Color Vision, Color Theory and Color Models

Pengolahan Citra

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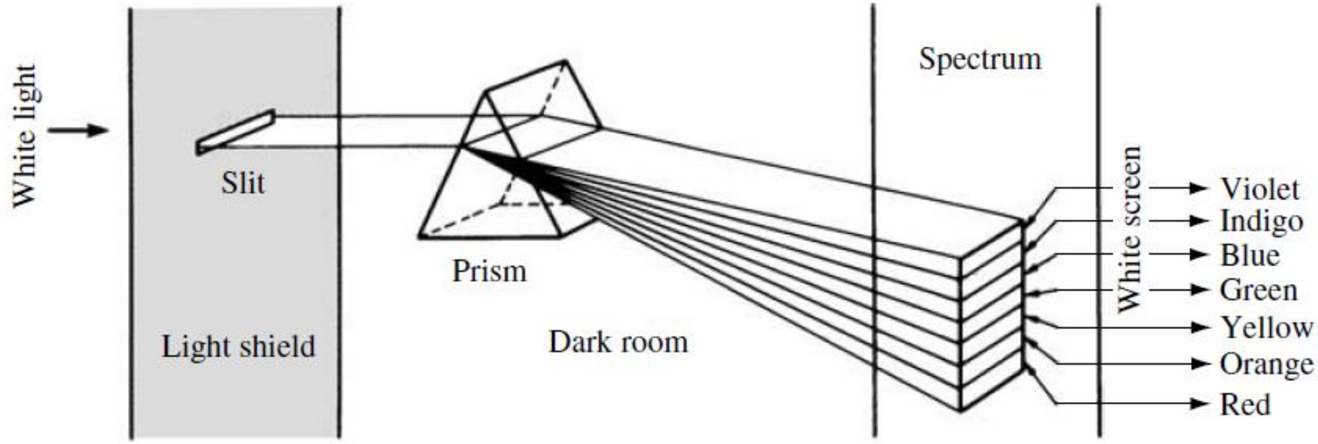
Color

- What is color?
- What is the relation between color and light?

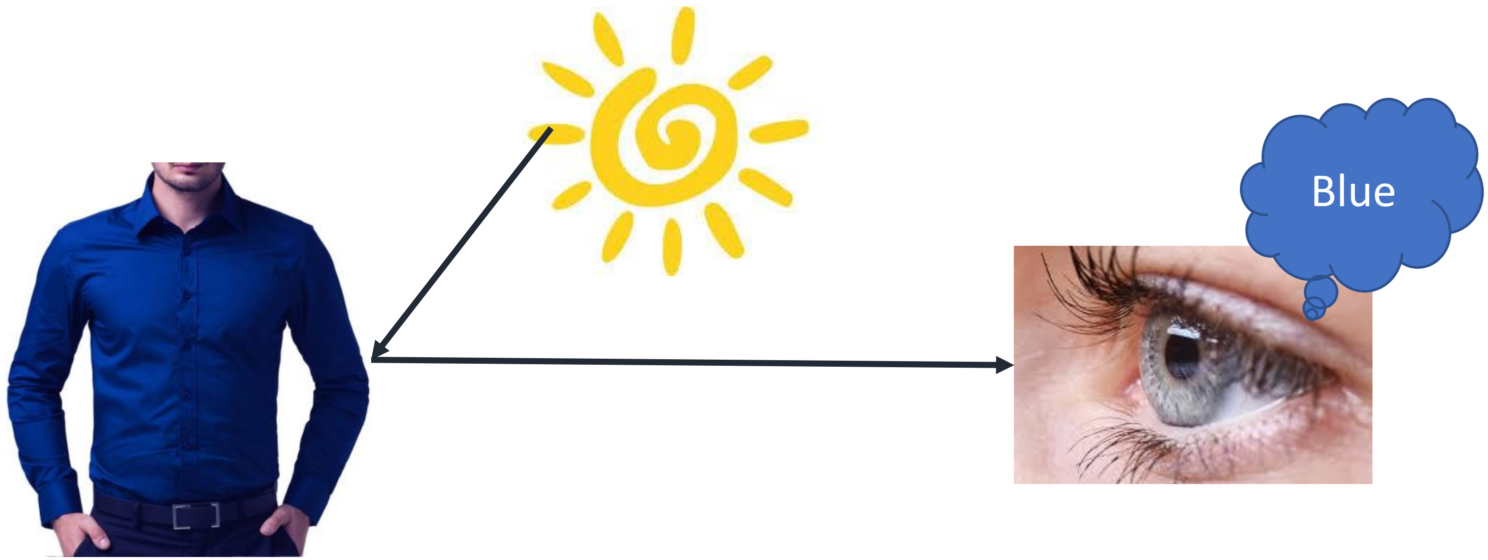
Newton's Experiment



- **Conclusion 1**: the white light was composed of a mixture of all colours in the spectrum
- **Conclusion 2**: the spectral colours were in fact the basic components (monochromatic lights) of the white light
- **Conclusion 3**: all the colours in the spectrum can be reunited to form the original white light again (by focusing the components back through a reversed prism).

