
(B-R)A ak max = G
(R-G)A ak max = B



ak max = 0, S nie je definovaná
ak *R* = *G* = *B*, H nie je definovaná

HSV → RGB



I = floor(3H/π)
f = H-I
p = V(1-S)
q = V(1-Sf)
t = = V(1-S(1-f))

[R G B] = [V t p] ak I = 0
[q V p] ak I = 1
[p V t] ak I = 2
[p q V] ak I = 3
[t p V] ak I = 4
[V p q] ak I = 5
[0 0 0] ak S = 0

HSV PLANES

H

S

V

RGB → HSI

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

$$H = \begin{cases} \theta & \text{for } B \le G \\ 360 - \theta & \text{for } B > G \end{cases}$$

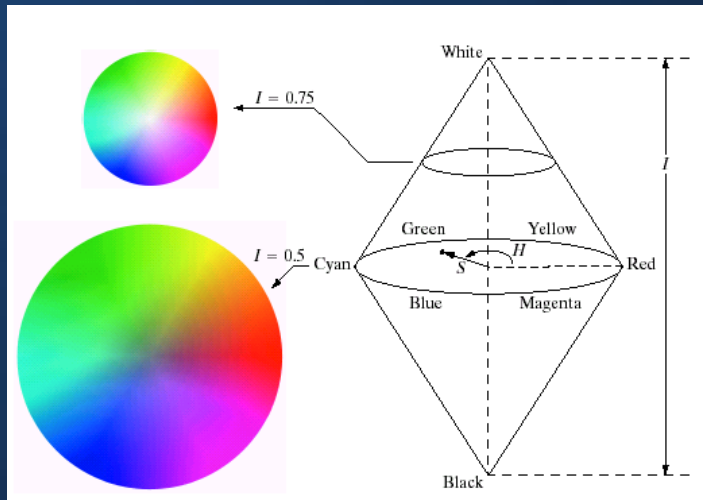
$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2+(R-B)(G-B)]^{\frac{1}{2}}} \right\}$$

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

H – normalizácia do ⟨0,1⟩: $H / 360$

ak $R = G = B$, H nie je definovaná

ak $I = 0$, S nie je definovaná



HSI → RGB

Záleží na tom, v ktorom sektore leží H

RG sektor ($0^0 \le H \le 120^0$):

$$b = \frac{1}{3}(1 - S)$$

$$r = \frac{1}{3}\left[1 + \frac{S\cos(H)}{\cos(60^0 - H)}\right]$$

$$g = 1 - (r + b)$$

GB sektor ($120^0 \le H \le 240^0$):

$$H = H - 120^0$$

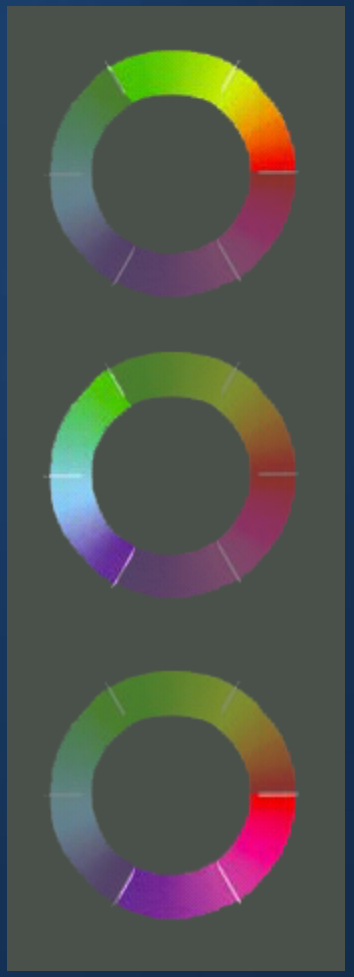
$$g = \frac{1}{3}\left[1 + \frac{S\cos(H)}{\cos(60^0 - H}\right]$$

$$r = \frac{1}{3}(1 - S)$$

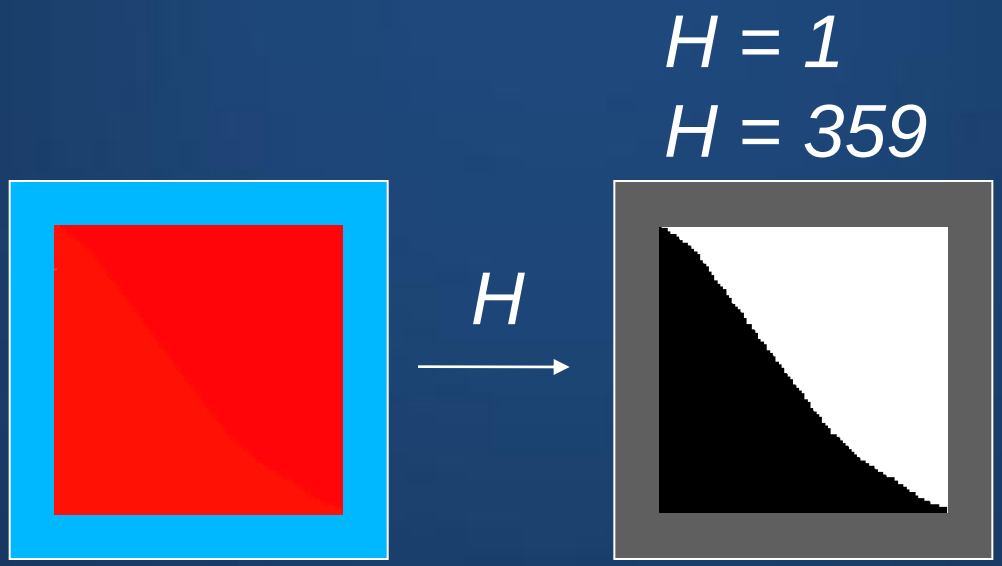
$$b = 1 - (r + b)$$

BR sektor ($240^0 \le H \le 360^0$):

$$g = \frac{1 - S}{3}, \qquad b = \frac{1}{3}\left[1 + \frac{S\cos H}{\cos(60 - H)}\right], \qquad r = 1 - g - b$$



