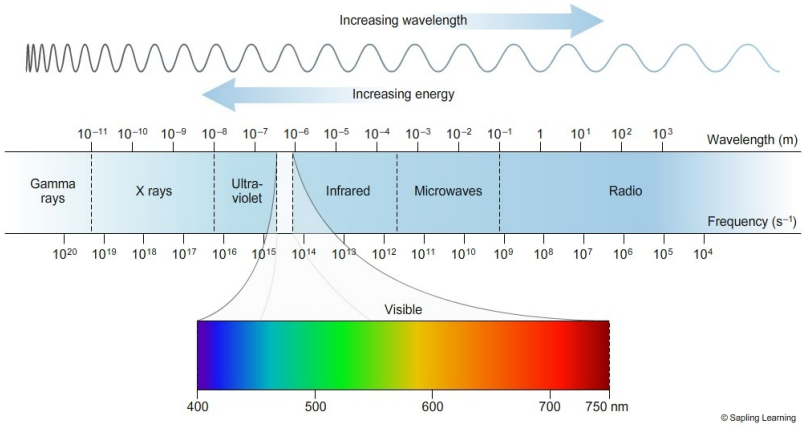
Světlo a barvy v počítačové grafice

Počítačová grafika

Mgr. Markéta Trnečková, Ph.D.

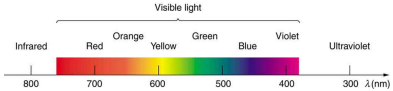
Palacký University, Olomouc

EM spektrum



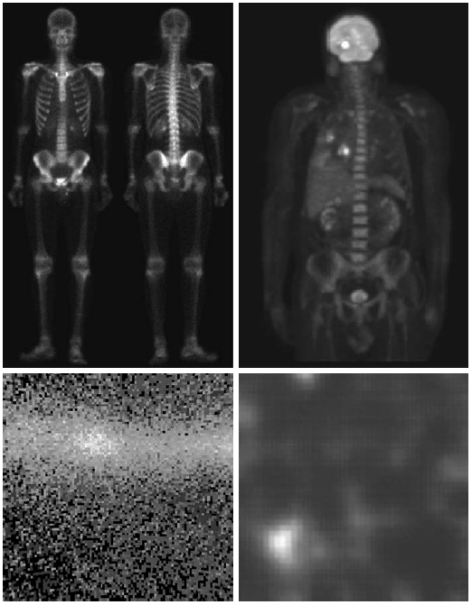
- $\lambda = \frac{c}{f}$, $E = h * f$
- c . . . rychlost světla (300000 km/s)
- h . . . Planckova konstanta ($6.6252 * 10^{-34}$ J*s)