Color Vision

- Recall image acquisition

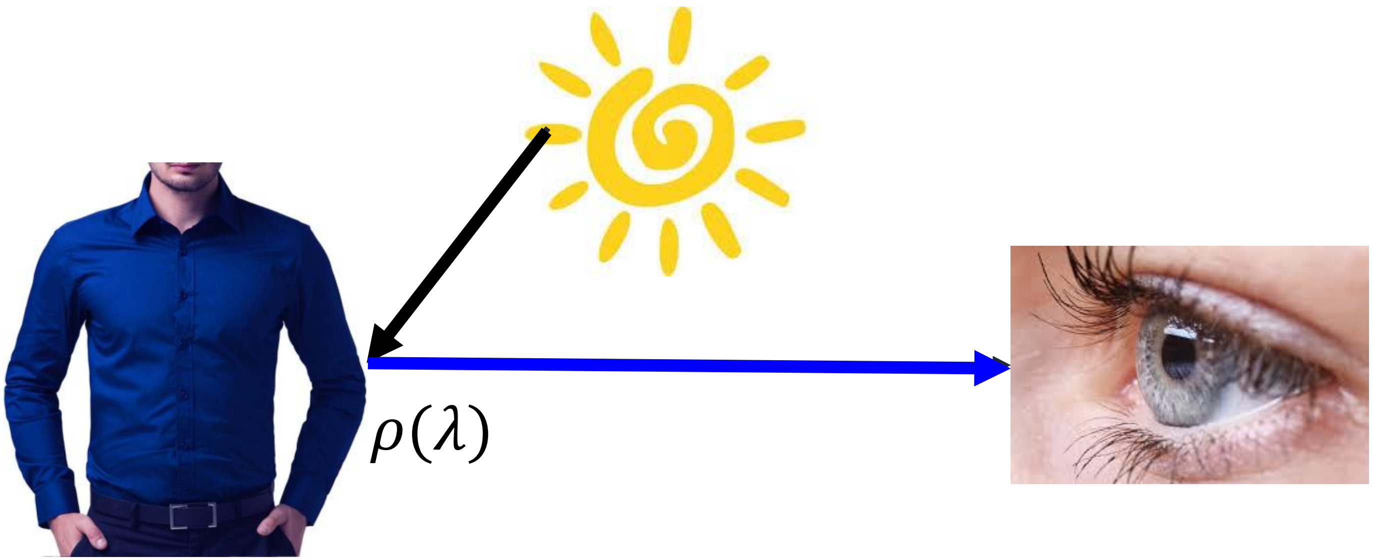


- Bagaimana sifat cahaya asal dari sumber cahaya?

White Light

Color Vision (2)

- Obyek berwarna memiliki *reflectance coefficient*.



- Obyek yang disinari *white light* akan memantulkan komponen cahaya pada panjang gelombang tertentu sesuai dengan *reflectance coefficient* → Mata manusia melihat **warna.**

Warna

- Warna adalah *persepsi / sensasi.*
- *Stimulus* warna adalah cahaya.

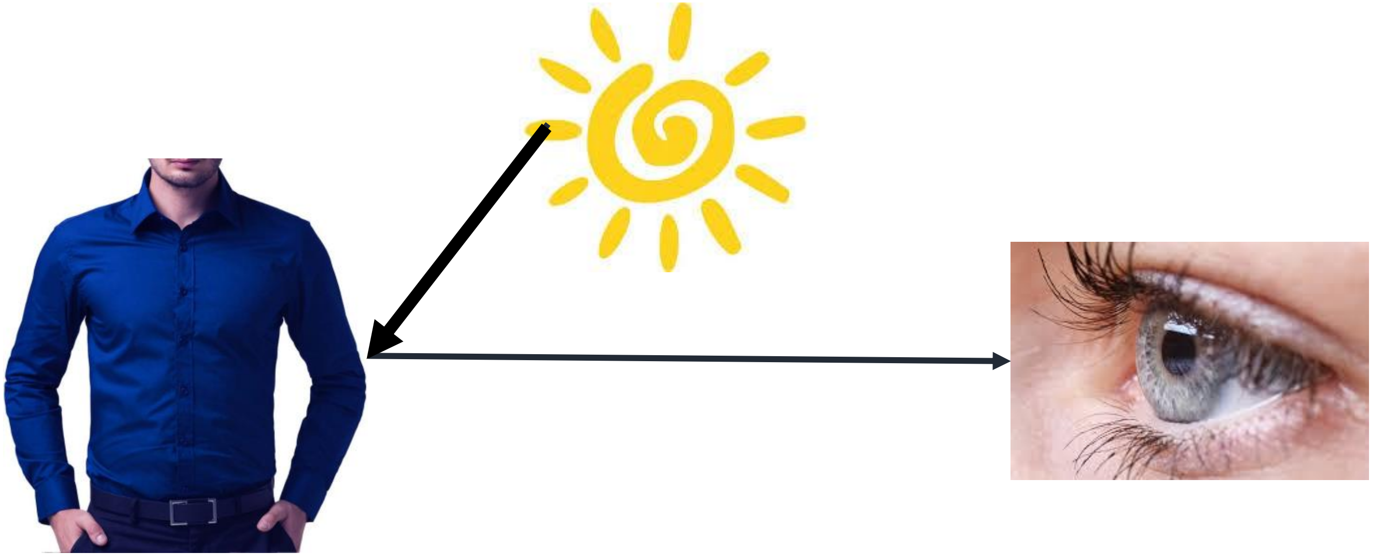
Ceritakan warna ini

Relative Perceptual Attributes of Color

- ***Brightness/Lightness***:
  - intensitas (sering disebut gray levels pada citra, dapat diukur dengan radiance atau luminance)
- ***Hue/Chroma***:
  - panjang gelombang dominan dalam campuran gelombang
  - kita menyebut suatu benda ‘merah’ atau ‘biru’ → berarti kita menyebutkan *hue*-nya
- ***Saturation***:
  - kemurnian relatif atau banyaknya kandungan warna murni dibandingkan dengan warna putih murni.

Color Theory

- Bagaimana peran mata dalam persepsi warna?



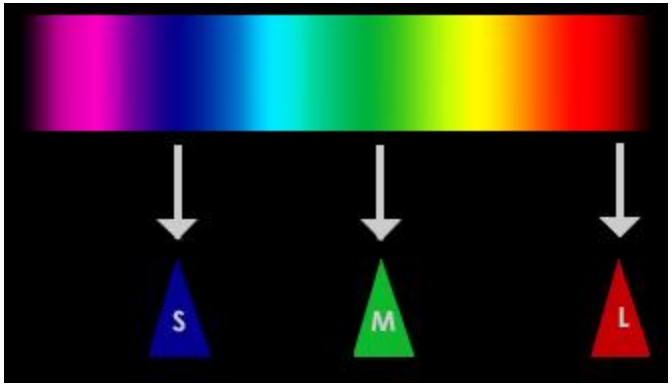
Color Theory: Trichromatic Color Vision

- Thomas Young (1802)
  - there are 3 types of photoreceptors in the eye.
  - the variables responsible for our color vision were in the eye and not in the light.
- James Clerk Maxwell (1855)
  - demonstrated by experiment that most colors could be matched by the mixture of 3 colors (3 primaries).
- Hermann von Helmholtz
  - proposed a hypothesis of 3 channels with different spectral sensitivities, supporting Maxwell's experiments

