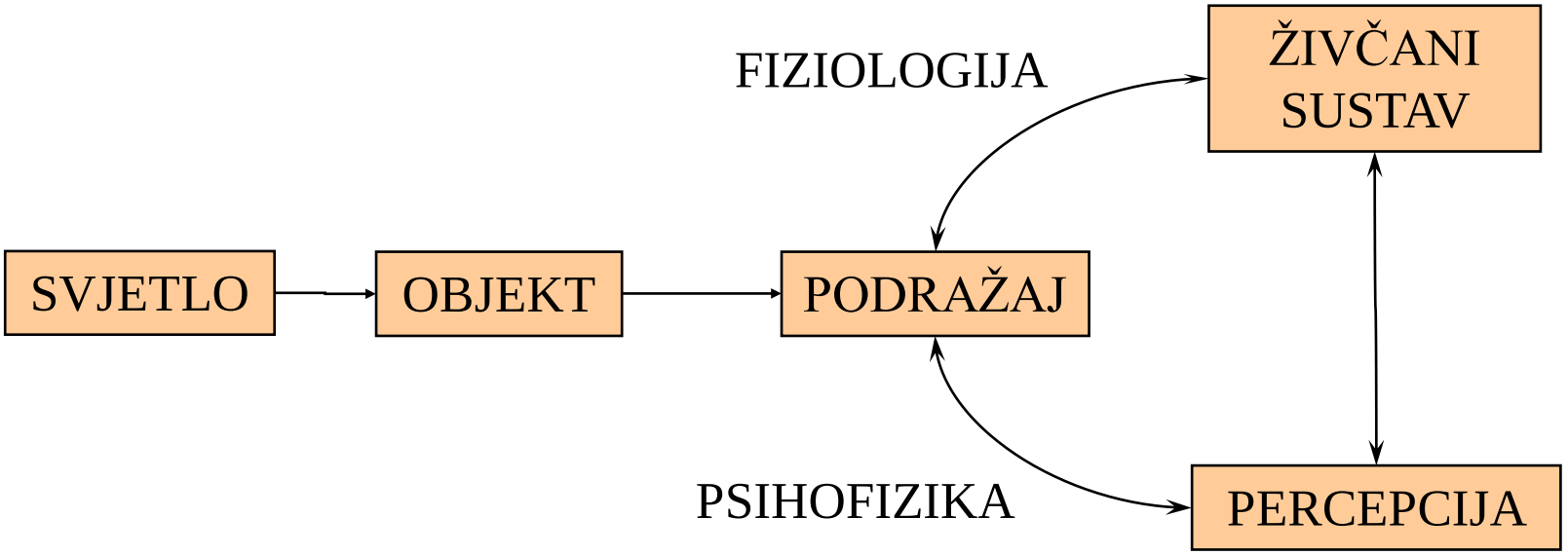
9. Boje

Stvaranje slike:

- osjet boje je biološki osjet



http://www.echalk.co.uk/amusements/OpticalIllusions/mona/mona.html
(maska, MonaLisa)

Čovjekov vid:

- prostorna razdioba fizikalnih veličina
- informacija predstavljena atributima kao što su svjetlina, boja, rubovi
- boja je rezultat interakcije svjetlosti s živčanim sustavom čovjeka

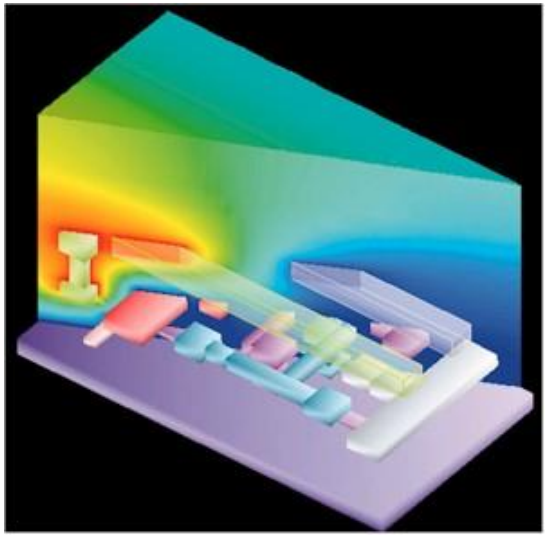
(podražaj počinje s 5 fotona), boja je subjektivni psihički doživljaj,
ista boja može dati različiti psihički doživljaj ovisno o prilagođenosti oka

http://www.echalk.co.uk/amusements/OpticalIllusions/colourPerception/colourPerception.html

- čovjek razlikuje 10 milijuna boja
- boje se češće koriste u kvalitativnom

nego u kvantitativnom smislu

- pridjeljivanje različitog značenja boji



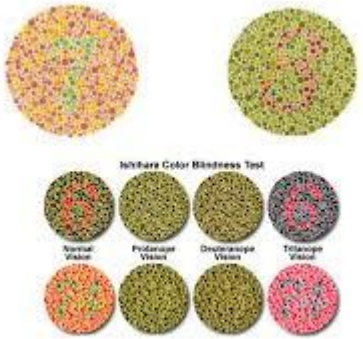
– slika se formira na mrežnici (retini) gdje se nalaze dvije vrste fotoreceptora osjetljivih na svjetlost
  - štapići - ~ 120 milijuna, uski i dugački, aktivni pri slaboj svjetlosti
  - čunjići - ~ 6.5 milijuna, manje osjetljivi, prema tropodražajnoj teoriji

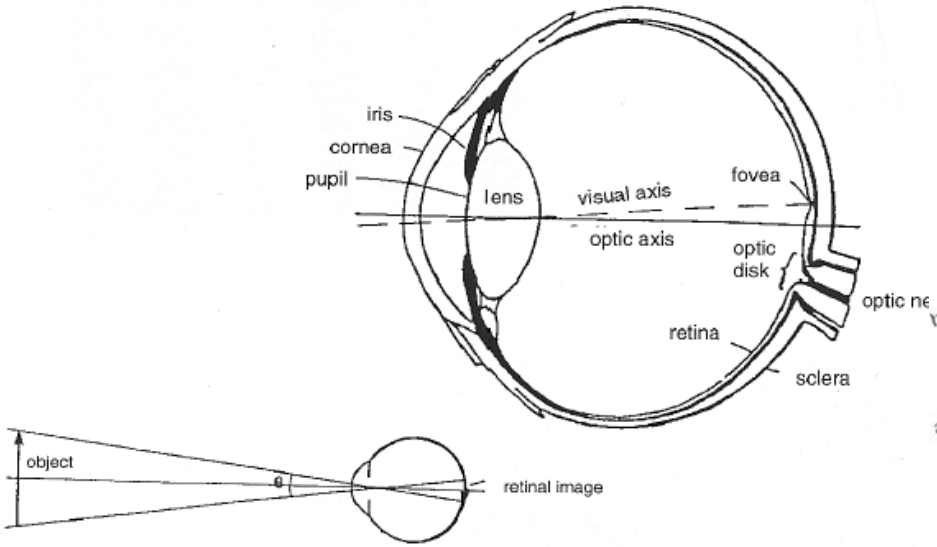
postoje tri vrste čunjića (boja)