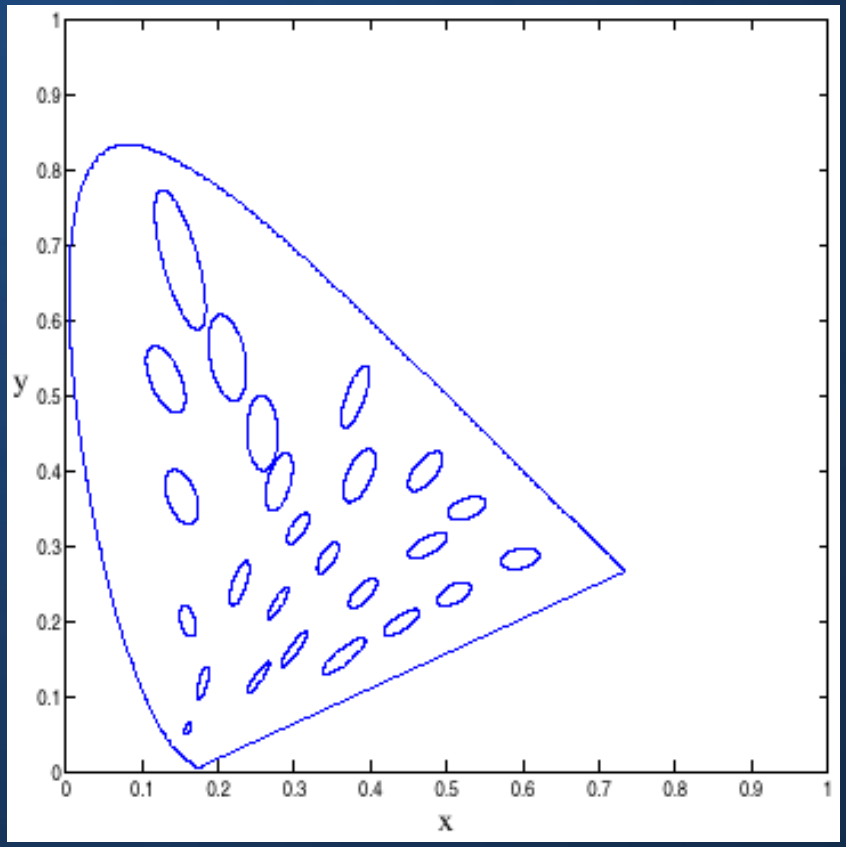
PROBLÉM?



McAdamove elipsy

- *V doteraz spomínaných modeloch:*
- *Euklidovská vzdialenosť farieb nezodpovedá vizuálnej „vzdialenosti“*

McAdamove elipsy v xy – pre pozorovateľa nerozlíšiteľné farby



CIE UVW

Lineárna aproximácia vnemovo rovnomerného priestoru

$$\begin{bmatrix} U \\ V \\ W \end{bmatrix} = \begin{bmatrix} 0.66 & 0 & 0 \\ 0 & 1 & 0 \\ -0.5 & 1.5 & 0.5 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

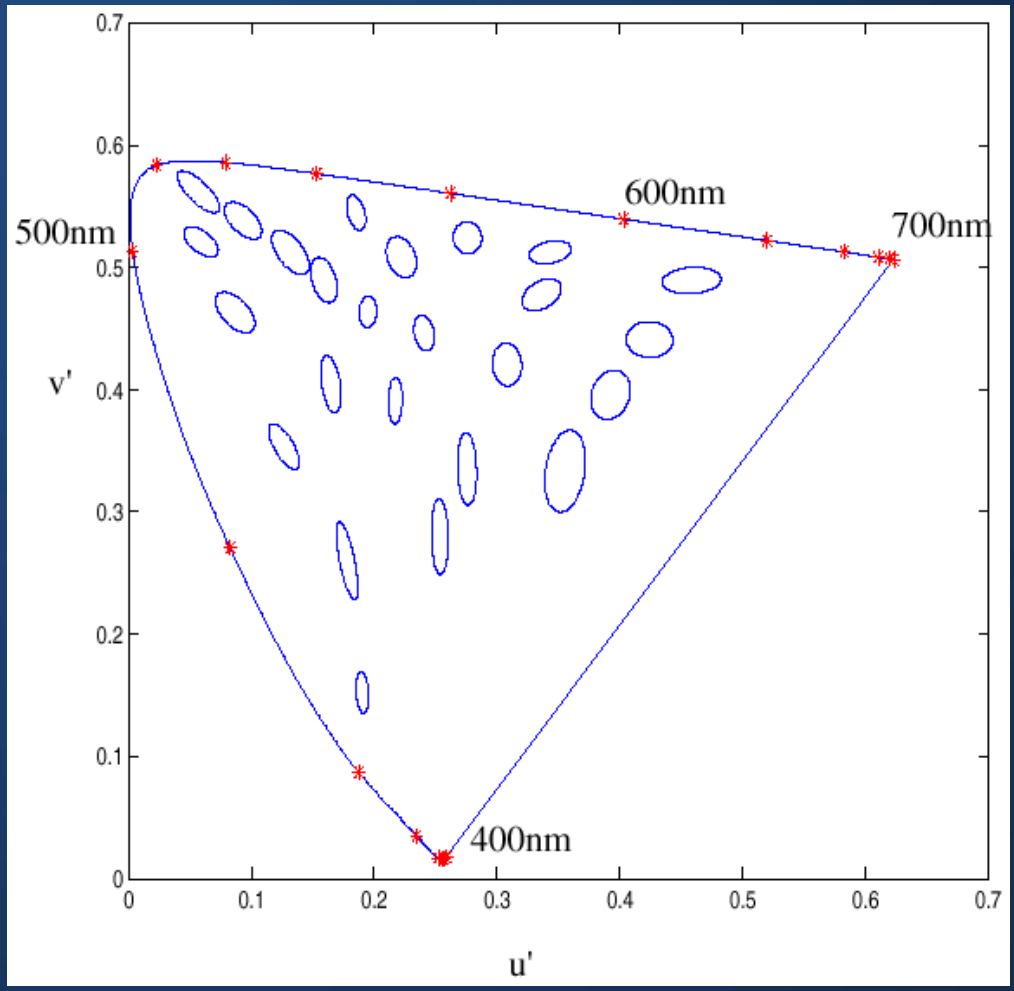
Nerieši problém úplne

$\rightarrow$ nelineárne transformácie

CIE YU'V'