Young-Helmholtz Trichromatic Theory of Color Vision

Young-Helmholtz Trichromatic Theory of Color Vision

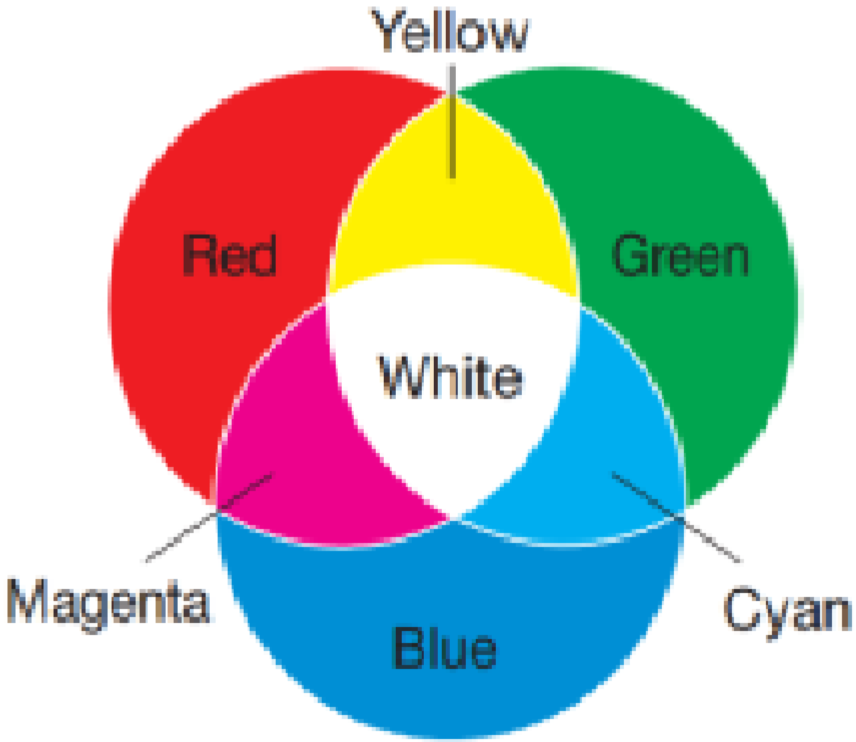
- There are three receptors in the retina that are responsible for the perception of color.
  - One receptor is sensitive to the color green, another to the color blue and a third to the color red.
- These three colors can then be combined to form any visible color in the spectrum.



Warna Primer vs Sekunder **Pada Cahaya**

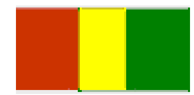
- Warna primer:
  - red (R)
  - green (G)
  - blue (B)
- Warna sekunder:
  - magenta (R+B)
  - cyan (G+B)
  - yellow(R+G)
- R+G+B: putih

Additive Color

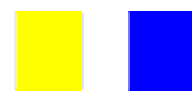


Three Sensitive Channels

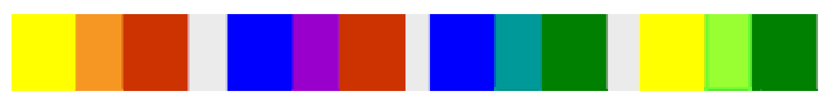
- Three sensitive channels are not **simply additive** in their response to light.
  - Red dan Green dapat menjadi warna kuning, yang tidak menampilkan unsur Red dan Green (tidak ada efek reddish-green)



  - Campuran warna Yellow dan Blue dapat menghasilkan putih yang tidak menampilkan unsur Yellow



  - Blue dan Yellow dapat bercampur dengan Red dan Green dengan tetap menampilkan unsur warna kandungannya



Color Theory: Opponent Color Theory

- Ewald Hering (1892)
  - pointed out a specific antagonism between certain hues
  - proposed three separated antagonistic (opponent) channels in the retina:
    - R-G channel
    - Y-B channel
    - B-W channel

Chromatic

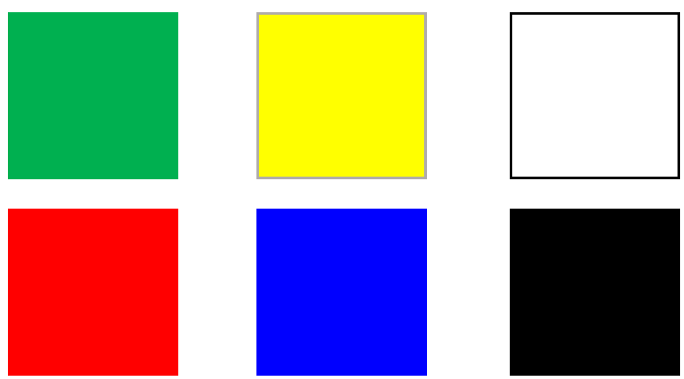
Luminance

- Boynton & Gordon (1965)
  - with only four unique hues (red, green, yellow and blue), all hues can be produced.