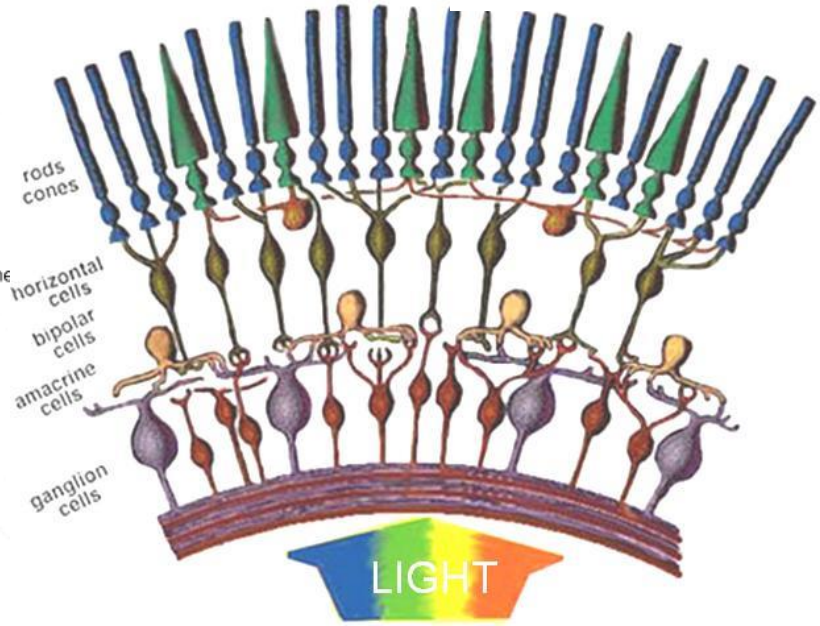
- daltonizam – problem u razlikovanju nekih boja

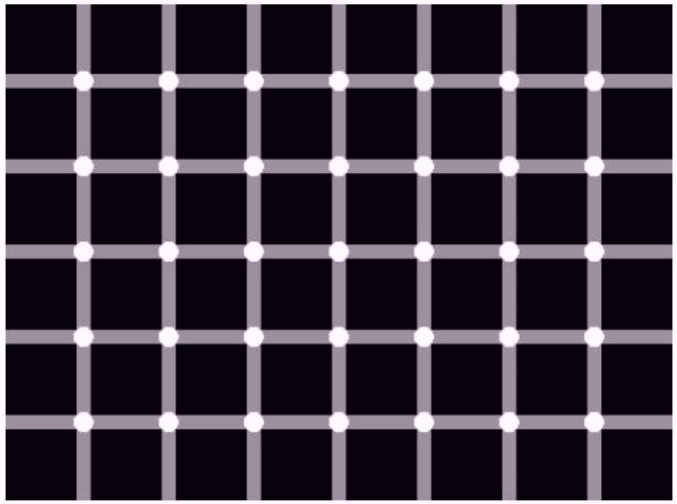
https://andrewmacheret.com/projects/colorblind/ http://www.color-blindness.com/ishihara_cvd_t