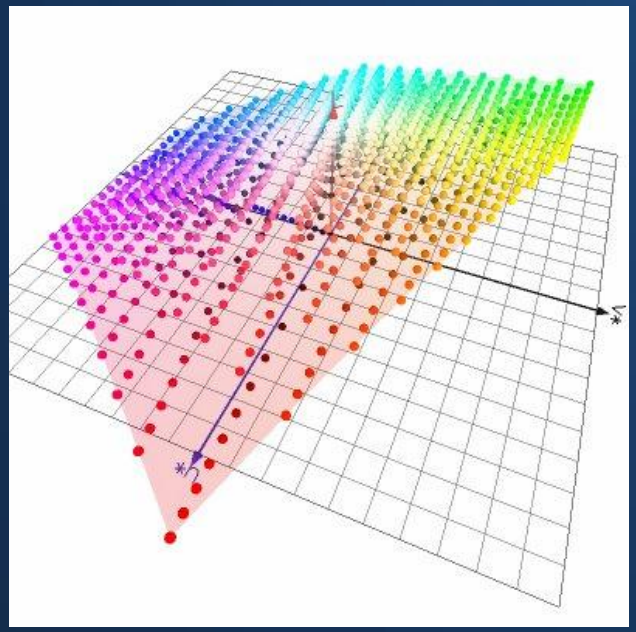
$$u' = \frac{4X}{X+15Y+3Z}$$

$$v' = \frac{9Y}{X+15Y+3Z}$$



CIE L*U*V*

L* - jas
u*, v* - farebné súradnice
n – súradnice bieleho bodu



$$L^* = \begin{cases} 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 & \text{ak } \frac{Y}{Y_n} > 0.008856 \\ 903.3\frac{Y}{Y_n} & \text{ak } \frac{Y}{Y_n} \le 0.008856 \end{cases}$$

$$u^* = 13L^*\left(u' - u'_n\right)$$

$$v^* = 13L^*\left(v' - v'_n\right)$$

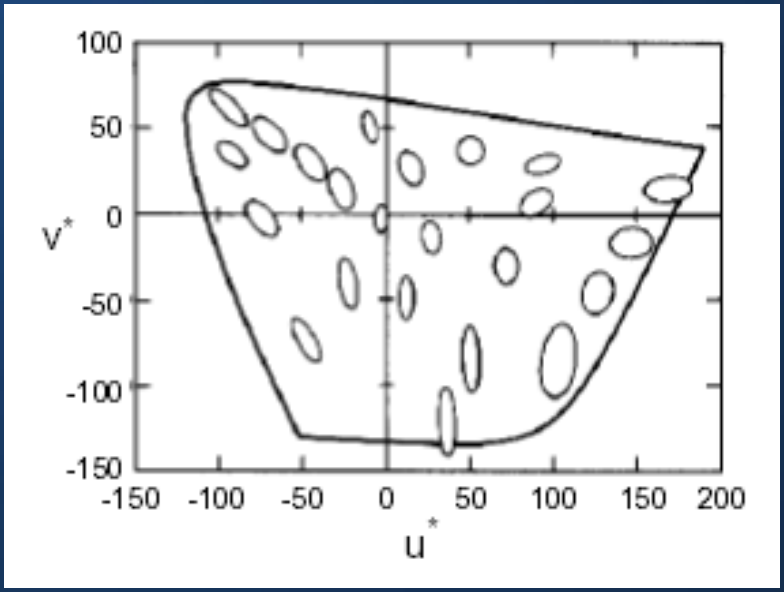
CIE L*U*V*

Polárne súradnice
Farebnosť
Odtieň (u,v>0)

$$C^*_{uv} = \sqrt{u^{*2} + v^{*2}}$$

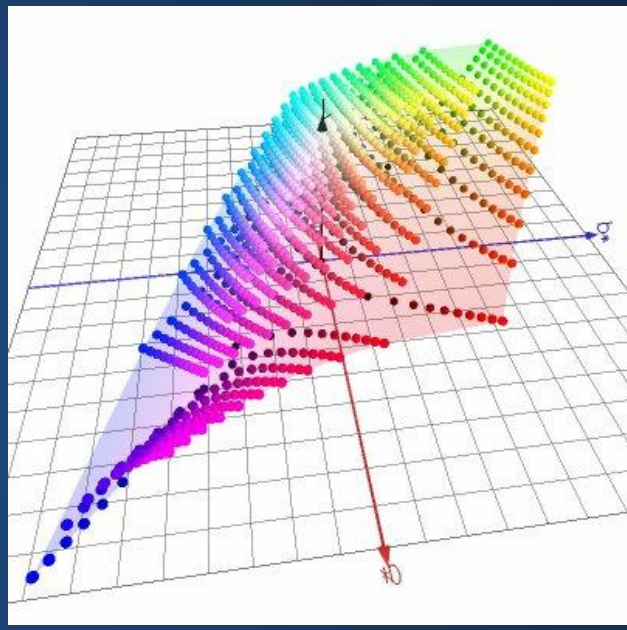
$$h_{uv} = \arctan\left(\frac{v^*}{u^*}\right)$$

McAdamove elipsy



CIE L*A*B*

L* - jas výpočet ako pri CIE L*u*v*
a*, b* - farebné súradnice
n – súradnice bieleho bodu
Používaný v priemysle