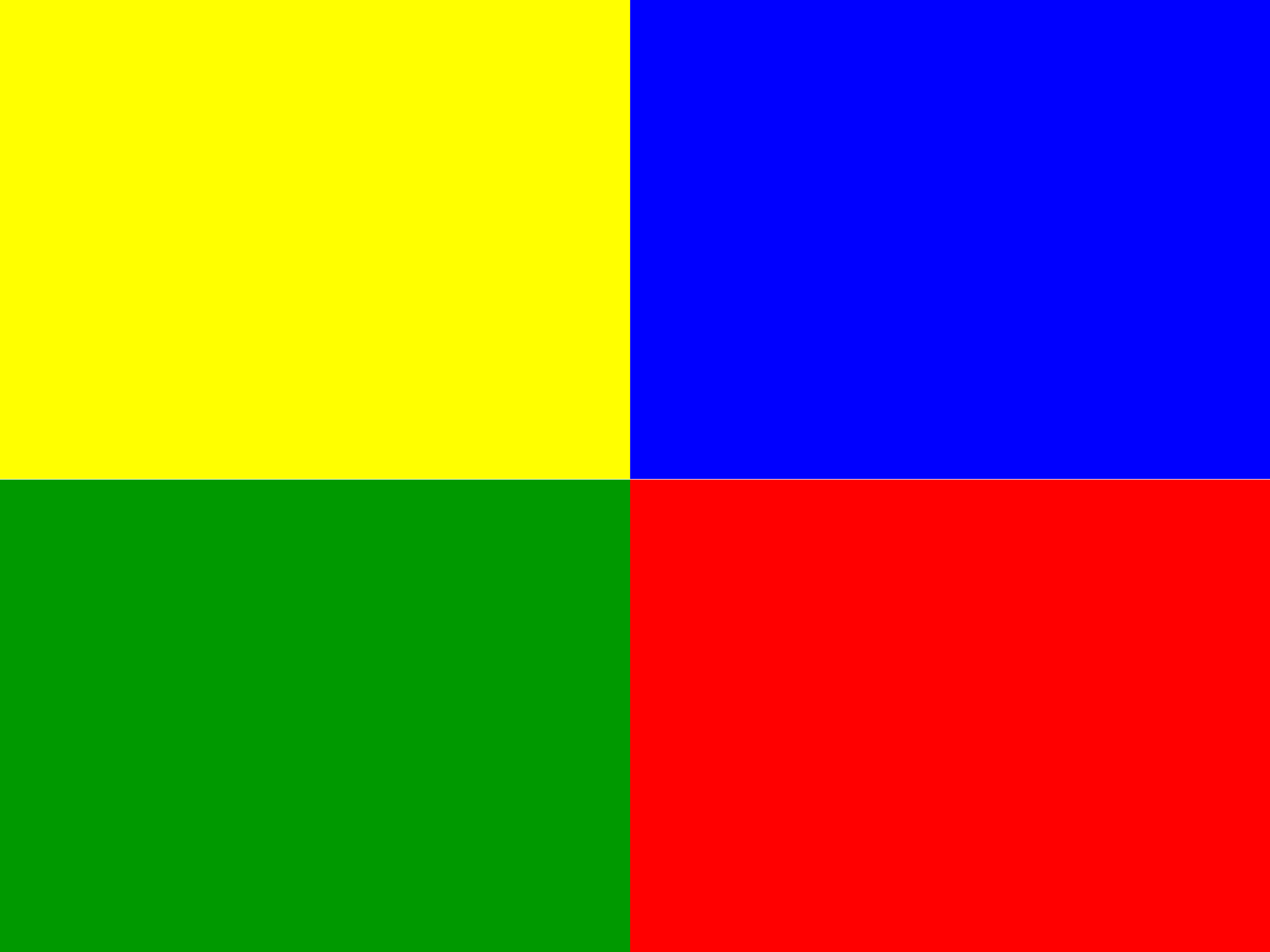
Opponent Theory of Color Vision

The Opponent Theory of Color Vision

- The four unique hues of red, green, yellow and blue when taken together with white and black form a group of six basic color properties.
  - Red and green are not only unique hues but are also psychologically opponent color sensations.
  - In the same way, yellow and blue are an opponent pair of color perceptions as are white and black.



The Opponent Theory of Color Vision



Complementary Afterimage

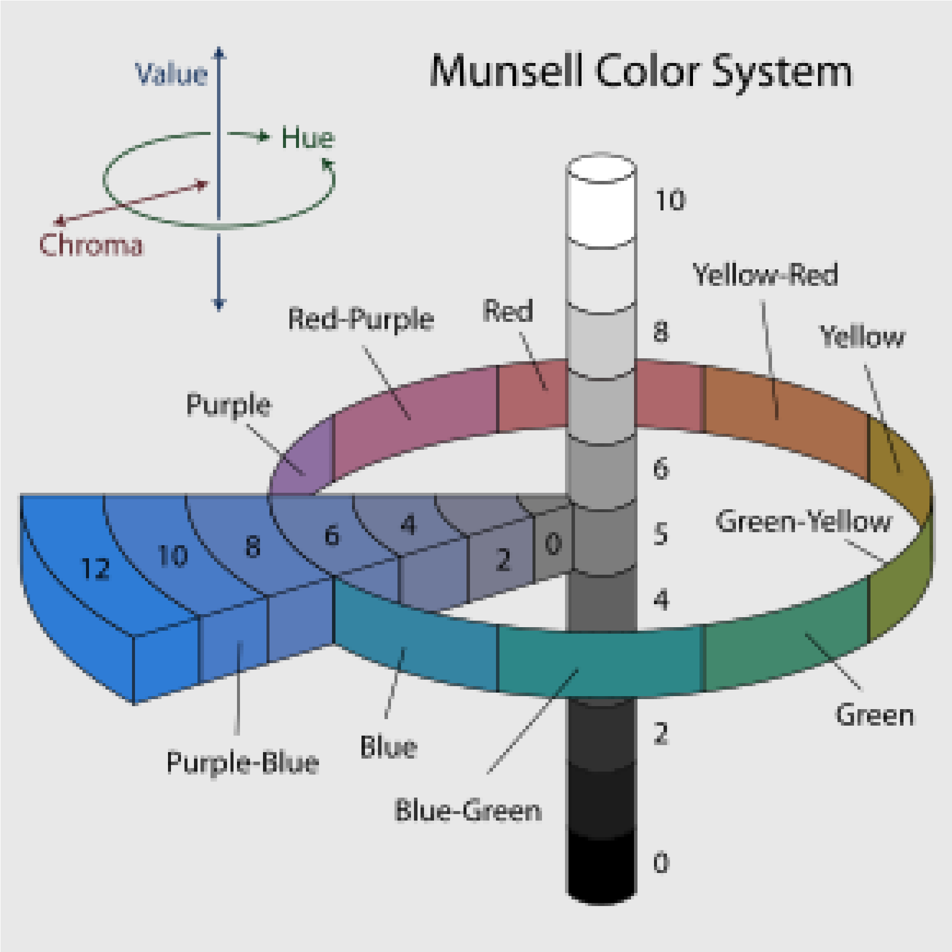
Serba-Serbi Warna

- Ada berapa warna yang bisa dibedakan oleh mata manusia?
  - Estimasinya lebih dari 1 juta warna yang unik
- Bagaimana caranya kita bisa saling mengkomunikasikan secara akurat suatu persepsi warna?
  - Sampel. Selain itu kosa kata manusia sangat terbatas.
- Kita butuh suatu sistem untuk mengurutkan warna-warna dan menfasilitasi spesifikasi warna berdasarkan attribut yang disepakati.