https://quote.com/health-insurance/human-eye/

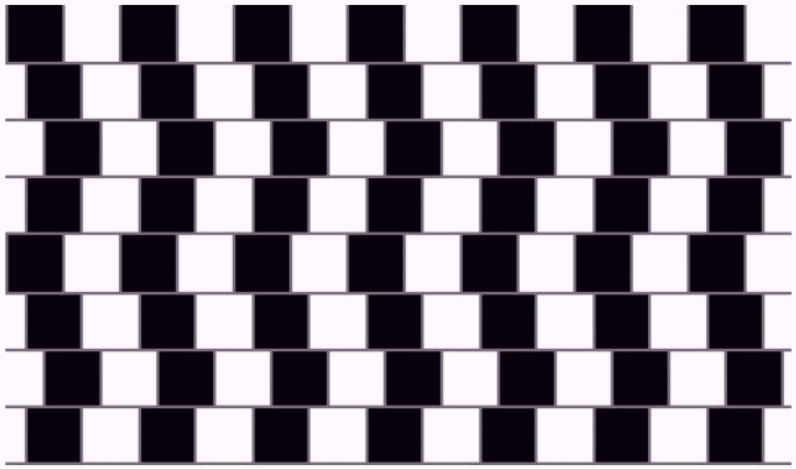




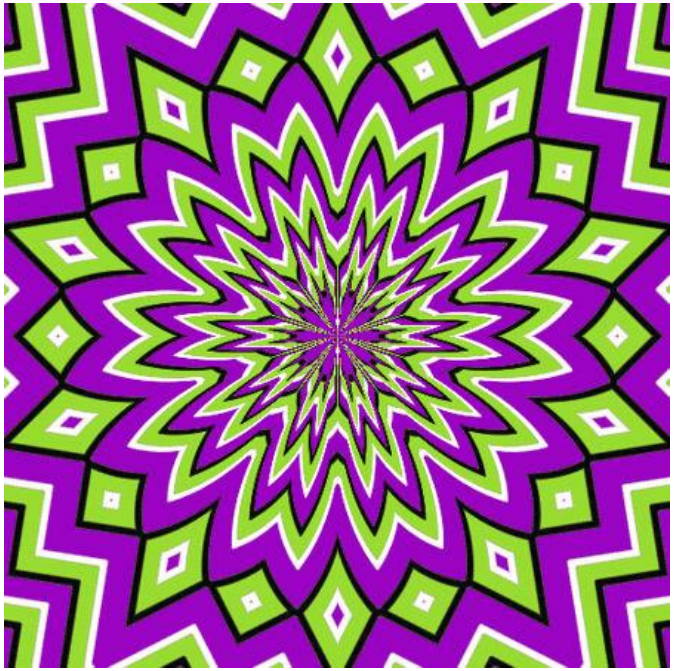


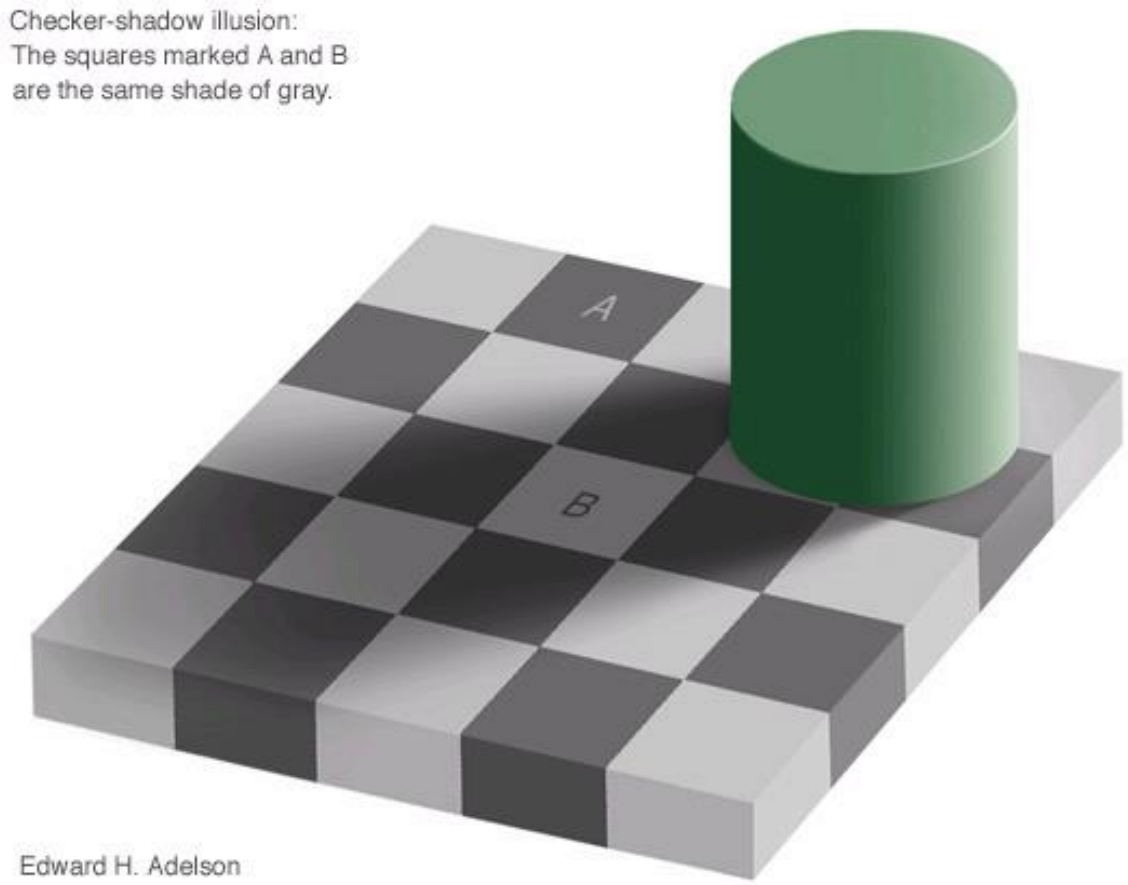


Count the black dots! :o)



Are the horizontal lines parallel or do they slope?



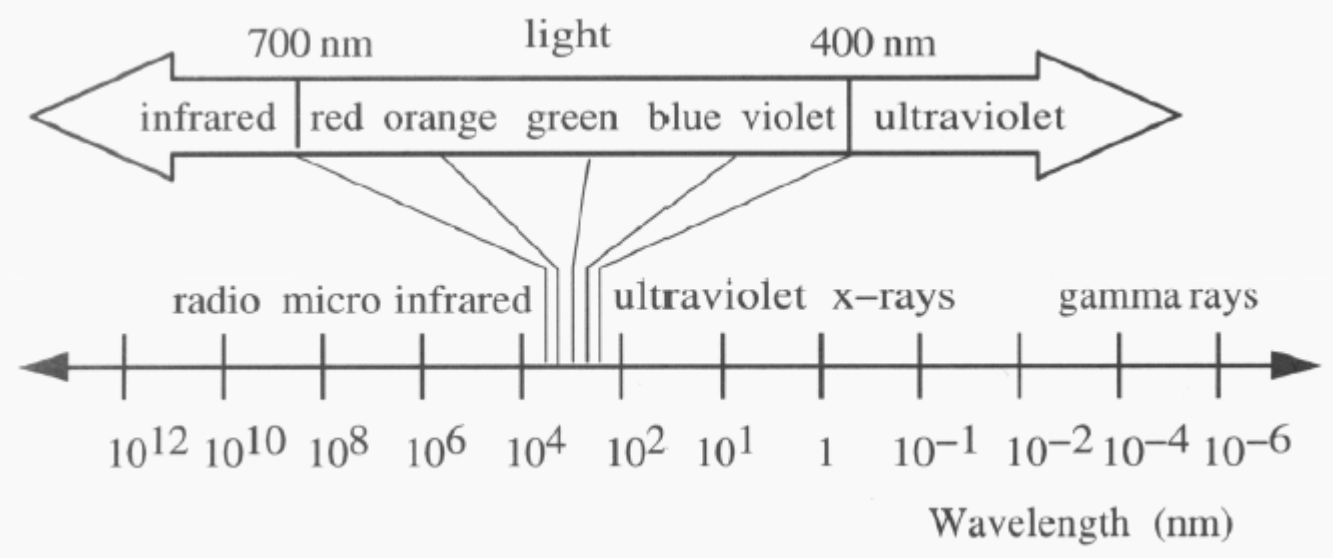


Utjecaj visokih i niskih frekvencija:
https://michaelbach.de/ot/fcs-SpatFreqComposites/

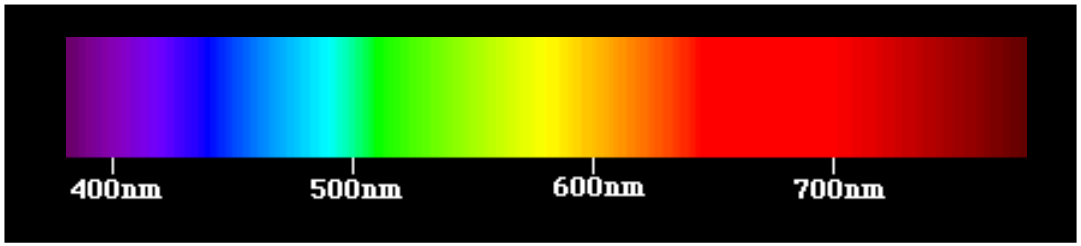
Svjetlost je elektromagnetsko zračenja

Vidljivi spektar ~ 400 – 700 nm

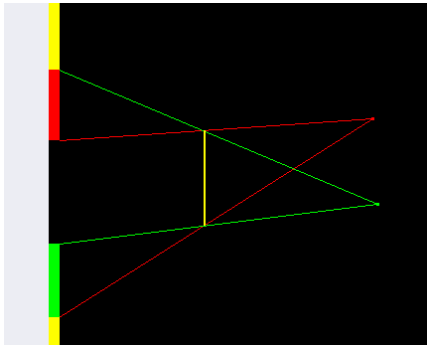
http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Youngs-Experiment/Youngs-Experiment-Interactive