$$a^* = 500\left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right)$$

$$b^* = 200\left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right)$$

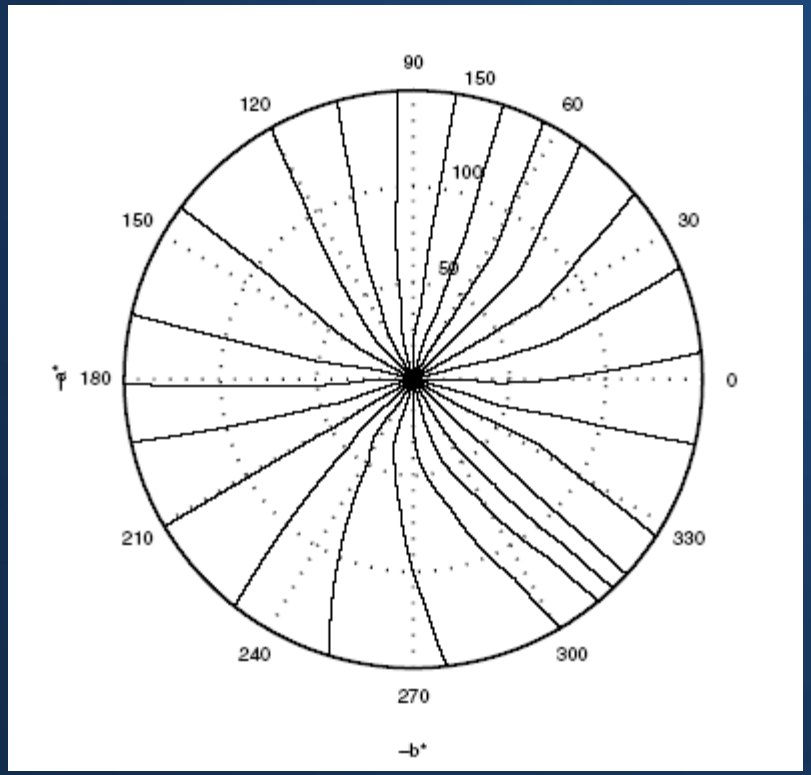
$$f(t) = \begin{cases} t^{\frac{1}{3}} & \text{ak } t > 0.008856 \\ 7.787t + \frac{16}{116} & \text{ak } t \le 0.008856 \end{cases}$$

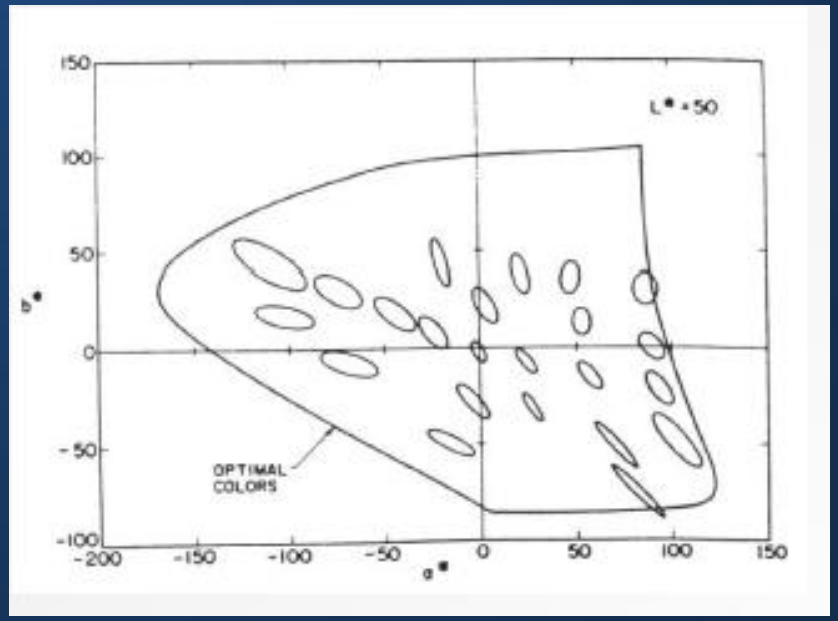
CIE L*A*B*

Polárne súradnice
Farebnosť
Odtieň (a,b>0)

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$$

$$h_{ab} = \arctan\left(\frac{b^*}{a^*}\right)$$

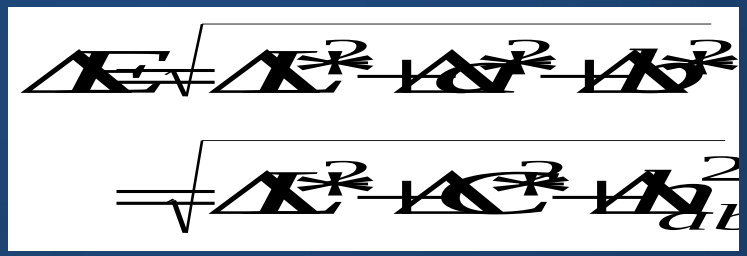




VZDIALENOSŤ FARIEB

Euklidovská vzdialenosť

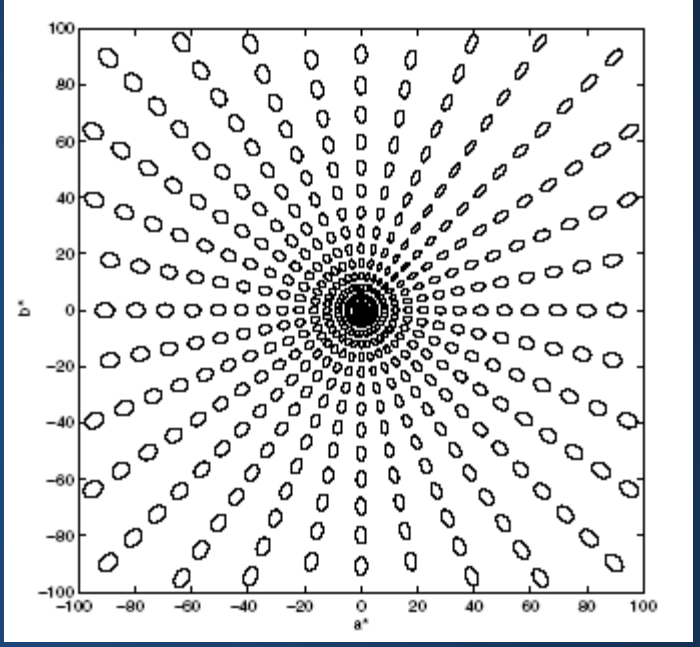
CIE L*a*b*



CIE L*u*v* podobne

ΔE^*_{Lab}	Effect
< 3	Not perceptible
$3 < 6$	Perceptible, but acceptable
> 6	Not acceptable

VZDIALENOSŤ FARIEB



$$\Delta E = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H^*}{k_H S_H}\right) + R_T \phi(\Delta C^* \Delta H^*)} \qquad (1.43)$$

where k_L, k_C, k_H = positive, real-valued scaling parameters chosen based on the application where the formula is used

S_L, S_C, S_H = lightness-, chroma-, and hue-dependent scaling functions, respectively

R_T = an additional scaling function that depends on chroma and hue

NEKORELOVANÉ MODELY

Farebné zložky (vo väčšine modelov)

- korelované (medzi sebou a najmä s jasovou zložkou)
- s malou varianciou (nízkou možnosťou diskriminácie objektov)