Color Order Systems / Color Model

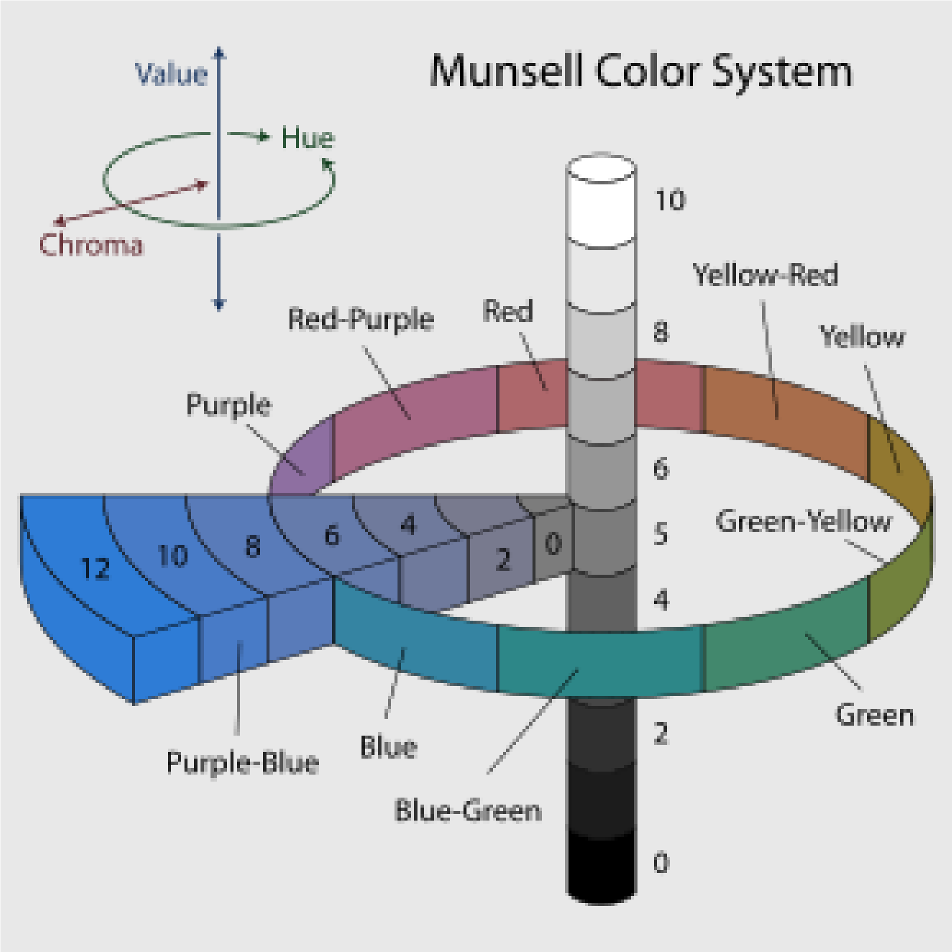
The Munsell Color System

- Oleh A.H. Munsell (1905)
- Menggunakan 3 atribut:
  - Hue
  - Value
  - Chroma



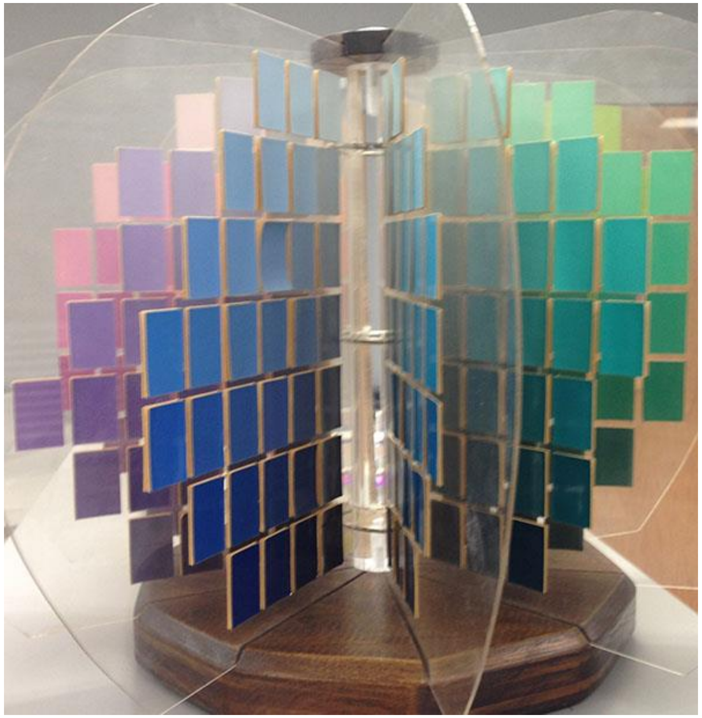
The Munsell Color System

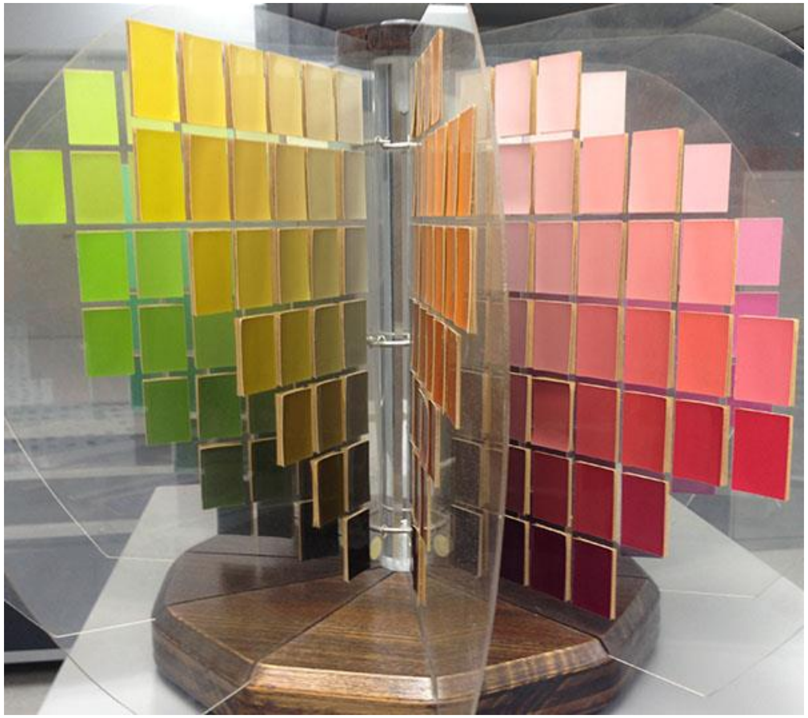
- *Hue* diatur dalam lingkaran
- *Value* adalah suatu sumbu yang tegak lurus terhadap lingkaran.
- *Chroma* adalah jarak dari tengah lingkaran Hue.