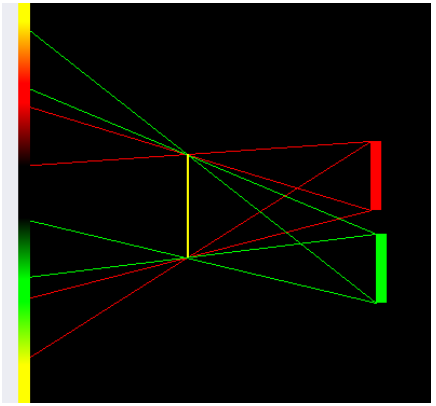


Vidljivi spektar ~ 400 – 700 nm



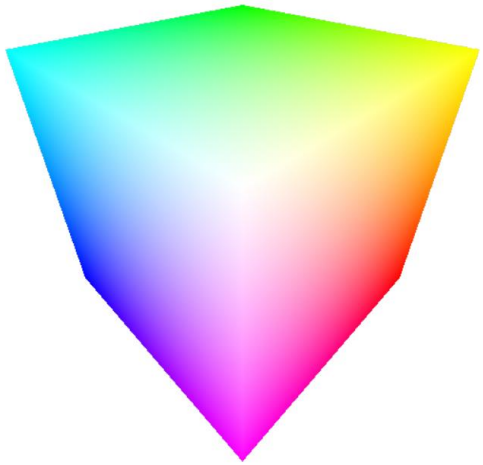
spektralna boja:	valna duljina:
ljubičasta	400 – 450
plava	450 – 500
zelena	500 – 570
žuta	570 – 590
narančasta	590 – 610
crvena	610 – 700





https://www.babylonjs.com/Demos/SoftShadows/

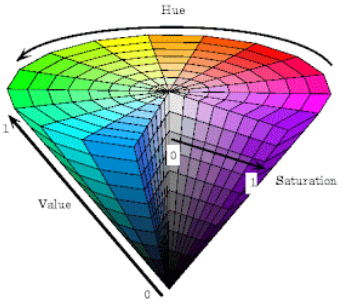
Sustavi boja



- RGB (aditivno miješanje boja)
  - koristi se kod miješanja svjetlosti – valne duljine
    http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/RGB-Color-Addition/RGB-Color-Additior
  - https://cs1230.graphics/demos/additive_colormixing/index.html

- CMYK (suptraktivno miješanja boja)
  - miješanje pigmenata boje
- https://cs1230.graphics/demos/subtractive_colormixing/index.html

- HLS http://math.hws.edu/graphicsbook/demos/c2/rgb-hsv.html



- dijagram kromatičnosti CIE

  (franc. Commission Internationale de l'Eclairage)
  - Munsell Color Science Laboratory

RGB – aditivan sustav boja

R – red

G – green

B – blue

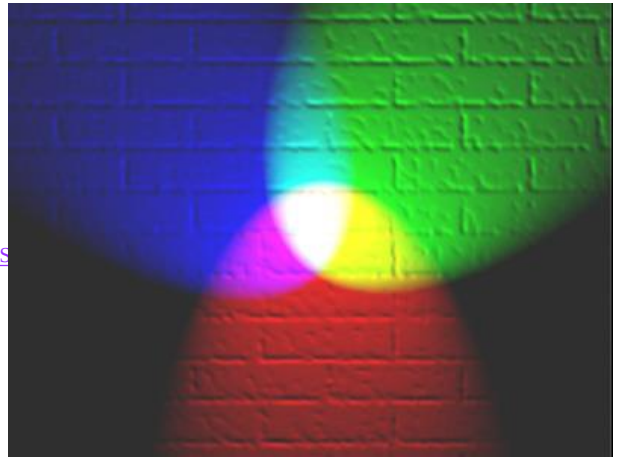
- http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Colored-Shadows/Colored-S
- http://cs.wellesley.edu/~cs307/threejs/demos/Color/colorcube.html
- https://experiments.withgoogle.com/h3stogram

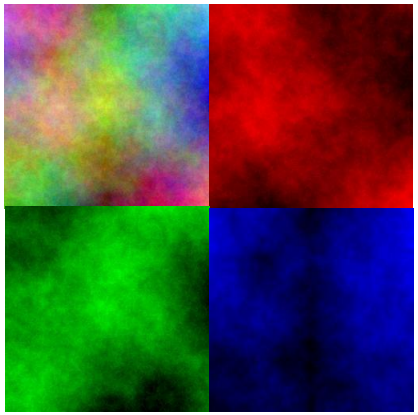
- aditivni sustav boja

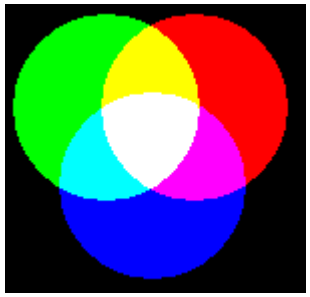
– smjesa tri primarne boje RGB

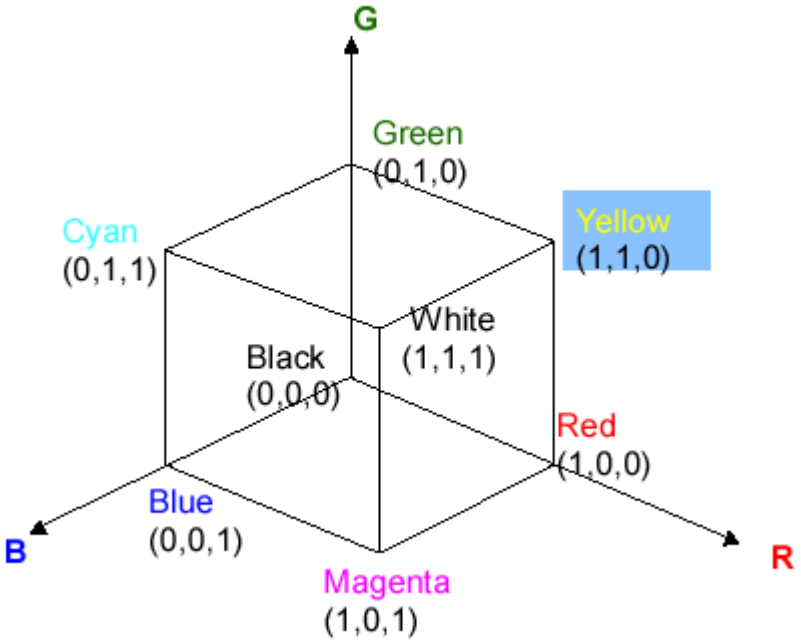
$256 \times 256 \times 256 = 16.777.216$