Viditelné světlo

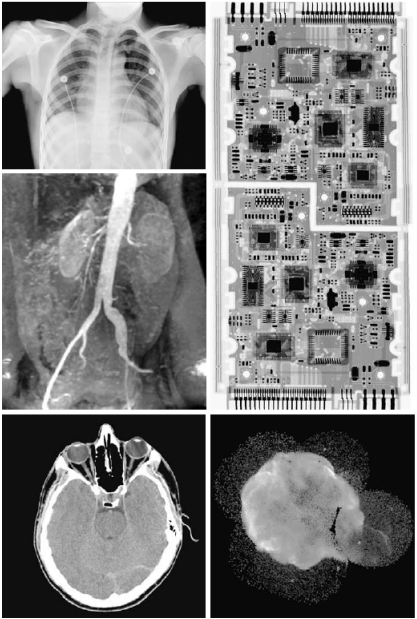


- $380nm$ fialová
- $760nm$ červená

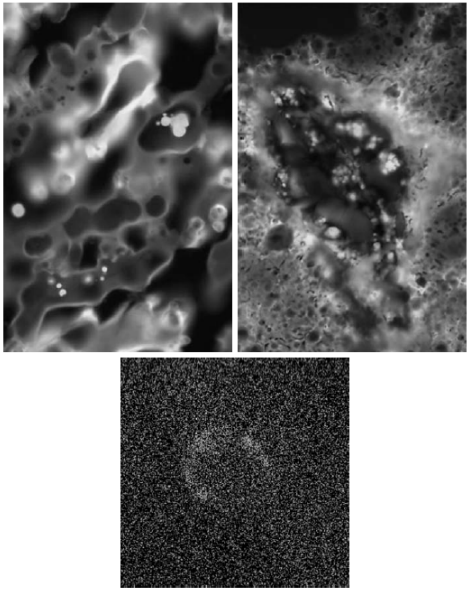
Gamma záření



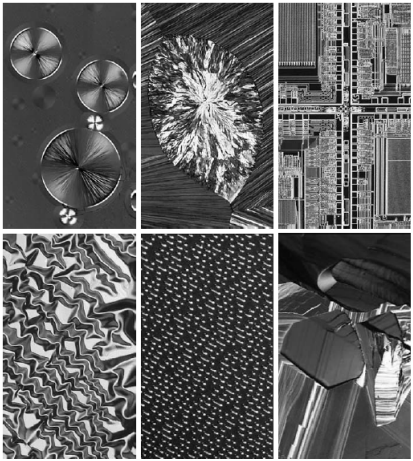
X záření



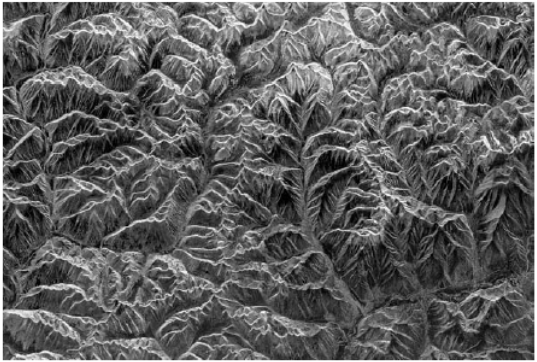
Ultrafialové



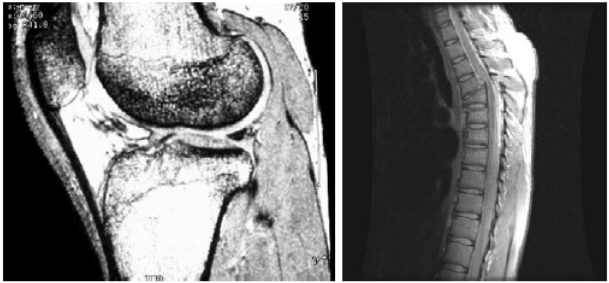
Infračervené



Mikrovlny



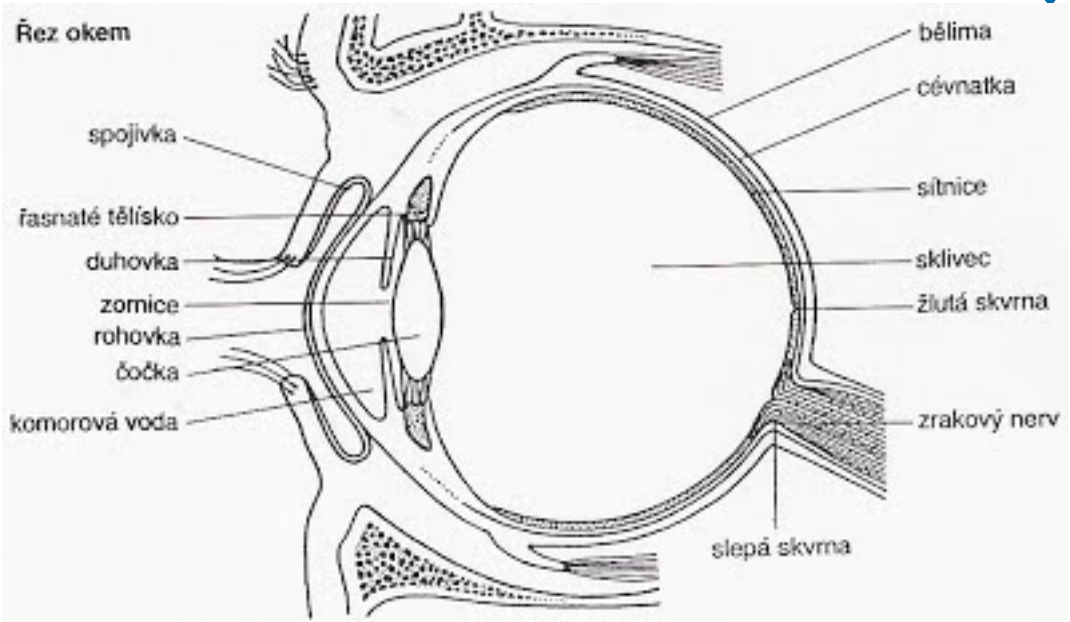
Radiové vlny

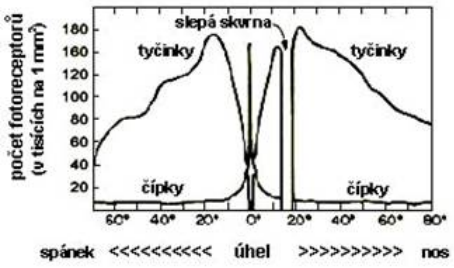


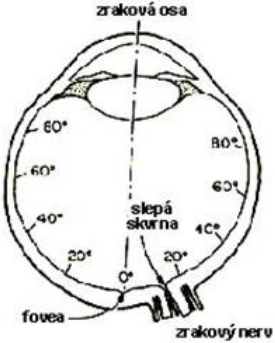
Světlo

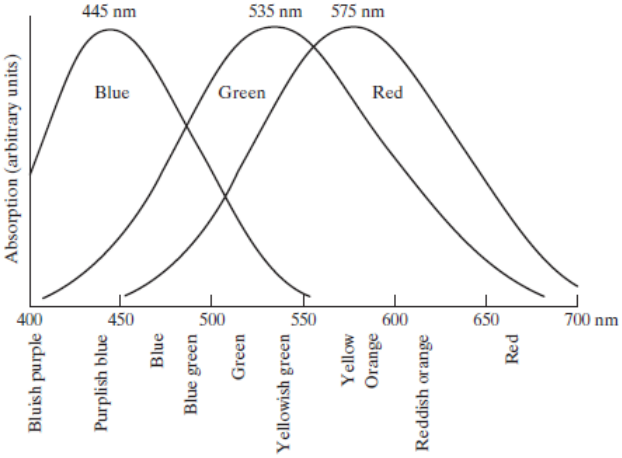
- **Jas** – intensity
- **Sytost** – saturation
- **Světlost** – brightness