Nové modely, kde zložky nie sú korelované

NEKORELOVANÉ MODELY

$K_1K_2K_3$ - Karhunen-Loeve transformácia (výpočtovo náročná, kovariančná matica, vlastné vektory, ...)
Dátovo závislá – pre každý obrázok treba novú transformačnú maticu

$$\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \begin{bmatrix} u_{11} & u_{12} & u_{13} \\ u_{12} & u_{22} & u_{23} \\ u_{13} & u_{23} & u_{33} \end{bmatrix} \begin{bmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{32} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} = \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix}$$

INÉ FAREBNÉ MODELY

$$
\begin{aligned}
T &= \arctan(r'/g')/\pi + 1/2 \\
S &= [9/5(r'^2 + g'^2)]^{1/2} \\
V &= (R+G+B)/3,
\end{aligned}
$$

$r' = (r - 1/3)$

$g' = (g - 1/3)$

„uhlový“ model

$$
T = \begin{cases} \arctan(r'/g')/2\pi + 1/4 & g' > 0 \\ \arctan(r'/g')/2\pi + 3/4 & g' < 0 \\ 0 & g' = 0 \end{cases}
$$

$$
\begin{aligned}
S &= [9/5(r'^2 + g'^2)]^{1/2} \\
L &= 0.299R' + 0.587G' + 0.114B',
\end{aligned}
$$

I1I2I3 (Ohta) – oponent model
lineárna transformácia

$$
\begin{aligned}
I_1 &= (R+G+B)/3 \\
I_2 &= R - G \\
I_3 &= B - \frac{R+G}{2}.
\end{aligned}
$$

„Modrá = 0“

$$
\begin{bmatrix} I \\ V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ \frac{-1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & \frac{2}{\sqrt{6}} \\ \frac{1}{\sqrt{6}} & \frac{-1}{\sqrt{6}} & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}
$$

$$
H = \arctan\left\{\frac{V_2}{V_1}\right\}
$$

$$
S = (V_1^2 + V_2^2)^{1/2}
$$

Log oponent model

$$
\begin{aligned}
L(x) &= 105 \log_{10}(x + 1 + n) \\
I &= L(G) \\
R_g &= L(R) - L(G) \\
B_y &= L(B) - \frac{L(G) + L(R)}{2},
\end{aligned}
$$

$$
\begin{aligned}
L &= (R+1)^{0.3}(G+1)^{0.6}(B+1)^{0.1} - 1 \\
U &= \begin{cases} \frac{M}{2}\frac{R+1}{L+1} & R < L \\ M - \frac{M}{2}\frac{L+1}{R+1} & otherwise \end{cases} \\
X &= \begin{cases} \frac{M}{2}\frac{B+1}{L+1} & B < L \\ M - \frac{M}{2}\frac{L+1}{B+1} & otherwise, \end{cases}
\end{aligned}
$$

contrast enhancement
logarithmic image processing

$$
\hat{U} = \begin{cases} 256\frac{G}{R} & R > G \\ 255 & otherwise. \end{cases}
$$

$$
\begin{bmatrix} Y \\ E \\ S \end{bmatrix} = \begin{bmatrix} 0.253 & 0.684 & 0.065 \\ 0.5 & -0.5 & 0 \\ 0.25 & 0.25 & -0.5 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}
$$

XEROX – IR imagery

Table 1.3. Color Model

Color System	Transform (from RGB)	Component correlation
RGB	-	highly correlated
$R'G'B'$	non linear	
XYZ	linear	correlated
YIQ	linear	uncorrelated
YCC	linear	uncorrelated
I1I2I3	linear	correlated
HSV	non linear	correlated
HSI	non linear	correlated
HLS	non linear	correlated
$L^*u^*v^*$	non linear	correlated
$L^*a^*b^*$	non linear	correlated
Munsell	non linear	correlated