256 razina sive









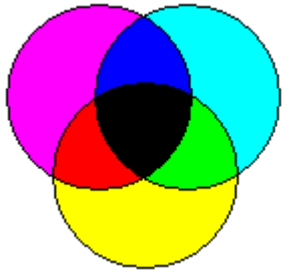
CMYK – suptraktivan sustav boja

C – cyan (tirkizna, plavozelena) = 1 - R

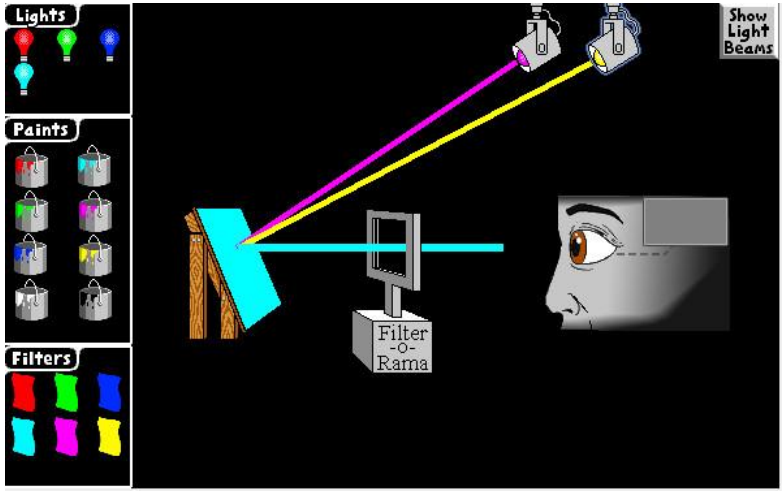
M – magenta (ljubičasta) = 1 - G

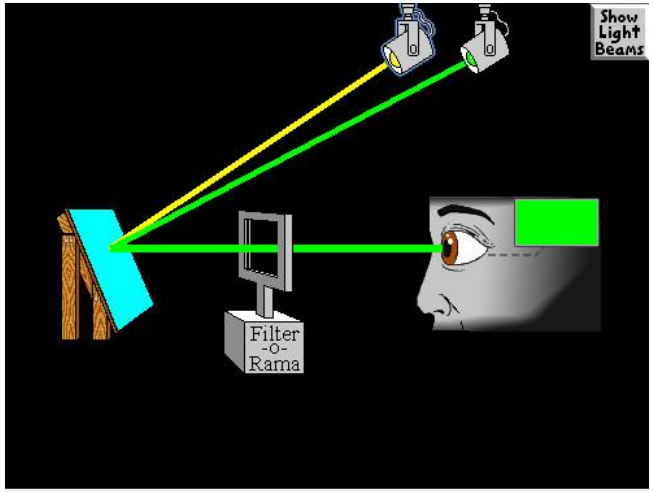
Y – yellow (žuta) = 1 - B

K – black



https://www.physicsclassroom.com/Concept-Checkers/Interactives/Painting-With-CMY/Concept-Checker





– smjesa pigmenata apsorbira određene valne duljine i reflektira preostale npr. cyan filtrira crvenu boju pa ostaje plava i zelena

zeleni papir je zelen jer reflektira zelenu boju, a apsorbira ostale.

Ukoliko su filtrirane sve boje preostaje crna.

https://cs1230.graphics/demos/combined_colormixing/index.html

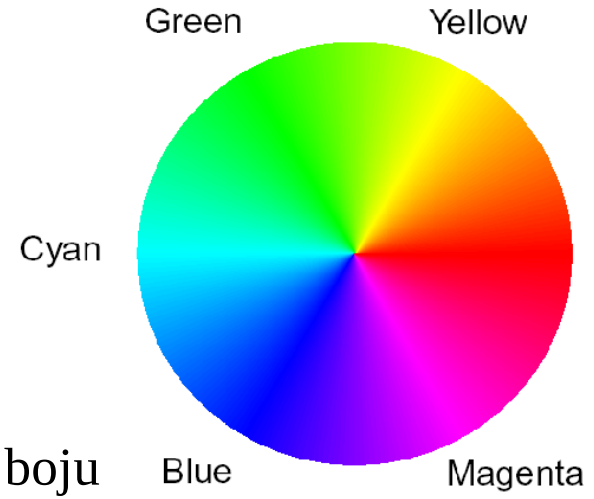
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/primarycolors/colorseparation/index.html

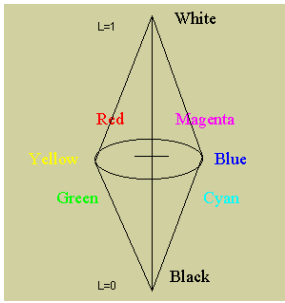
http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Color-Filters/Color-Filters-Interactive

http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Stage-Lighting/Stage-Lighting-Interactive

http://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Painting-with-CMY/Painting-with-CMY-Interactive

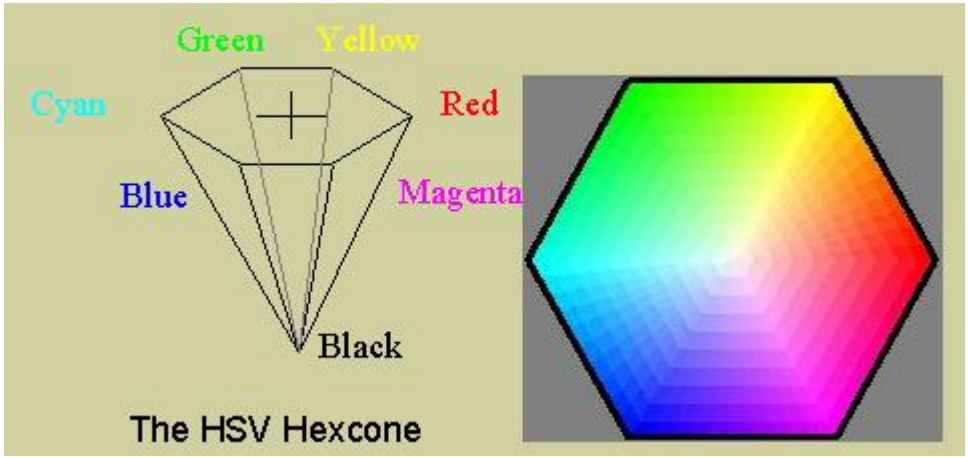
HLS, HIS, HSV – sustav





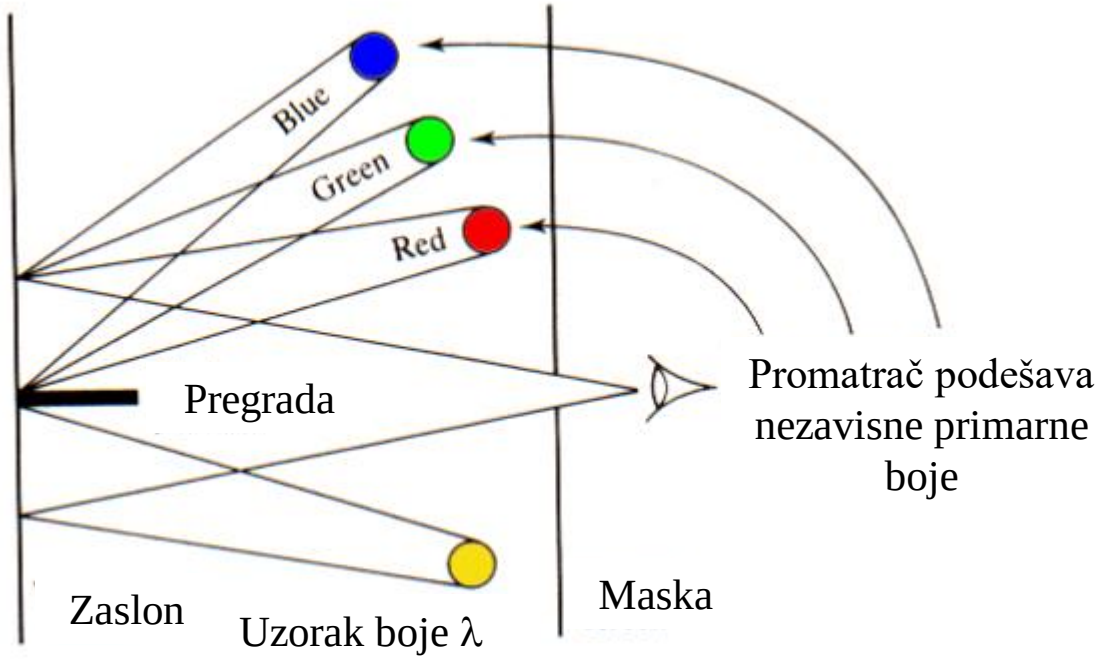
H (hue) nijansa boje, tonalnost,
ime spektralne boje
L (lightness, luminance) svjetlina,
I (intensity) intenzitet
S (saturation) zasićenje – koliko je boju razrijedila bijela odnosno siva svjetlost
- pogodno za odabir boje