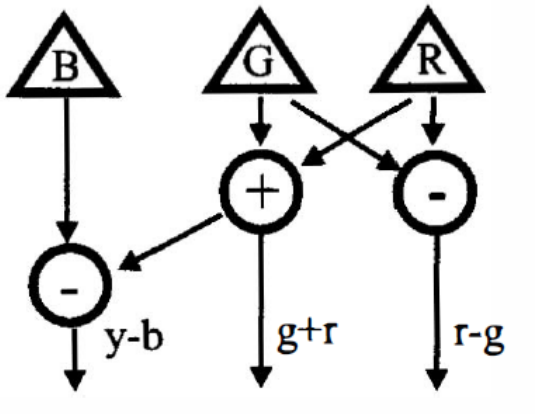
Lidské oko

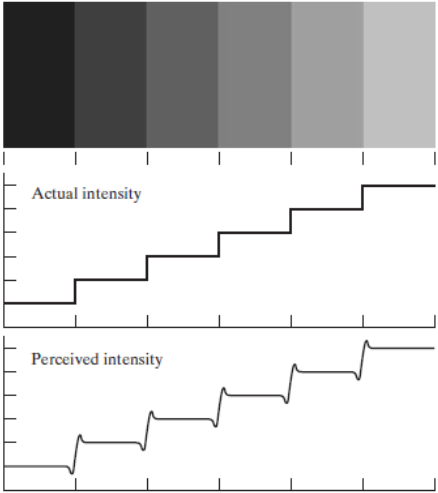

Řez okem
bělima
cévnatka
spojivka
sítnice
řasnaté tělísko
duhovka
sklivec
zornice
žlutá skvrna
rohovka
čočka
komorová voda
zrakový nerv
slepá skvrna

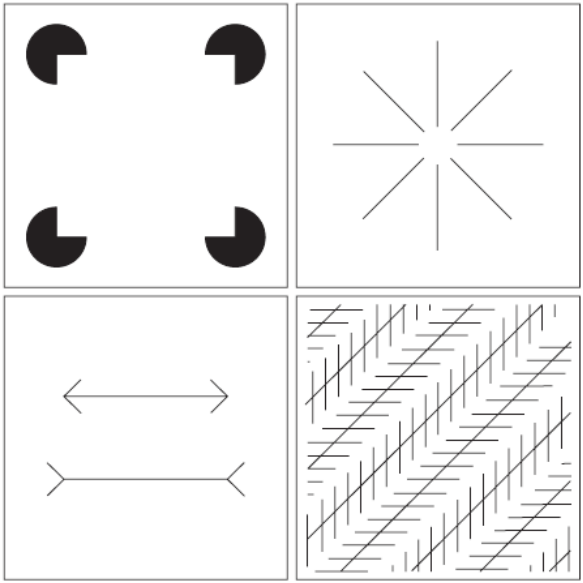

počet fotoreceptorů
(v tisících na 1 mm²)
180
160
120
100
80
60
40
20
slepá skvrna
tyčinky
tyčinky
čípky
čípky
60°
40°
20°
0°
20°
40°
60°
80°
spánek <<<<<<<<<< úhel >>>>>>>>>> nos