The Munsell Color System

- Pada dasarnya mempunyai 5 *hue* utama: Red, Yellow, Green, Blue, Purple





CIE 1931 Color Space

- CIE: Commission internationale de l'éclairage (International Commission on Illumination) is the international authority on light, illumination, colour, and colour spaces.
- CIE Color Spaces:
  - first defined quantitative links between distributions of wavelengths in the electromagnetic visible spectrum, and physiologically perceived colors in human color vision.
- CIE Color Spaces
  - CIE 1931 RGB
  - CIE 1931 XYZ

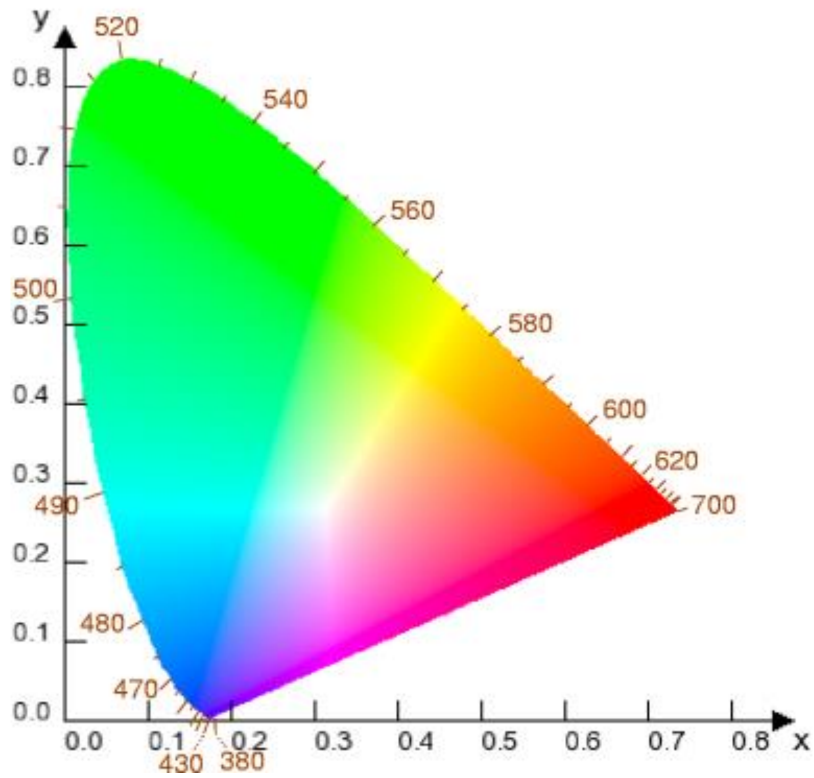
XYZ Tristimulus Values

- Additive color theory:
  - 3 buah warna (R,G, and B) yang diterima di retina dapat dikombinasikan menjadi warna apa saja dalam spectrum.
- Jumlah warna R, G, dan B yang dibutuhkan disebut sebagai *tristimulus values*: X,Y,Z.
- Warna tsb lalu bisa dinyatakan dengan *trichromatic values: z,y,z*

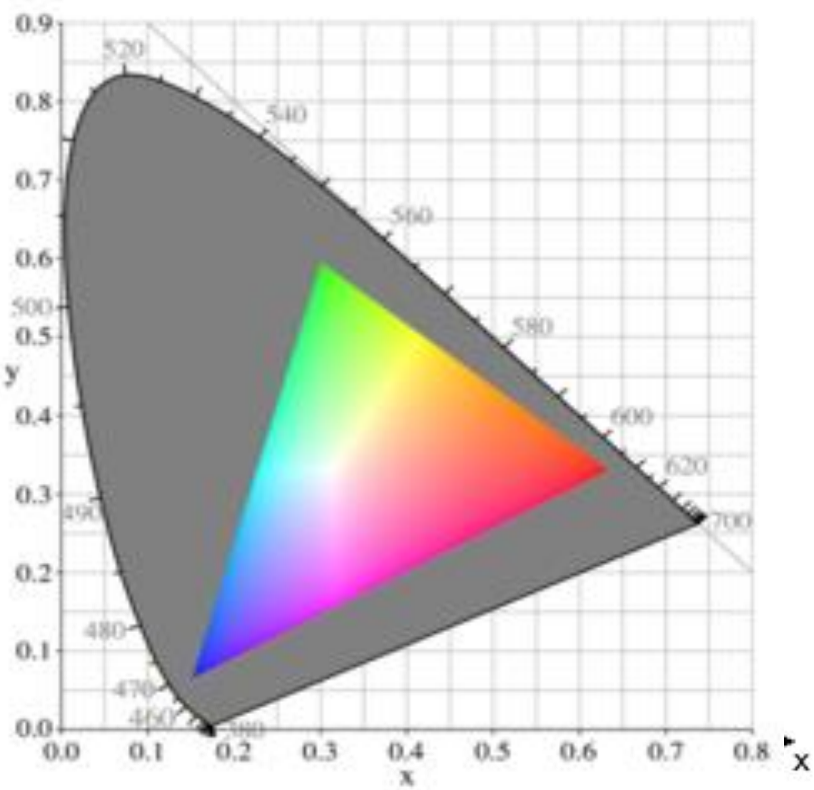
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

  - Note that $x + y + z = 1$
  - Using x and y, we can plot the colors..

CIE Chromaticity Diagram



What about digital monitors?



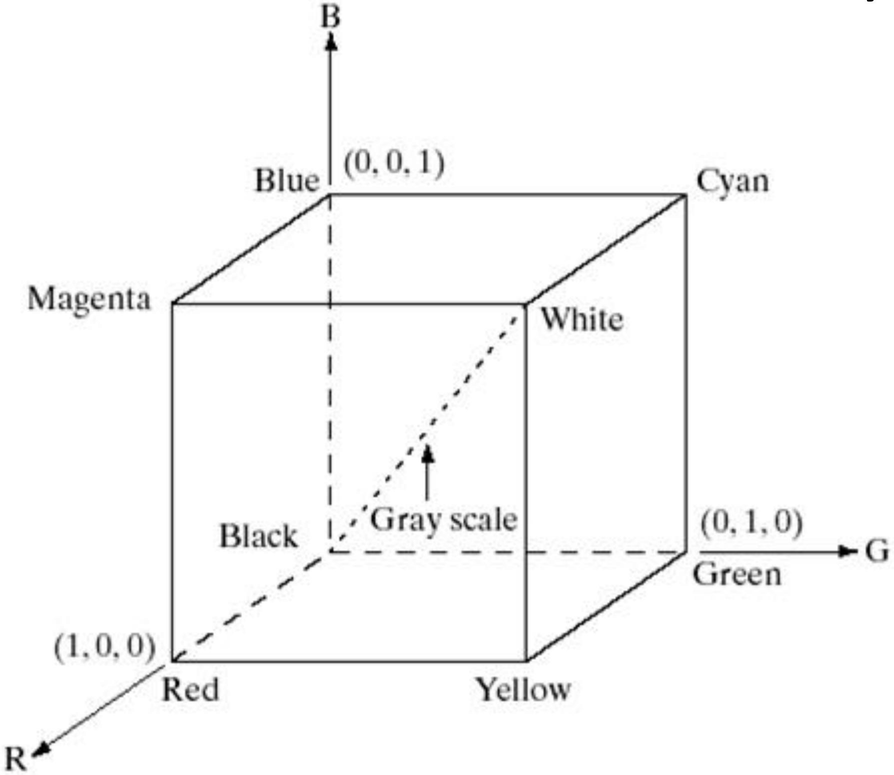
- Colors that exist ≠colors we can reproduce digitally

