IIT Jodhpur

Biological Vision and Applications
Module 02-04: Color Perception

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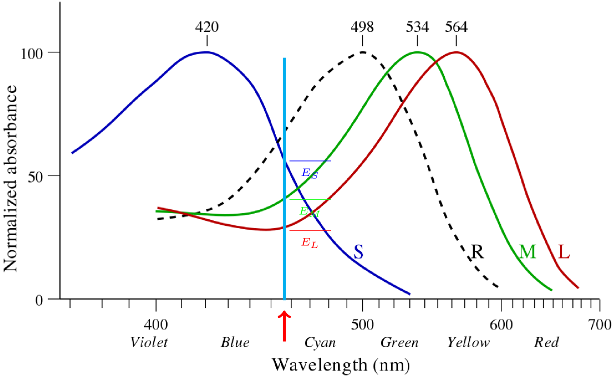
Color perception

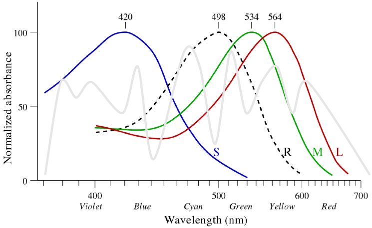
... not a property of spectral component of light, but how your eyes respond to it



- Perceived color $C = f(E_S, E_M, E_L)$

Color perception

Color is an emergent entity, distinct from properties of light



- Incident light: $I(\lambda)$
- Excitation levels of the cones are given by

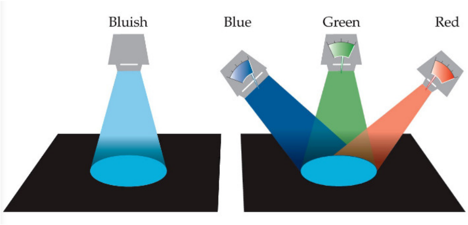
$$
\begin{aligned}
E_S &= \int_\lambda S(\lambda).I(\lambda).d\lambda \\
E_M &= \int_\lambda M(\lambda).I(\lambda).d\lambda \\
E_L &= \int_\lambda L(\lambda).I(\lambda).d\lambda
\end{aligned}
$$

- Perceived color $C = f(E_S, E_M, E_L)$
- Metamars: Lights with different spectral components that give rise to same color perception

EdPuzzle: Is your red the same as my red ?

Trichromatic Color Theory

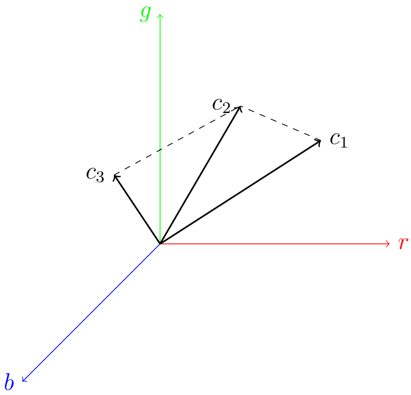
- A perceived color can be matched by a combination of three primary colors
  - Proved by psychological experiments
  - By convention, R, G and B are taken as primary colors



The three colors need not necessarily be "Blue", "Green" and "Red"

Device dependent color models

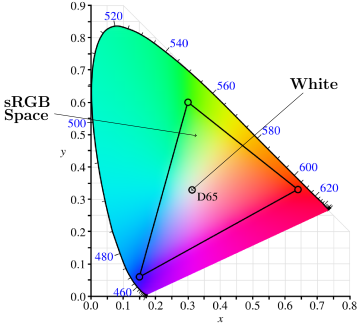
RGB Model



- Electronic devices typically use “red”, “green” and “blue” color guns
- Each color is represented by a point in 3D space
  - $\vec{c} = \{\alpha.\vec{r} + \beta.\vec{g} + \gamma.\vec{b}\}$
  - Are the vectors $\vec{r}, \vec{g}, \vec{b}$ orthogonal?

- Let $\vec{c_1}$, $\vec{c_2}$ and $\vec{c_3}$ represent three colors in *rgb* space
  - $| \vec{c_1} - \vec{c_2} | < | \vec{c_2} - \vec{c_3} |$ does not necessarily mean that
    - $\vec{c_2}$ is perceptually closer to $\vec{c_1}$ than $\vec{c_3}$

sRGB Color space

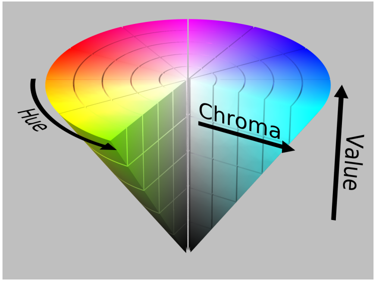


- Electronic devices use three primary color guns
- Perceived color can be matched by a "linear combination" of three primary colors
- Unfortunately, we can only add (not subtract) color in electronic devices
  - We can produce only a subset of perceivable colors with the devices
- The color space that can be produced by a device is called sRGB space
  - Depends of the device characteristics

Device independent color models

HSV Model, CIE Model

- Munsell described color in terms of its three perceptual properties, namely
  - Hue (shade), Value (brightness), and Chroma (color purity)
- ... referred to as device-independent color model
- It has been later refined to many other models
  - HSV (Hue-Saturation-Value), CIE-XYZ and CIE-LAB
- In these models too, a color is represented by a point in a 3D space
  - The color distances in these spaces closely conform to perceptual distances