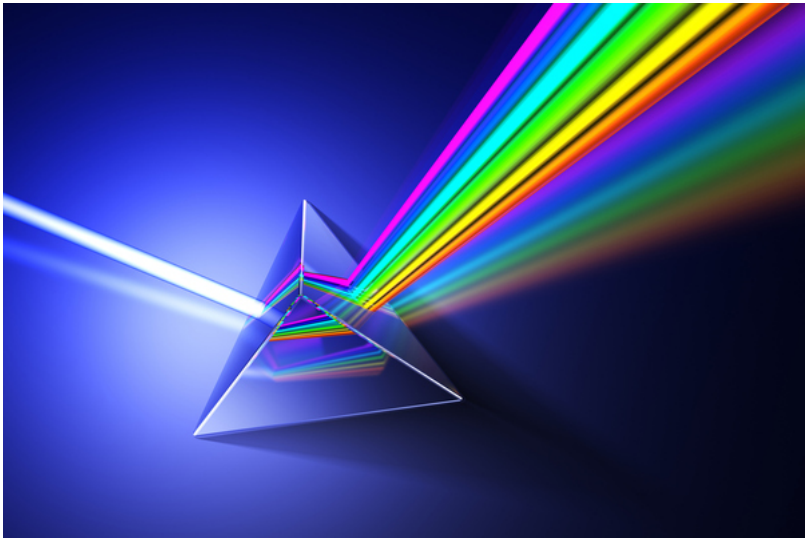

zraková osa
60°
60°
40°
20°
0°
20°
40°
60°
80°
slepá skvrna
fovea
zrakový nerv

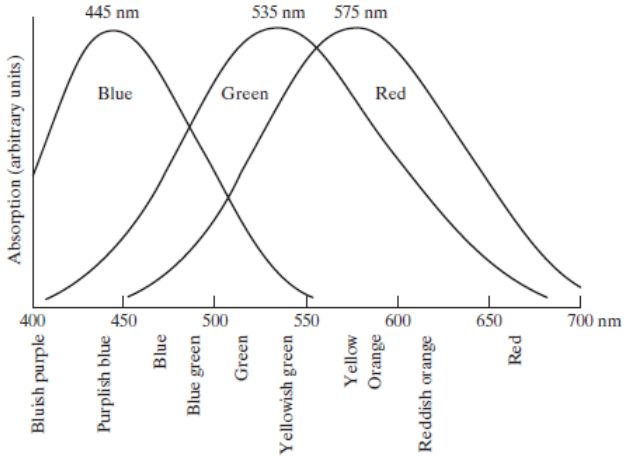

445 nm
535 nm
575 nm
Blue
Green
Red
Absorption (arbitrary units)
400
450
500
550
600
650
700 nm
Bluish purple
Purplish blue
Blue
Blue green
Green
Yellowish green
Yellow
Orange
Reddish orange
Red


B
G
R
+
-
-
y-b
g+r
r-g

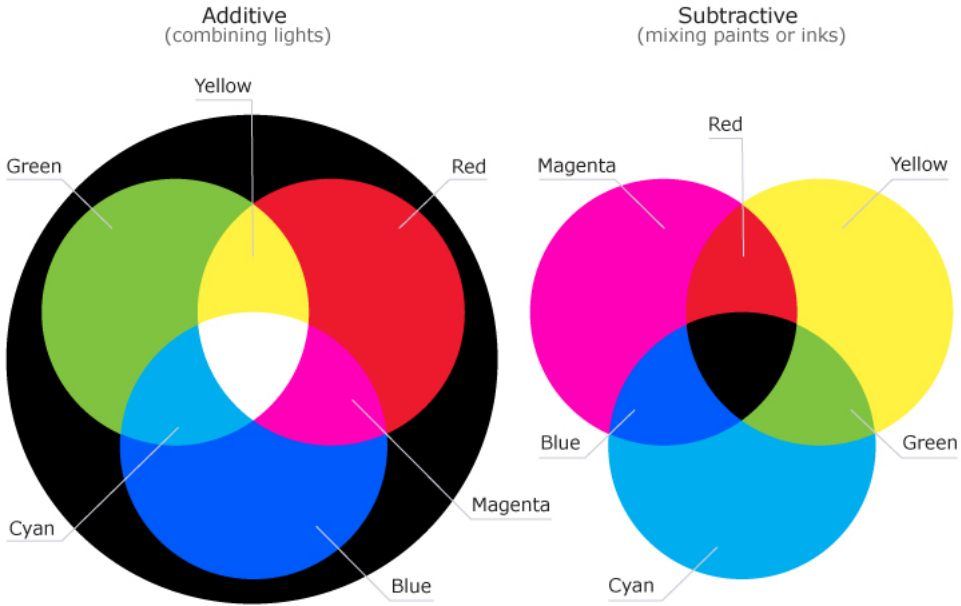

Actual intensity
Perceived intensity



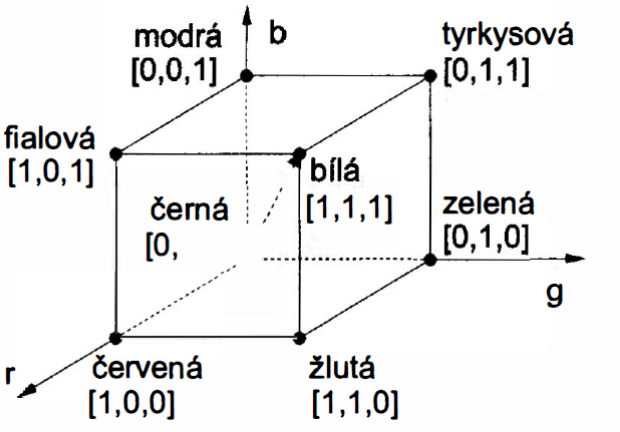




- Červená - 700 nm
- Zelená - 546,1 nm
- Modrá - 435,8 nm



RGB


modrá
[0,0,1]
b
tyrkysová
[0,1,1]
fialová
[1,0,1]
bílá
[1,1,1]
černá
[0,
zelená
[0,1,0]
g
r
červená
[1,0,0]
žlutá
[1,1,0]