http://math.hws.edu/graphicsbook/demos/c2/rgb-hsv.html
http://cs.wellesley.edu/~cs307/threejs/demos/Color/colorcones.html
https://afc163.github.io/color3d/



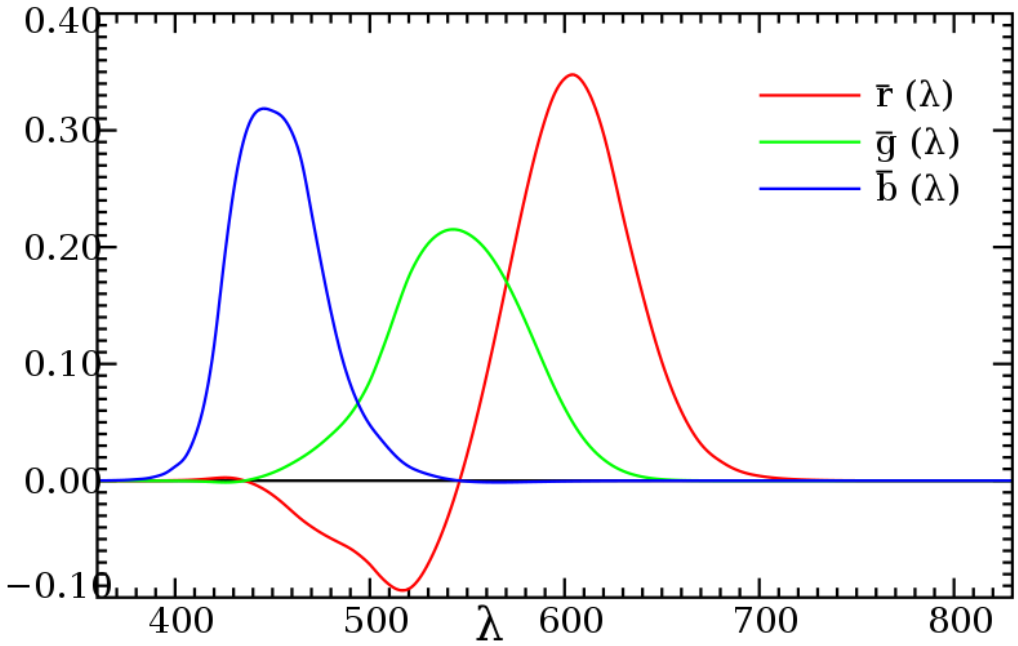
Pokus podudaranja boja

http://phet.colorado.edu/simulations/sims.php?sim=Color_Vision



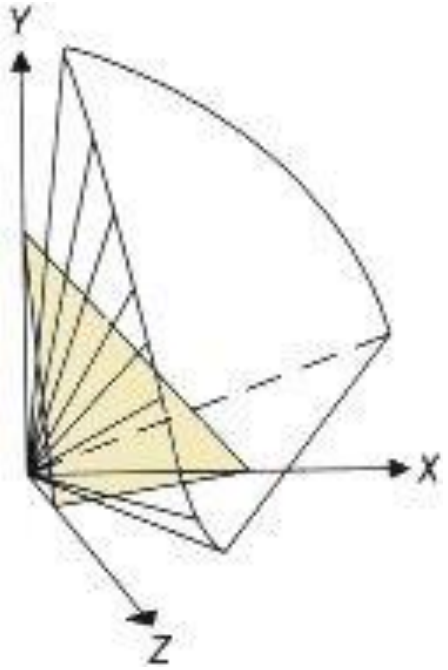
Pokus podudaranja boja

- u području oko 500 nm podudaranje boja nije ostvarivo kao aditivna kombinacija tri primarne boje



CIE (franc. Commission Internationale de l'Eclairage)
(engl. International Commission on Illumination)
Dijagram kromatičnosti

- definira tri primarne hipotetske boje koje ne postoje i nisu vidljive, kako bi se izbjegli negativni koeficijenti
- boja se označava s XYZ
- koordinate kromatičnosti *x y z*
- projekcija na XY ravninu daje dijagram kromatičnosti



$$x = \frac{X}{X+Y+Z},$$

$$y = \frac{Y}{X+Y+Z},$$

$$z = \frac{Z}{X+Y+Z},$$

$$x + y + z = 1.$$

rub potkove označava (eng. spectral locus)

- krivulju spektralnih boja Npr. duga

ravna linija određuje

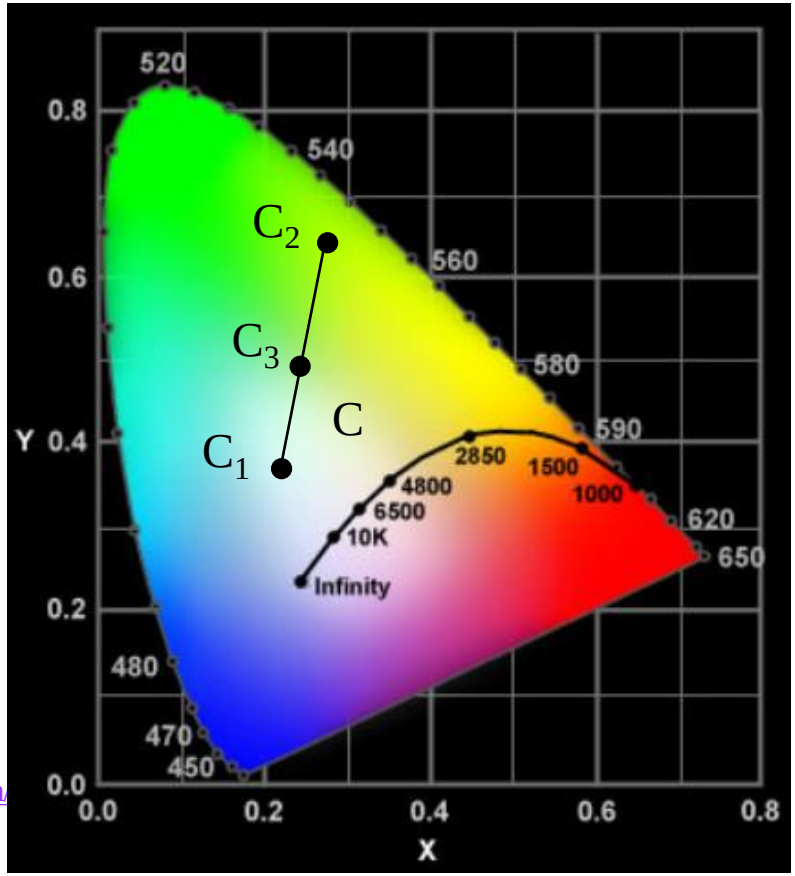
- dužinu purpurne boje (nespektarlne boje).

