Computer Vision

Color and Color Images

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Abstract

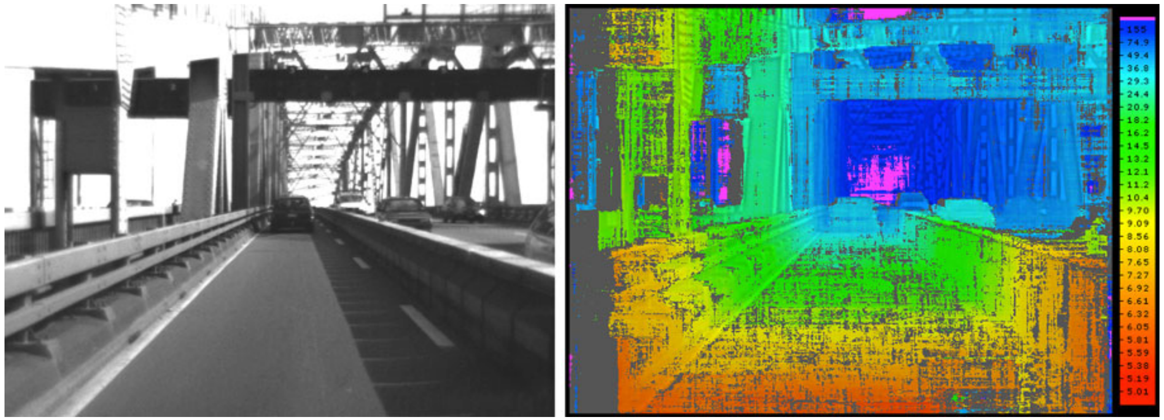
- This lecture informs about some subjects related to the topic *color* and provides details for the *RGB* and *HSI color models*.

Color and Color Images

- Color is not objectively defined. Color perception varies for people, and it depends on lighting.
- If there is no light, there is no color, such as, for example, inside of a non-transparent body.
- Human vision can only discriminate a few dozens of grey levels on a screen, but hundreds to thousands of different colors.

Color and Color Images

- Color can be an important component of given image data, and it is valuable for visualizing information by using false colors.



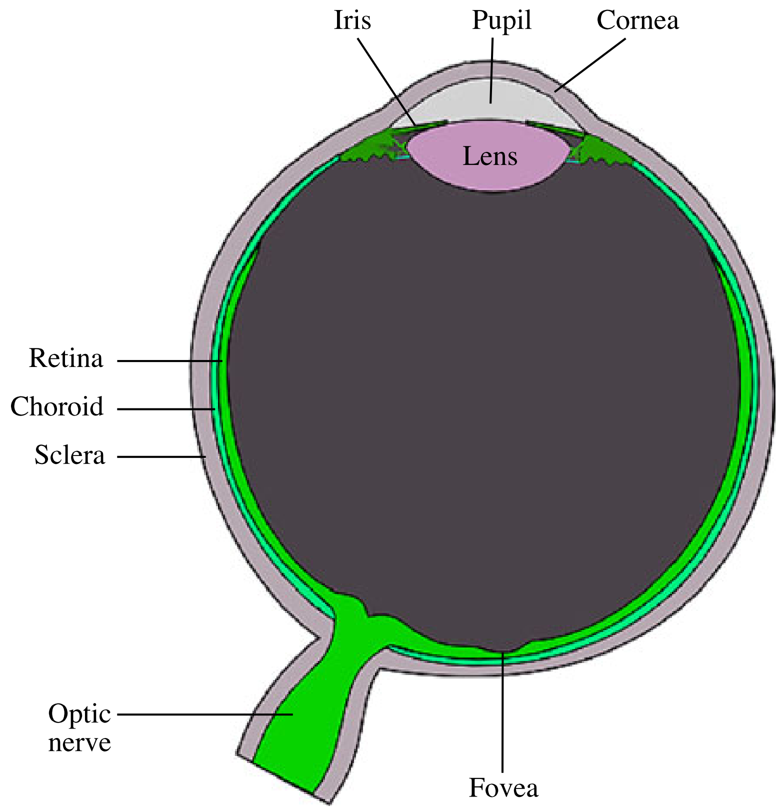
Source: R. Klette

Color Definitions

- An “average human” perceives color in the visible spectrum as follows:
  - Red (625 to 780 nm) and Orange (590 to 625 nm) for the *long wavelengths* of the visible spectrum;
  - Yellow (565 to 590 nm), Green (500 to 565 nm), and Cyan (485 to 500 nm) in the *middle range*.
  - Blue (440 to 485 nm) for the *short wavelengths* and violet (380 to 440 nm) for very short wavelengths.