RGB

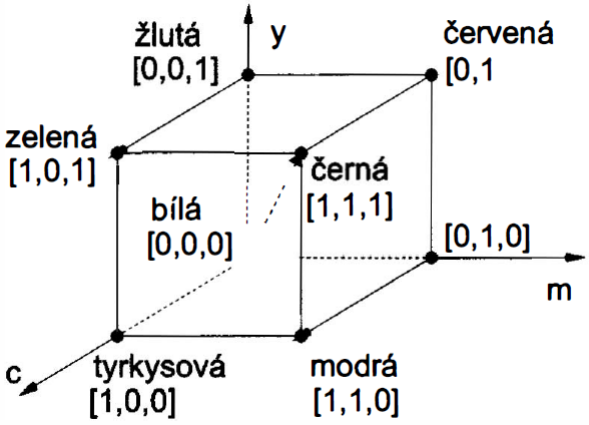
$$I = 0.299R + 0.587G + 0.114B$$

Matlab:

```
I = rgb2gray(A)
```

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

CMY


žlutá
[0,0,1]
y
červená
[0,1
zelená
[1,0,1]
černá
[1,1,1]
bílá
[0,0,0]
[0,1,0]
m
c
tyrkysová
[1,0,0]
modrá
[1,1,0]

RGB a CMY

RGB → CMY

$$\begin{bmatrix} c \\ m \\ y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

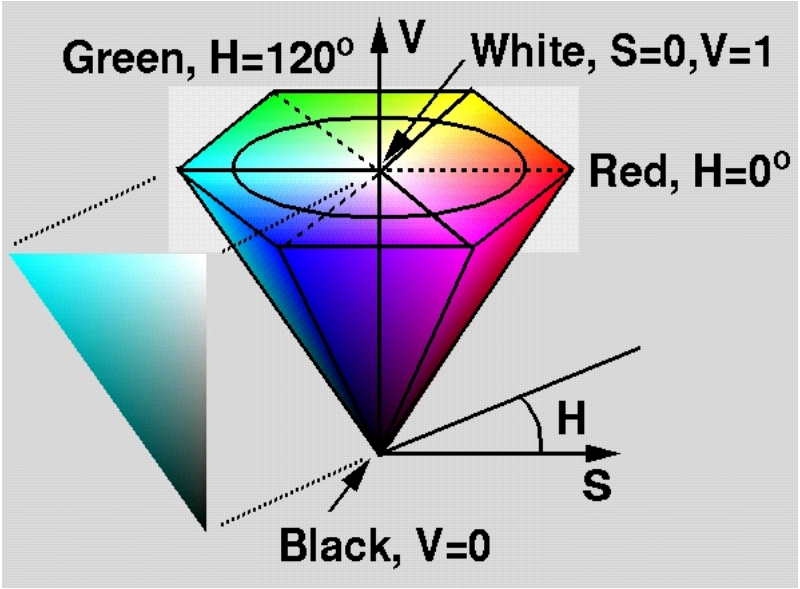
```
Icmy = 1 - Irgb
Icmy = imcomplement(Irgb)
```

CMY → RGB

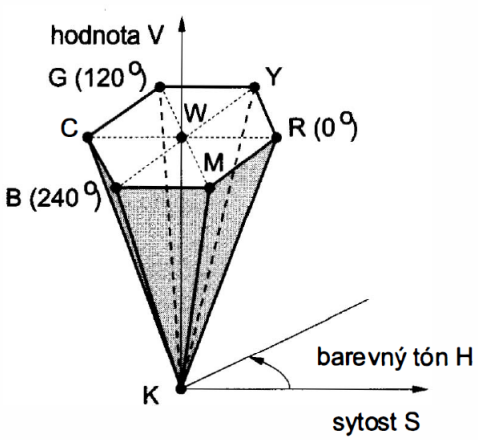
$$\begin{bmatrix} r \\ g \\ b \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} c \\ m \\ y \end{bmatrix}$$

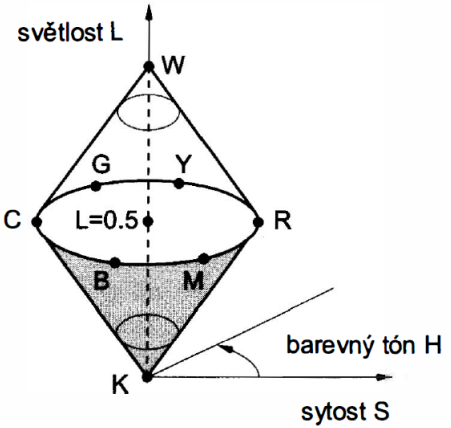
```
Irgb = 1 - Icmy
Irgb = imcomplement(Icmy)
```

HSV



HSV a HSL


hodnota V
G (120°)
Y
W
C
R (0°)
M
B (240°)
K
barevný tón H
sytost S


světlost L
W
G
Y
C
L=0.5
R
B
M
K
barevný tón H
sytost S

RGB → HSV

r, g, b . . . jednotlivé barevné složky

$max = max(r, g, b)$

$min = min(r, g, b)$

$$h = \begin{cases} \text{undef} & \text{if } max = min \\ 60^o \frac{g-b}{max-min} + 0^o & \text{if } max = r \text{ and } g \geq b \\ 60^o \frac{g-b}{max-min} + 360^o & \text{if } max = r \text{ and } g < b \\ 60^o \frac{b-r}{max-min} + 120^o & \text{if } max = g \\ 60^o \frac{r-g}{max-min} + 240^o & \text{if } max = b \end{cases}$$

$$s = \begin{cases} 0 & \text{if } max = 0 \\ \frac{max-min}{max} & \text{else} \end{cases}$$