boje u unutrašnjosti

- manje su zasićene od dominantne spektralne boje
- aditivna smjesa dvije boje C_1C_2 leži C_3 na njihovoj spojnici

spektar zračenja crnog tijela

- boja užarenog karbona
- dnevna svjetlost 6500K
- https://phet.colorado.edu/sims/html/blackbody-spectrum/



C – standardno bijelo svjetlo,
- neuniformna područja

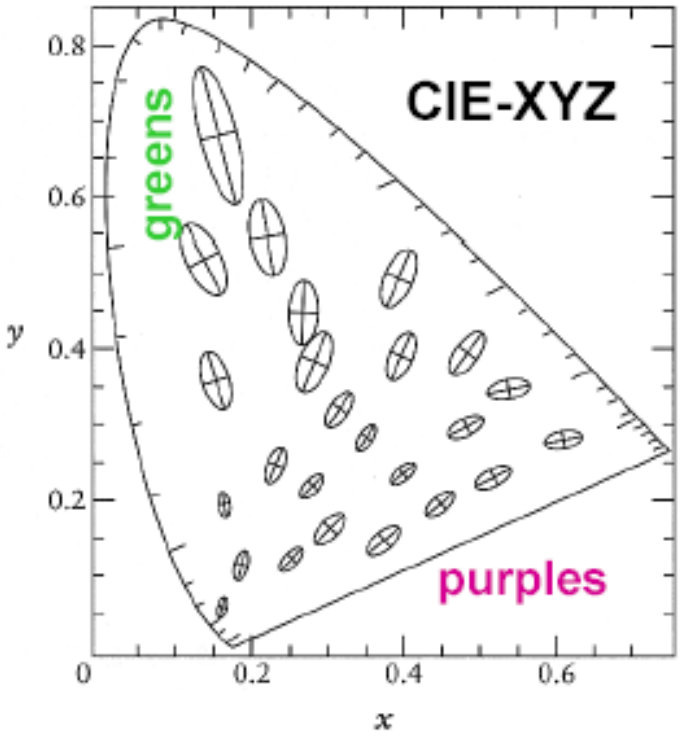
komplementarne boje su one čijim se miješanjem može dobiti bijela boja

smeđa boja - je crveno narančasta uz manju svjetlinu (lightness)

Metamerizam – dva izvora svjetlosti koji sadrže različite valne duljine mogu promatraču izgledati identični

https://cs1230.graphics/demos/metamers/metamers.html

- dva objekta za neko zadano osvjetljenje mogu izgledati isto a za drugo osvjetljenje različito

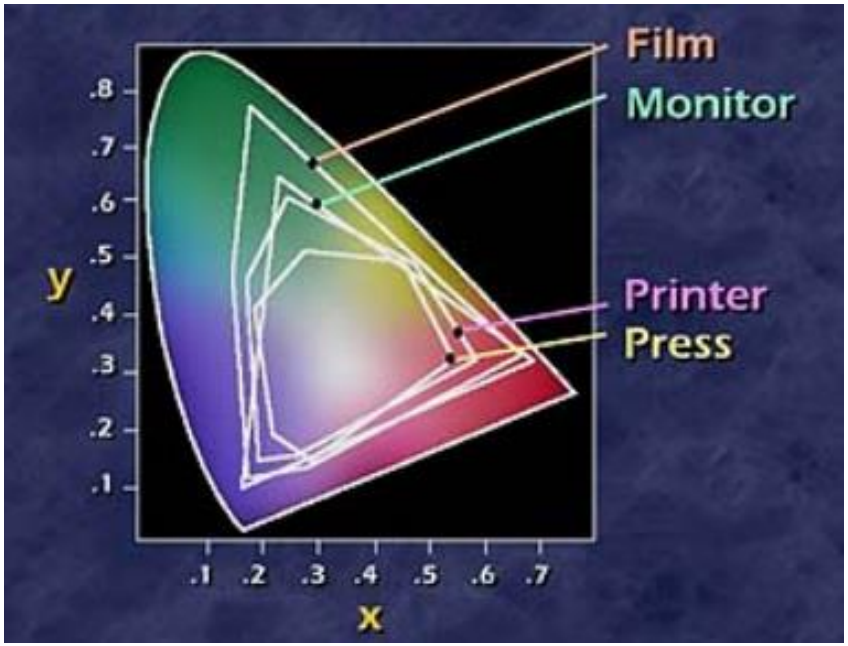


Gamut uređaja

gamut je definiran primarnim bojama koje uređaj koristi

ne mogu se ostvariti sve vidljive boje

- https://www.photo-mark.com/funhouse/html5color/



Odabir intenziteta

- odabir intenziteta ne uzima u obzir važnu činjenicu da je oko osjetljivo na omjer intenziteta, a ne na apsolutni iznos

Npr:

50 100 150 200 250

$$\frac{100}{50} = 2, \quad \frac{250}{200} = 1.25.$$

$$I_0 = I_0, \quad I_1 = rI_0, \quad I_2 = rI_1 = r^2 I_0, \quad \ldots \quad I_{255} = r^{255} I_0 = 1 \rightarrow \quad r = \left(\frac{1}{I_0} \right)^{\frac{1}{255}},$$

$$I_j = r^j I_0 = \left(\frac{1}{I_0} \right)^{\frac{j}{255}} I_0 = I_0^{\left(1 - \frac{j}{255}\right)}$$

$$n+1 \quad \text{razina} \qquad r = \left(\frac{1}{I_0} \right)^{\frac{1}{n}} \qquad I_j = I_0^{\left(1 - \frac{j}{n}\right)}, \quad j = 0..n$$