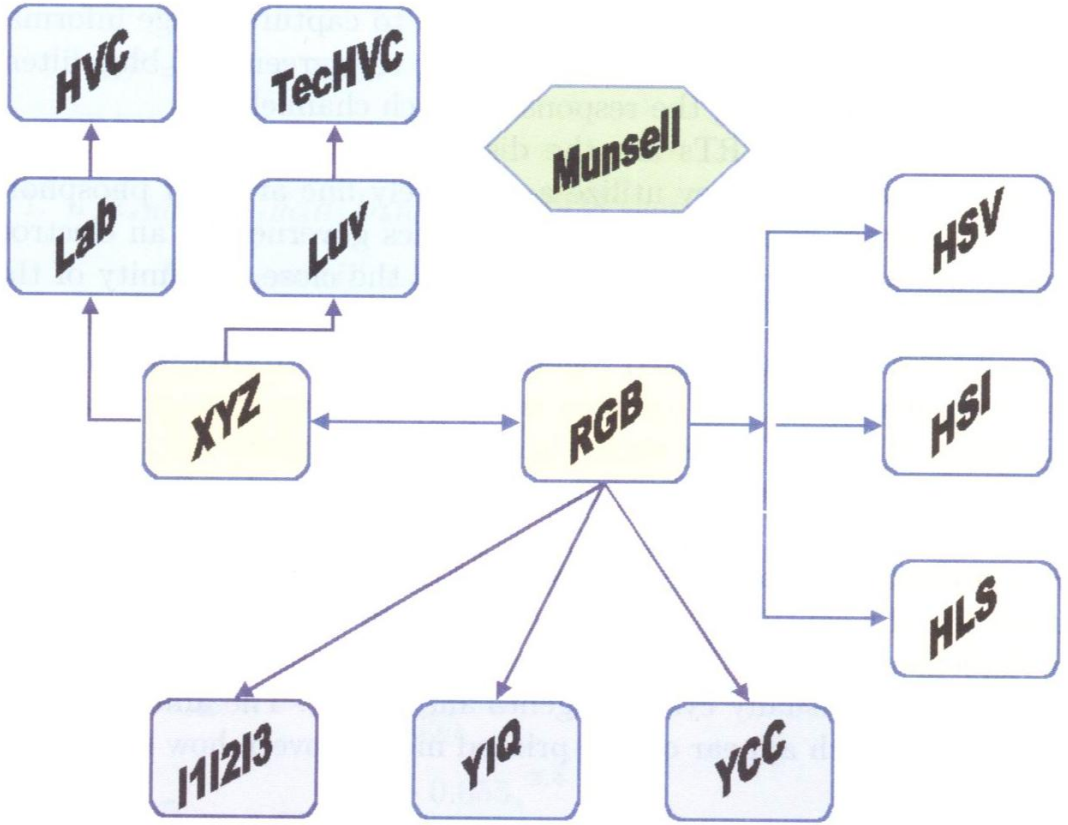
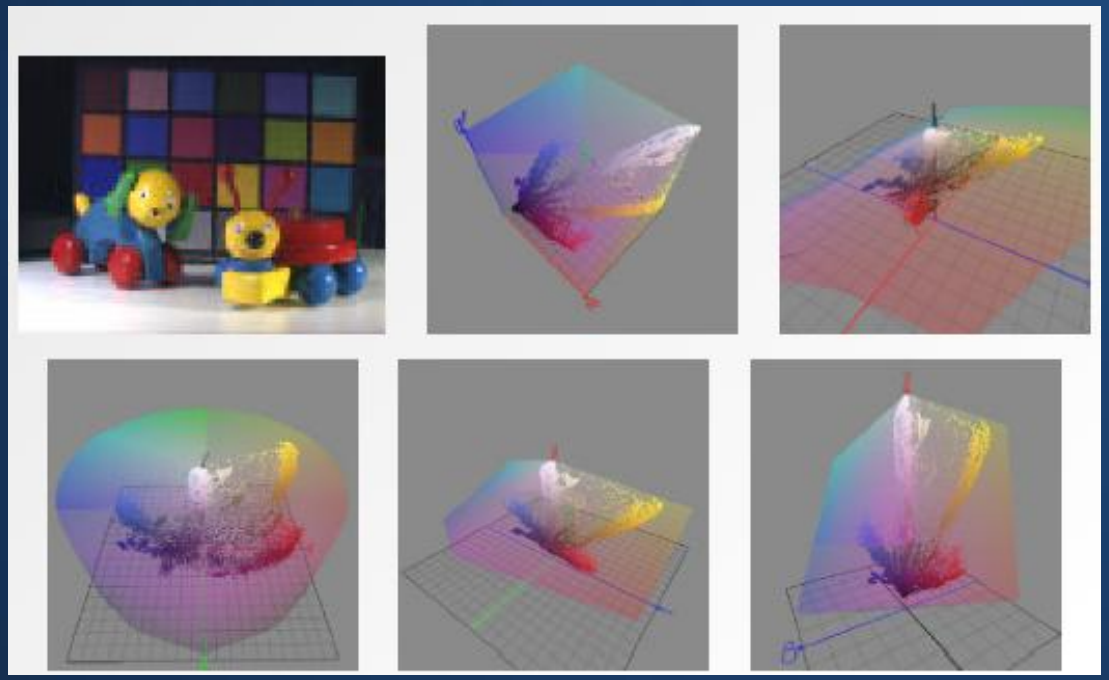
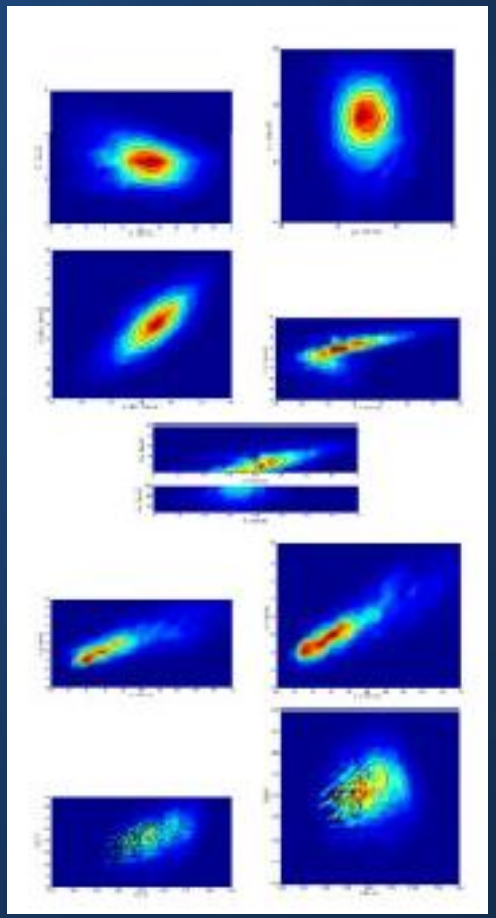