$v = max$

```
Ihsv = rgb2hsv(Irgb)
```

RGB → HLS

r, g, b . . . jednotlivé barevné složky

$max = max(r, g, b)$

$min = min(r, g, b)$

$l = \frac{1}{2}(max + min)$

$$s = \begin{cases} 0 & \text{if } I = 0 \text{or } max = min \\ \frac{max - min}{max + min} & \text{if } 0 < l \leq \frac{1}{2} \\ \frac{max - min}{2 - (max + min)} & \text{if } l > \frac{1}{2} \end{cases}$$

HSV → RGB

$$h_i = \frac{h}{60} \; mod \; 6$$

$$f = \frac{h}{60} - h_i$$

$$p = v \cdot (1 - s)$$

$$q = v \cdot (1 - f \cdot s)$$

$$t = v \cdot (1 - (1 - f) \cdot s)$$

$$(r, g, b) = \begin{cases} (v, t, p) & \text{if } h_i = 0 \\ (q, v, p) & \text{if } h_i = 1 \\ (p, v, t) & \text{if } h_i = 2 \\ (p, q, v) & \text{if } h_i = 3 \\ (t, p, v) & \text{if } h_i = 4 \\ (v, p, q) & \text{if } h_i = 5 \end{cases}$$

```
Irgb = hsv2rgb(Ihsv)
```

RGB a YUV

$$\begin{bmatrix} y \\ u \\ v \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.141 & -0.289 & 0.437 \\ 0.615 & -0.515 & -0.1 \end{bmatrix} \cdot \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

RGB a YCbCr

RGB $\rightarrow$ YCbCr

$$\begin{bmatrix} y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.1687 & -0.3313 & 0.5 \\ 0.5 & -0.4187 & -0.0813 \end{bmatrix} \cdot \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

```
Iycbcr = rgb2ycbcr(Irgb)
```

YCbCr $\rightarrow$ RGB

```
Irgb = ycbcr2rgb(Iycbcr)
```

CIE 1931

R = 700nm
G = 541.1nm
B = 435.8nm

monochromatická barva

$C = r \cdot R + g \cdot G + b \cdot B$

barevné srovnávací funkce

$r(\lambda)$, $g(\lambda)$, $b(\lambda)$

monochromatická barva o vlnové délce λ

$C(\lambda) = r(\lambda) + g(\lambda) + b(\lambda)$

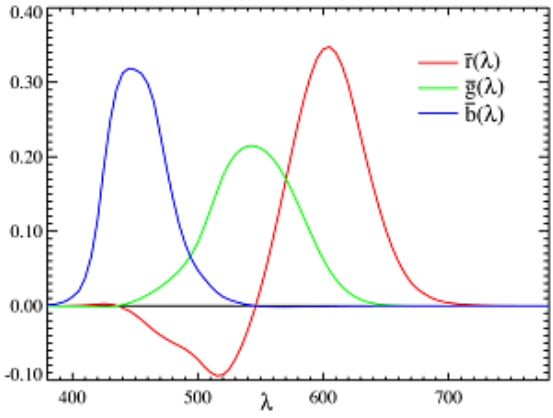
souřadnice obecné barvy

spektrální rozložení $p(\lambda)$

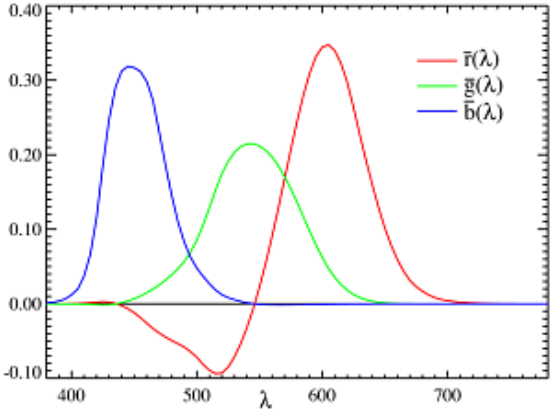
$r = \int_\lambda p(\lambda) \cdot r(\lambda) \mathrm{d}\lambda$

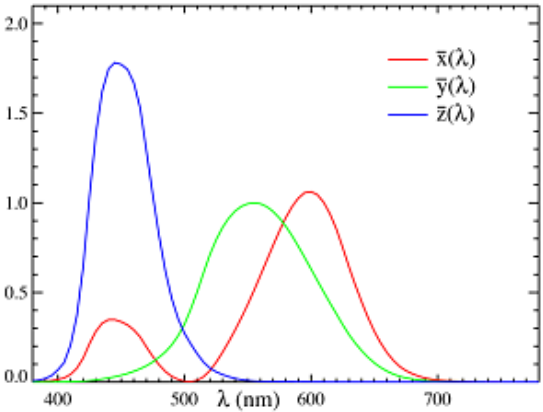
$g = \int_\lambda p(\lambda) \cdot g(\lambda) \mathrm{d}\lambda$