Tipično $I_0 = 0.005 - 0.025$

Gamma korekcija

– pored toga karakteristika monitora je nelinearna što se često ne uzima u obzir

$I = k N^{\gamma}$ I .. intenzitet koji emitira fosfor

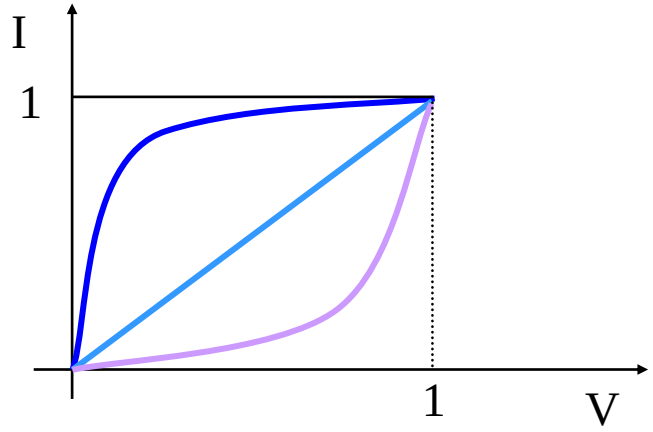
N .. broj elektrona koji pogađa fosfor

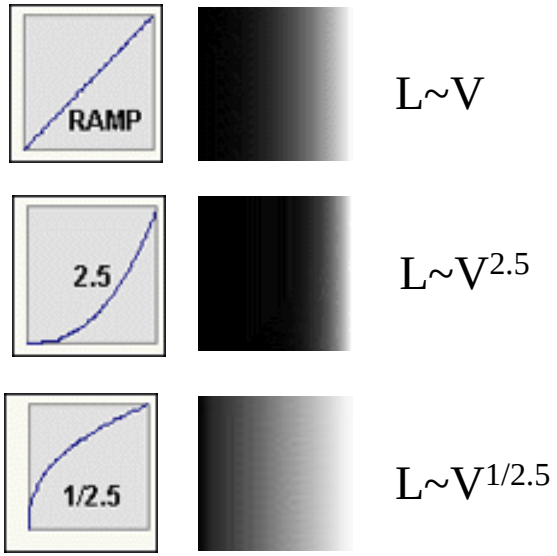
$I = K V^{\gamma}$ ~ proporcionalan je naponu V,

~ odnosno vrijednostima slikovnih elemenata

k, K, γ .. konstante, tipično za monitor γ = 2.5

LUT – tablice





L~V

$L \sim V^{2.5}$

$L \sim V^{1/2.5}$

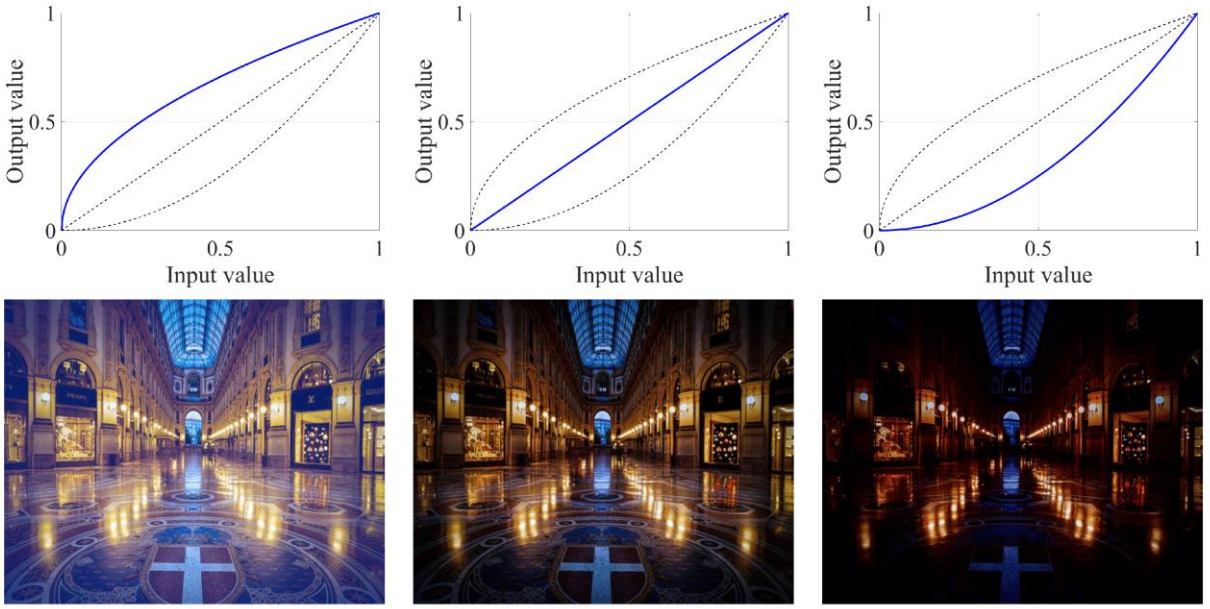
https://learnopengl.com/Advanced-Lighting/Gamma-Correction

Gamma korekcija

- podatak o korekciji načinjenoj na slici često nije predviđen u zapisu slike (za slike na Internetu često se pretpostavi γ i slike su korigirane)
- odabir intenziteta http://www.cs.cmu.edu/~efros/java/gamma/gamma.html
  http://epaperpress.com/monitorcal/index.html
  http://marcinignac.com/blog/pragmatic-pbr-hdr/305-exposure-basic/ http://pierrelepers.com/lab/jthree/

- neuniformna područja na dijagramu kromatičnosti + 8 bita za RGB je malo + pogreške kvantizacije uz gamma korekciju
  –> PROBLEM – poželjno je koristiti **nelinearni** sRGB

- NPR: R = 18 -> $\left(\frac{18}{256}\right)^{2.4} \cdot 256 \sim = 0.44$ (0-18 se preslika u 0 i izgubi)



HDR – tehnologija visoke dinamike prikaza (High Dynamic Range)

- 8 bita po boji (0-255) za visoko kvalitetan prikaz često nije dovoljno
- dolazi do izražaja na mjestima gdje se izvori svjetla vide izravno
- primjer kod fotografija:
  - promjenom kontrasta jedne slike nećemo dobiti dobre rezultate

kombinacija slika različitih osvjetljenja (ekspozicija) kako bi se ostvario rezultat
→s dobro vidljivim sjenama (tamno) i vidljivim zelenilom kroz prozor (svjetlo)
→https://threejs.org/examples/webgl_loader_texture_hdr.html
→https://threejs.org/examples/#webgl_read_float_buffer
https://viewer.openhdr.org/i/58923b780b13f30f9f8446fc/reinhard/a=15/Lwhite=6.2
http://szimek.github.io/webgl-hdr/ Chrome

HDR - vidimo detalje ili u osvijetljenom dijelu ili u pozadini

http://patapom.com/topics/WebGL/cathedral/index.html

– povećanje raspona za dobivanje, zapis i reprodukciju komponenti boje
  - kamera, CT – 14 bita, slike generirane praćenjem zrake jesu 0.0 - 1.0
  - zapisa - OpenEXR – ILM (Industrial Light & Magic)
  - slikovni elementi
    - 16-bit ili 32-bit floating-point,
    - 32-bit integer

sklopovska podrška na graf. karticama
  - izlazni uređaji – monitori (>8 bita)

https://threejs.org/examples/webgl_tonemapping