Fig. 1.16. A taxonomy of color models

POUŽITIE MODELOV



Ľudské tváre



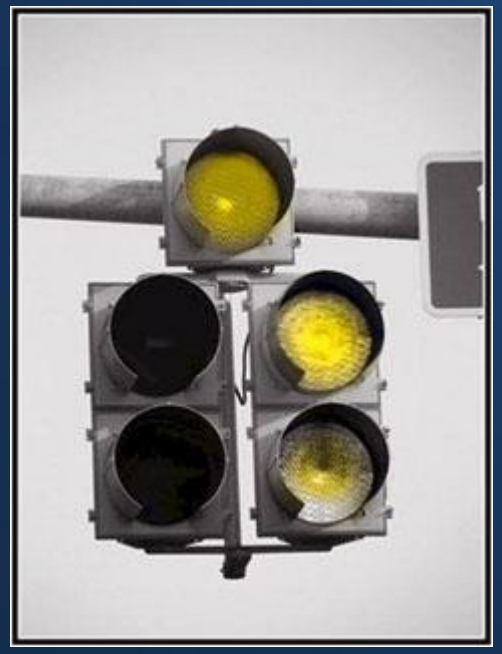
FARBOSLEPOTA

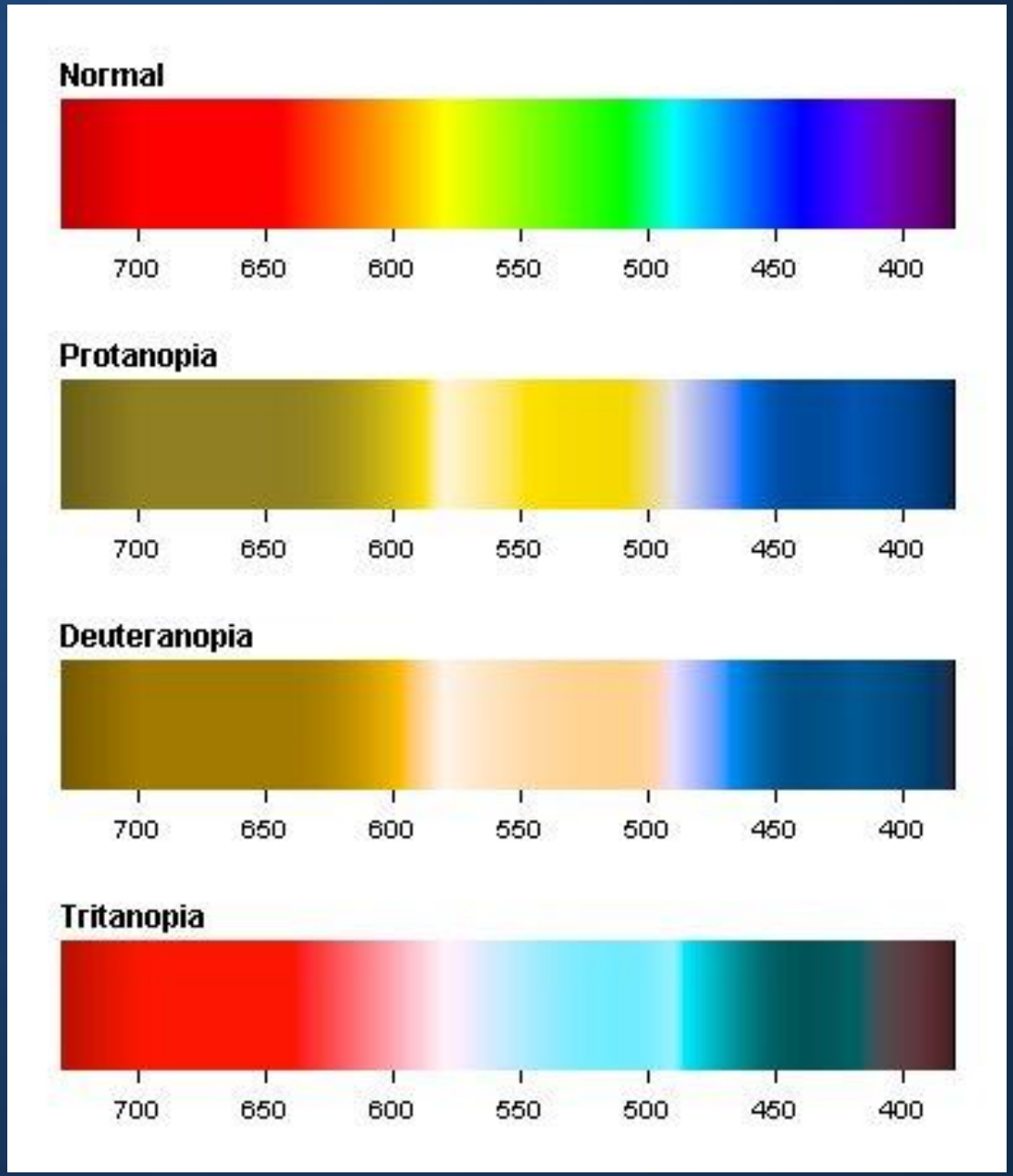
– porucha farbocitu (genetická alebo získaná)

Ku genetickým patria

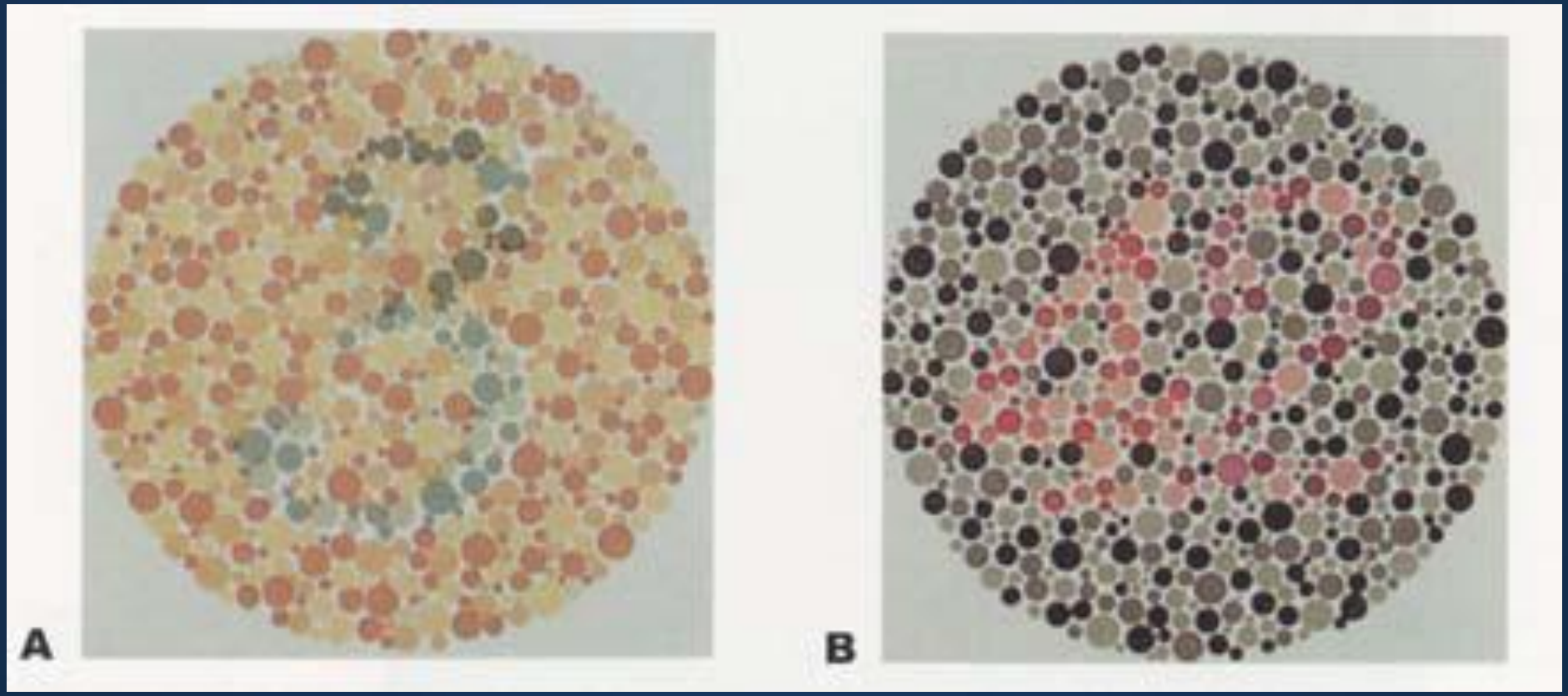
- Dichromázia
  jeden typ čapíkov chýba
  1. protanope nevidí červenú - Daltonizmus,
  2. deuteranope nevidí zelenú,
  3. tritanope nevidí modrú