$b = \int_\lambda p(\lambda) \cdot b(\lambda) \mathrm{d}\lambda$



CIE


0.40
0.30
0.20
0.10
0.00
-0.10
400
500
600
700
λ
r̄(λ)
ḡ(λ)
b̄(λ)


2.0
1.5
1.0
0.5
0.0
400
500
λ (nm)
600
700
x̄(λ)
ȳ(λ)
z̄(λ)

CIE 1931 – xyY

souřadnice barvy

spektrální rozložení $p(\lambda)$

$x = \int_\lambda p(\lambda) \cdot x(\lambda) \mathrm{d}\lambda$

$y = \int_\lambda p(\lambda) \cdot y(\lambda) \mathrm{d}\lambda$

$z = \int_\lambda p(\lambda) \cdot z(\lambda) \mathrm{d}\lambda$

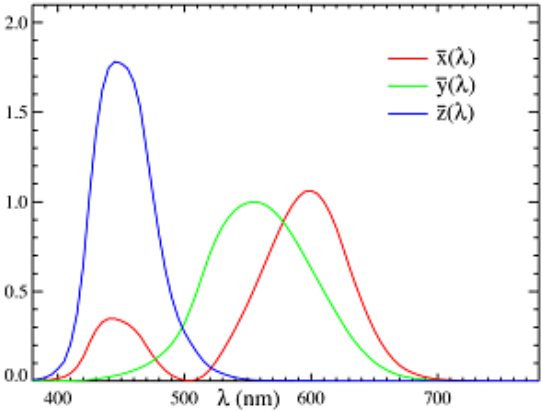
normalizovaný tvar

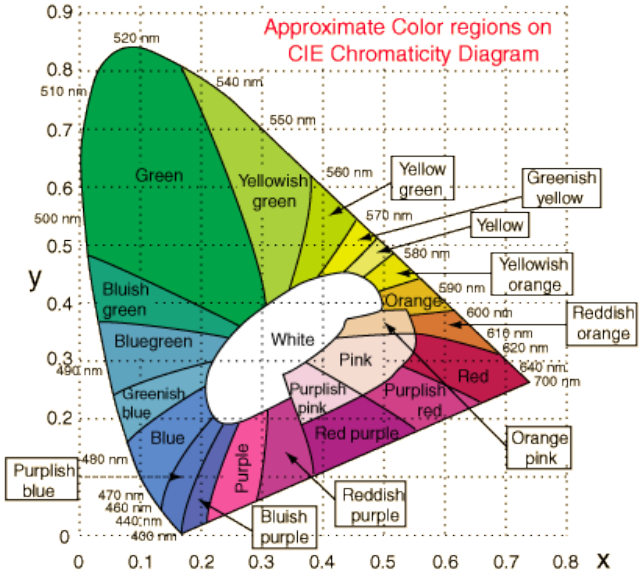
$x = \frac{x}{x+y+z}$

$y = \frac{y}{x+y+z}$

$z = \frac{z}{x+y+z}$

jelikož $x + y + z = 1$ stačí 2 souřadnice doplněné o jasovou hodnotu Y

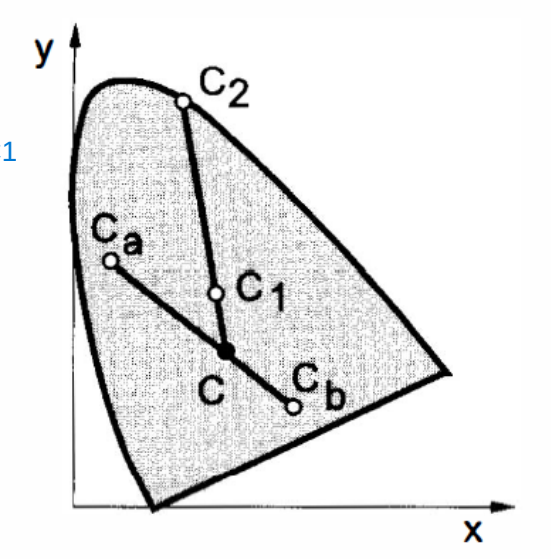



Approximate Color regions on
CIE Chromaticity Diagram
520 nm
540 nm
550 nm
560 nm
570 nm
580 nm
590 nm
600 nm
610 nm
620 nm
640 nm
700 nm
510 nm
500 nm
490 nm
480 nm
470 nm
460 nm
440 nm
400 nm
Green
Yellowish green
Yellow green
Greenish yellow
Yellow
Yellowish orange
Orange
Reddish orange
Red
Bluish green
Bluegreen
White
Pink
Purplish pink
Purplish red
Greenish blue
Blue
Red purple
Orange pink
Purplish blue
Purple
Reddish purple
Bluish purple
y
x
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