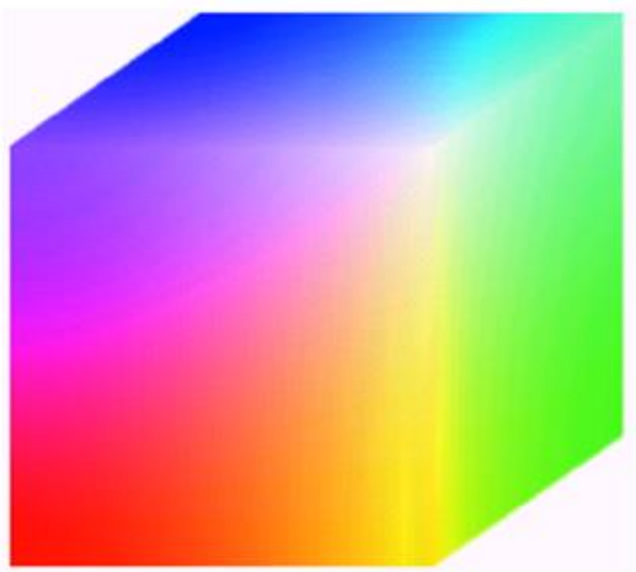
Color Models for Hardware

- **RGB** untuk monitor warna dan kamera video
- Model **CMYK** untuk printer warna

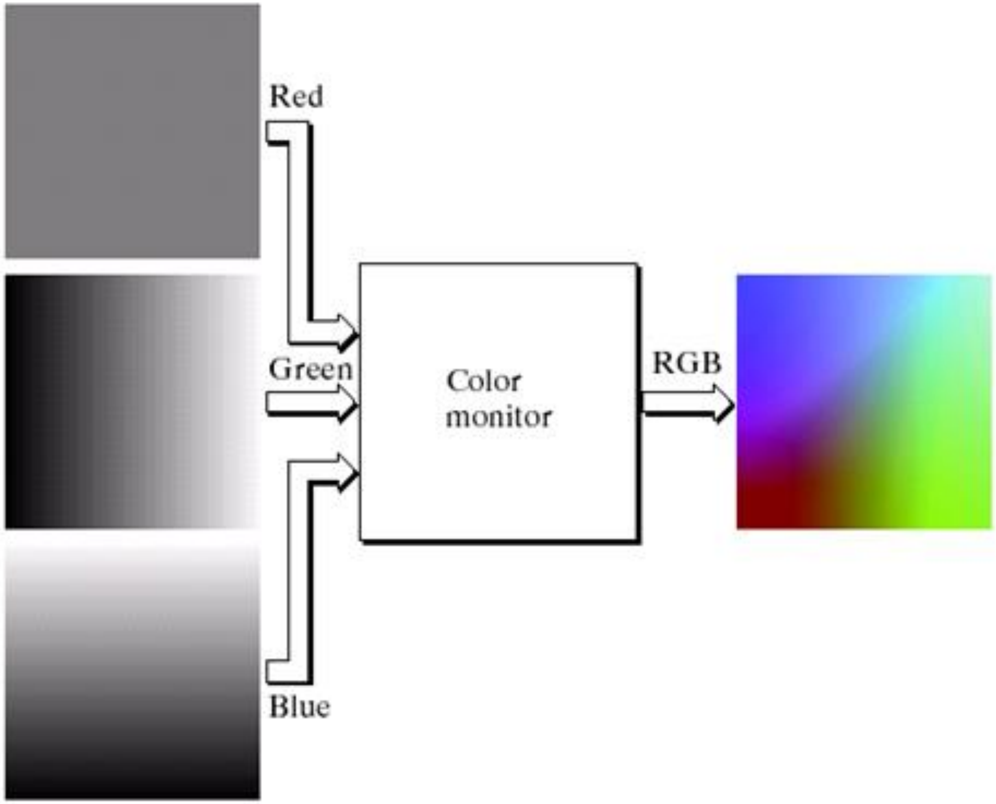
RGB Color Model

- Standard model for color monitor
- Based on tri-stimulus theory of color vision





RGB Channels



RGB Colors

- Antar sistem/hardware ada banyak variabel, jadi dibutuhkan ada subset warna yang selalu dapat direproduksi *reliably*
  - Safe RGB colors / all-systems safe colors / safe Web colors/ safe browser colors.
- Dengan variasi antar sistem warna bisa diproses dengan berbeda
  - Kita punya 216 warna yang bisa direproduksi **semua** sistem secara *de facto*

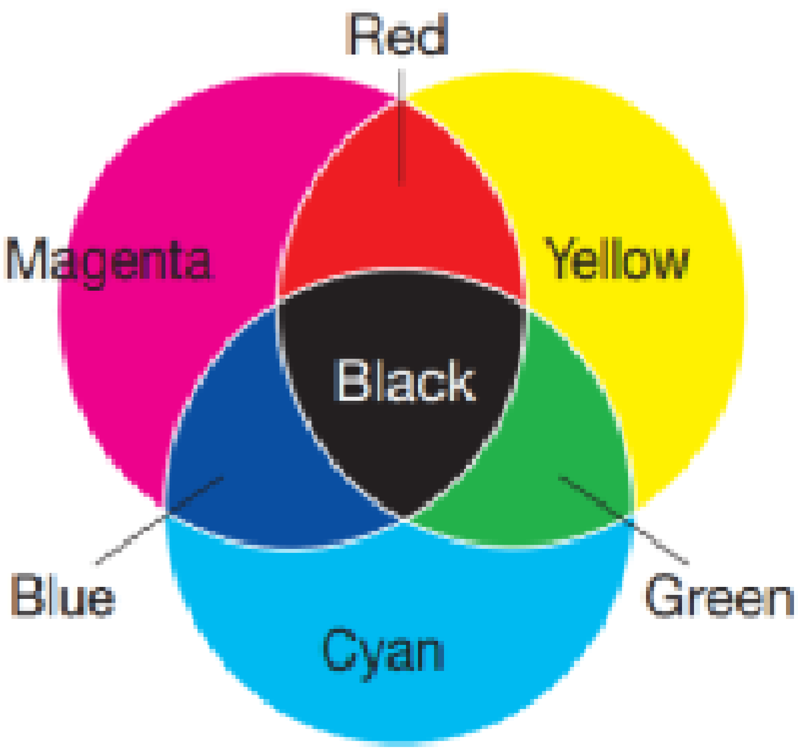
Warna

- Warna Primer pada cahaya:
  - R
  - G
  - B
- Reproduksi warna pada alat elektronik?
  - Cahaya
- Reproduksi warna pada media cetak?
  - **Pigmen**