  Protanopia a deuteranopia = červeno-zelená slepota
  8% mužov a 0.5% žien
- Anomálna trichromázia
  - Znížená citlivosť jedného typu čapíkov => Posunuté vnímanie farieb
- Monochromázia – nerozlišuje farby vôbec




Normal
700
650
600
550
500
450
400
Protanopia
700
650
600
550
500
450
400
Deuteranopia
700
650
600
550
500
450
400
Tritanopia
700
650
600
550
500
450
400

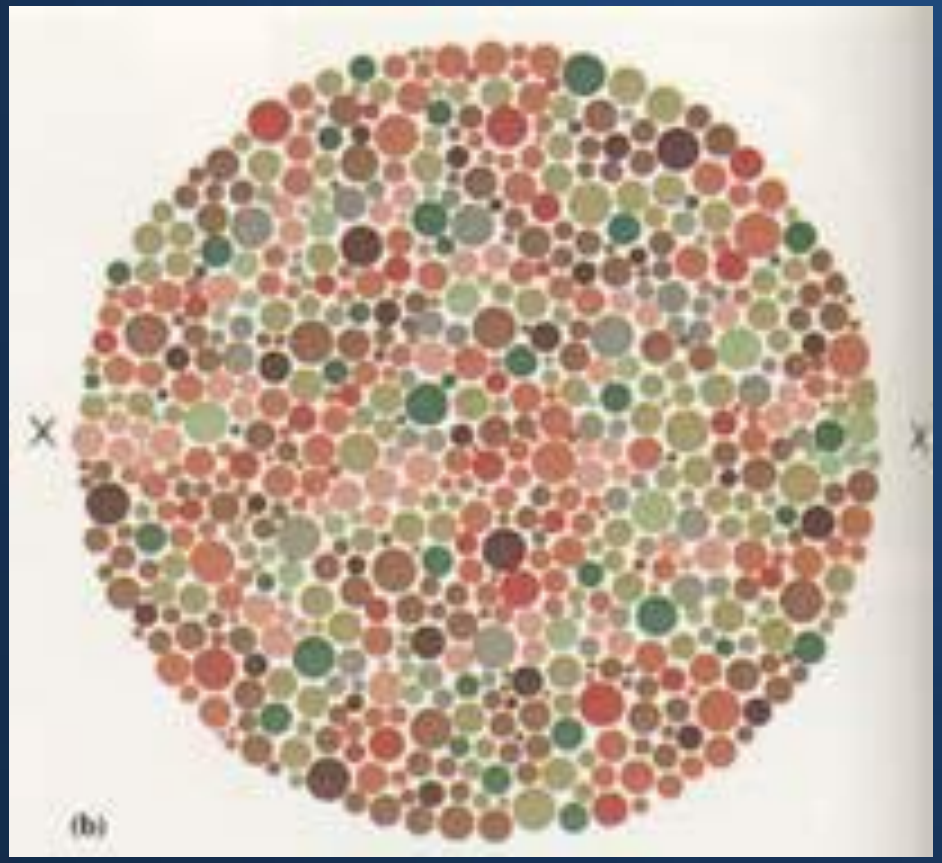
TEST FARBOSLEPOTY

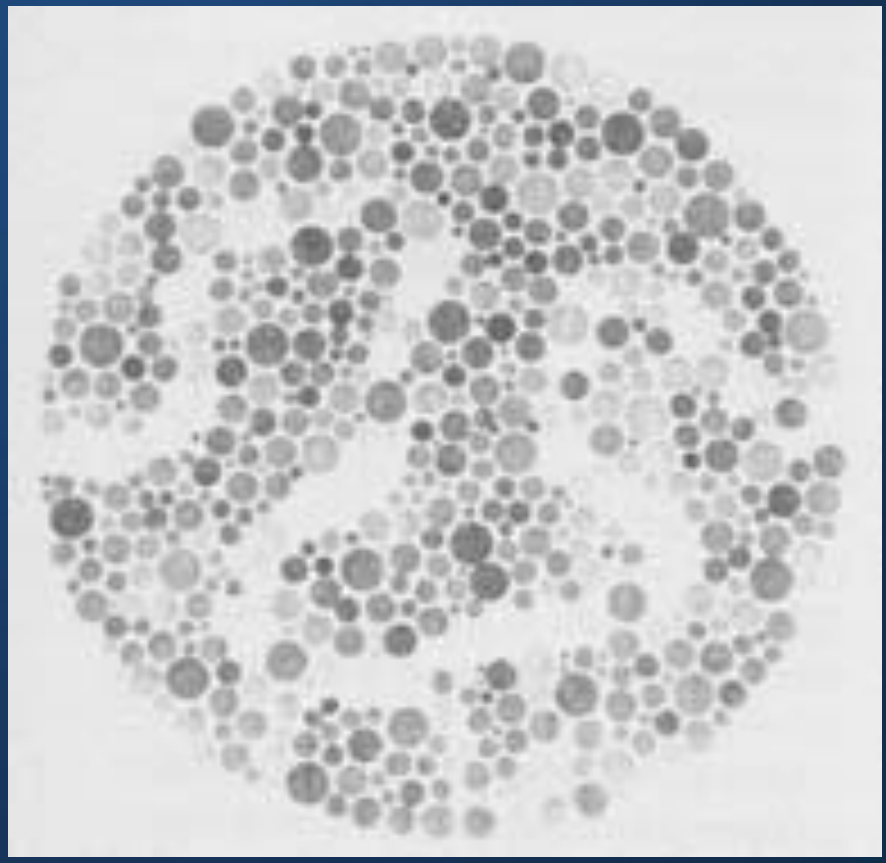


TEST FARBOSLEPOTY

Bludisko v intenzite farieb

- viditeľné len pre farboslepých





Meryon (a colorblind painter), *Le Vaisseau Fantôme*