CIE

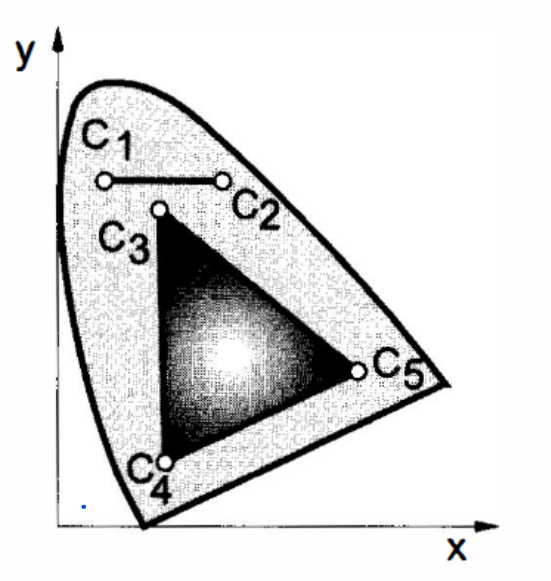
libovolný C1

sytost barvy – relativní vzdálenost C_1 od standardního bílého světla C
cca 25%
dominantní vlnová délka pro bod C_1 je bod C_2
doplňkové barvy C_a a C_b



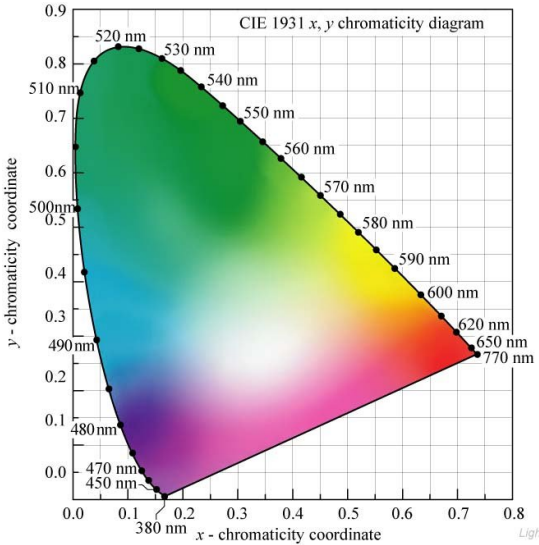
CIE

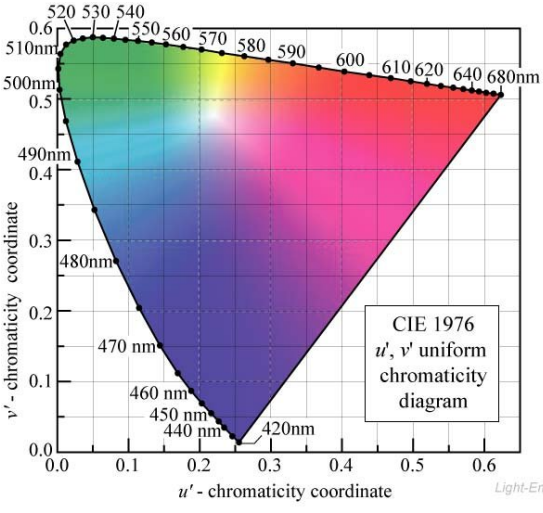
Barevné rozsahy – color gamut
konvexní množiny



CIE

Luv - rovnomerneji barvy





CIE 1976 - Luv

Převod CIE 1931 → CIE 1976

$$u = \frac{2x}{6y - x + 1.5}$$

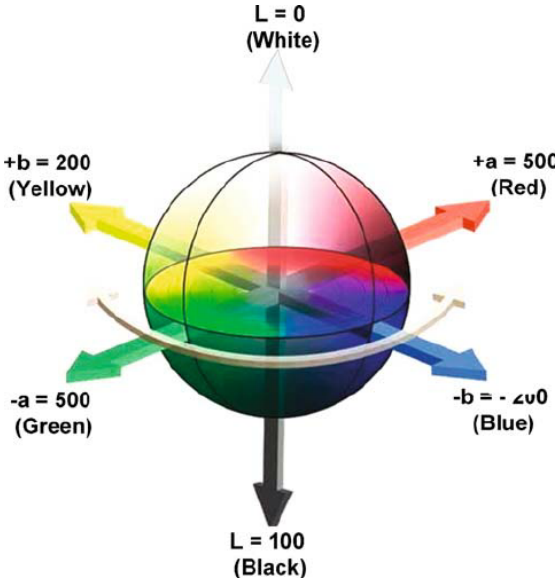
$$v = \frac{4.5y}{6y - x + 1.5}$$

Převod CIE 1976 → CIE 1931

$$x = \frac{27u}{4 \cdot (4.5u - 12v + 9)}$$

$$y = \frac{3v}{4.5u - 12v + 9}$$

CIE L*a*b


L = 0
(White)
+b = 200
(Yellow)
+a = 500
(Red)
-a = 500
(Green)
-b = - 200
(Blue)
L = 100
(Black)