Merits of Trichromatic Color Theory

- Accounts for the 3 independent dimensions of color space
- Can explain metameric matching
  - Mixing of 3 “primary” colors is sufficient to match any other visible color.
- Partially accounts for color blindness

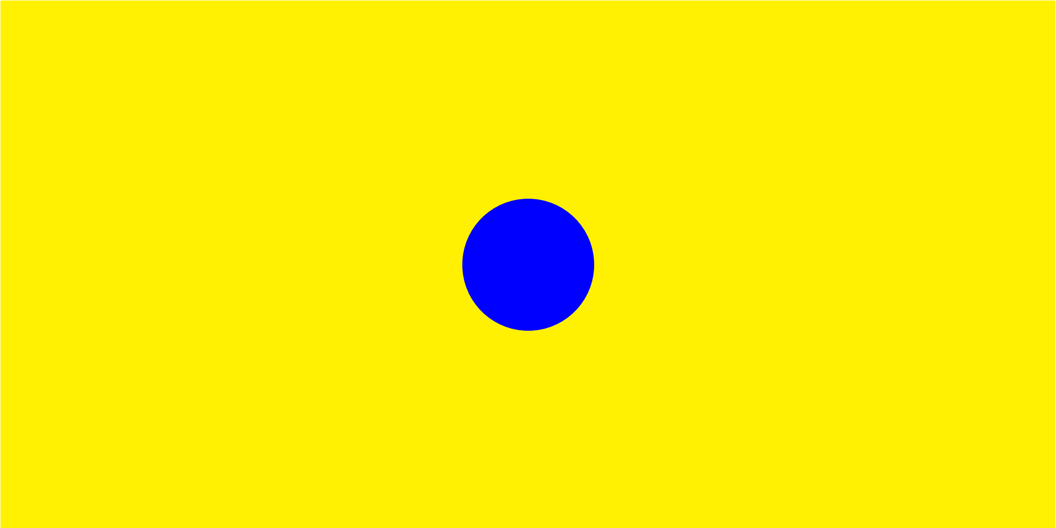
Are 24-bits sufficient to represent all perceivable colors?

- Human eye can distinguish between
  - Approximately 128 different hues
  - Around 20 to 30 different saturation values (for each hue)
  - Between 60 and 100 different brightness levels

- Combinatorially, human eye can distinguish between roughly 300,000 – 350,000 different color shades
- 24 bits has a provision to represent 16 million color shades!
  - The issue is how we intelligently utilize the 24 bits

After-images (experiment)

Concentrate on the picture below for about 15 sec



After-images (experiment)

... Contd.

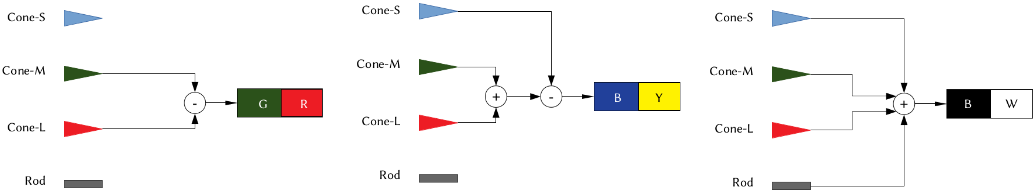
Opponent (color) process theory

- Opponent colors show up as after-image
  - Because of "fatigue" of the photoreceptors
- 3 pairs of opponent colors (observed through psychological experiments)
  - red *vs.* green
  - blue *vs.* yellow
  - dark (black) *vs.* bright (white)

Opponent process theory

(Continued)

- Opponent color contrasts are explained by neural connections
- 3 new (derived) color channels are formed



$GR = E_L - E_M$

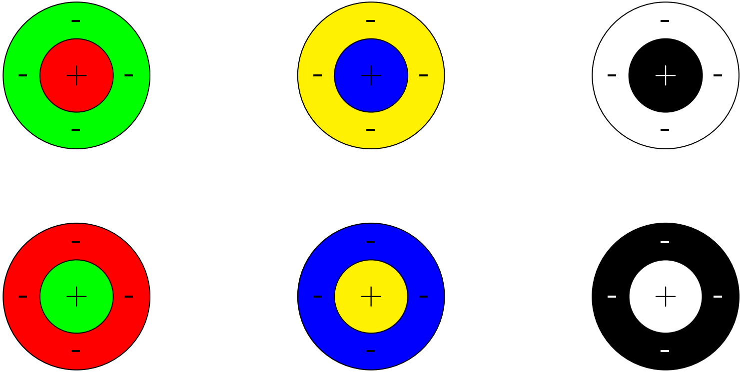
$BY = E_S - (E_L + E_M)$

$BW = E_L + E_M + E_S + E_R$

Opponent process theory

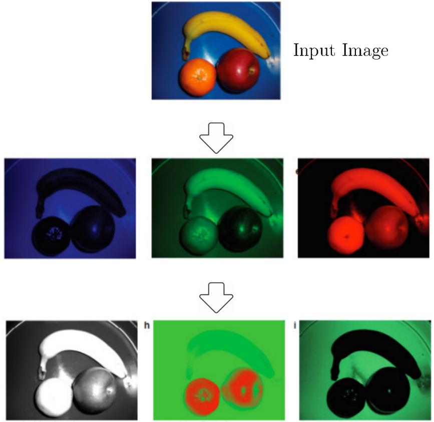
(Continued)

- Different organizations for opponent color sensitive cells



Dual (color) process theory

Stages of color processing



Input Image

Photosensors

Trichromatic Stage

Ganglion

Opponent Color Stage

Quiz

Quiz 02-04

End of Module 02-04