Warna Primer vs Sekunder **Pada Pigmen**

- Warna primer:
  - magenta
  - cyan
  - yellow
- Warna sekunder:
  - red
  - green
  - blue
- R+G+B: black

Subtractive Color



Model CMY

- Cyan Magenta Yellow (CMY) adalah *substractive primaries*, untuk pigmen.
- Model CMY digunakan sebagai *color model* bagi printer dan alat cetak lainnya.
- CMYK
  - K adalah warna HITAM
  - CMY dicampur tidak dapat menghasilkan warna hitam pekat

RGB ↔ CMY

- Range nilai RGB:
  - 8-bit: 0-255
- Jika nilai RGB dinormalisasi menjadi range [0,1]

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

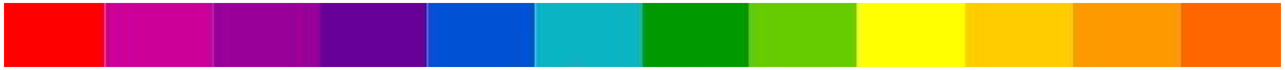
- Var K?
  - 1, di mana C,M,Y semuanya bernilai 0

RGB and CMY in a Glance

- Creating colors in RGB and CMY is straightforward
  - Additive or subtractive colors.
- It is easy to convert colors from RGB to CMY and vice versa.
- RGB: is easy to understand based on human photopic vision
  - The vision captured by the R,G,B cone cells
- RGB and CMY are both ideal for hardware implementation
- But,
  - RGB and CMY are not ideal to describe how *humans* perceieve colors.

HSI (also known as HSV / HSL)

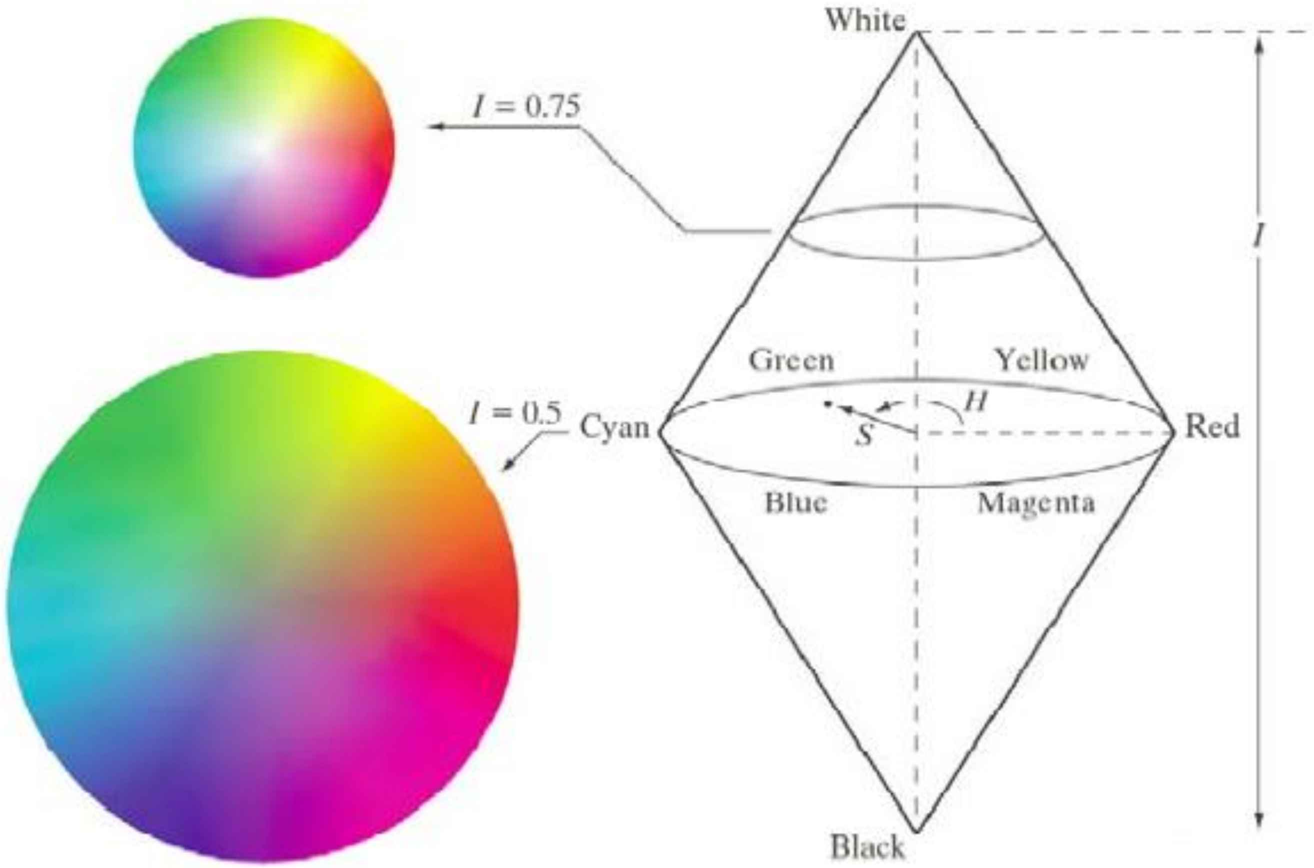
- Hue



- Saturation

- Intensity

HSV / HSL / HSI



RGB→HSI

- Intensity

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

- Saturation

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

- Hue

$$H \begin{cases} \theta & if\ B \leq G \\ 360 - \theta & if\ B > G \end{cases}$$

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

Look it up yourselves..

- **Color systems:**
  - CIEXYZ, CIELAB, CIELUV,…
  - RGB variants: sRGB, Adobe RGB, …
  - YIQ, YUV, YCbCr,…