Color and Color Images

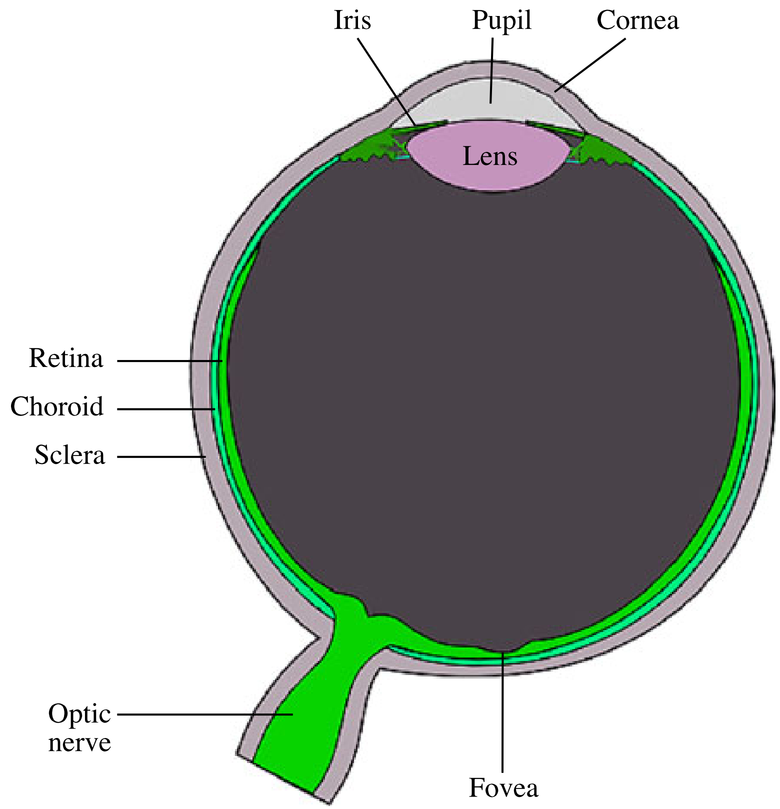
- The photoreceptors (about 120 million rods and 6 to 7 million cones) in the retina of the human eye are located in the fovea.



Source: R. Klette

Color and Color Images

- Experimental evidences suggest we have three types of color-sensitive cones, corresponding roughly to Red (64 % of the cones), Green (32 %), and Blue (2 %).



Source: R. Klette

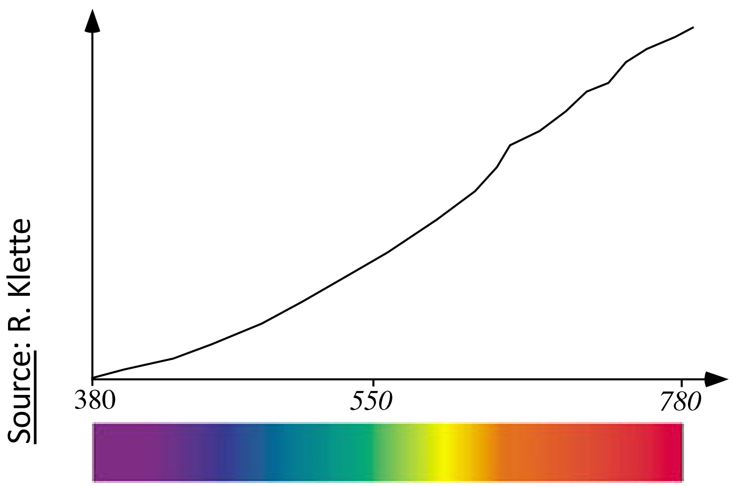
Tristimulus Values

- Visible color is modeled by *tristimulus values* for Red, Green, and Blue components of the visible light.

- The CIE (*Commission Internationale de l'Eclairage*) has defined color standards since the 1930s.

Tristimulus Values

- A light source creates an energy distribution $L(\lambda)$ for the visible spectrum for wavelengths $380 \leq \lambda \leq 780$ of monochromatic light. Example:



Tristimulus Values

- Such an energy distribution is mapped into three *tristimulus values* X, Y, and Z as follows:

$$X = \int_{400}^{700} L(\lambda)\overline{x}(\lambda)\,\mathrm{d}\lambda$$

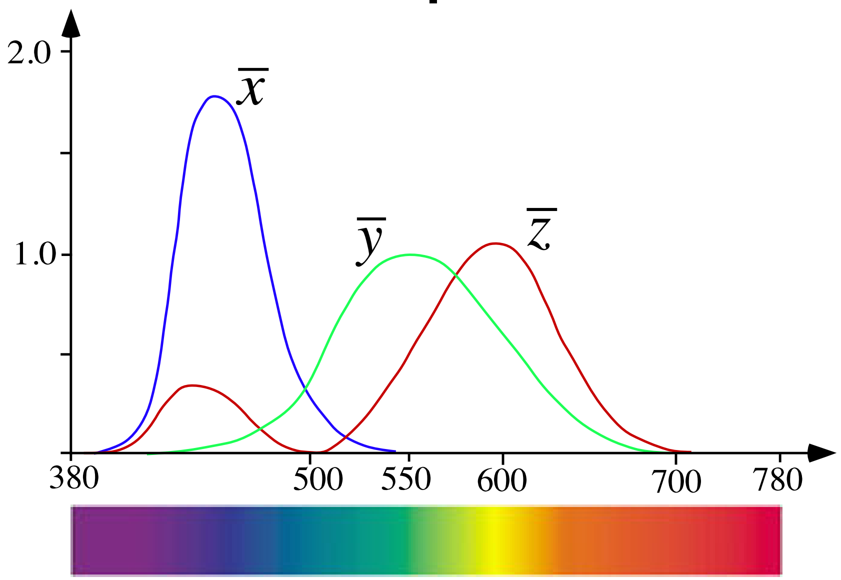
$$Y = \int_{400}^{700} L(\lambda)\overline{y}(\lambda)\,\mathrm{d}\lambda$$

$$Z = \int_{400}^{700} L(\lambda)\overline{z}(\lambda)\,\mathrm{d}\lambda$$

- The weighting functions $\overline{x}$, $\overline{y}$ and $\overline{z}$ have been defined by the CIE within the visible spectrum.

Tristimulus Values

- The cut-offs of those weighting functions do not correspond exactly to human-eye abilities:



- The weighting functions $\bar{x}$, $\bar{y}$ and $\bar{z}$ have been defined by the CIE within the visible spectrum.

Tristimulus Values

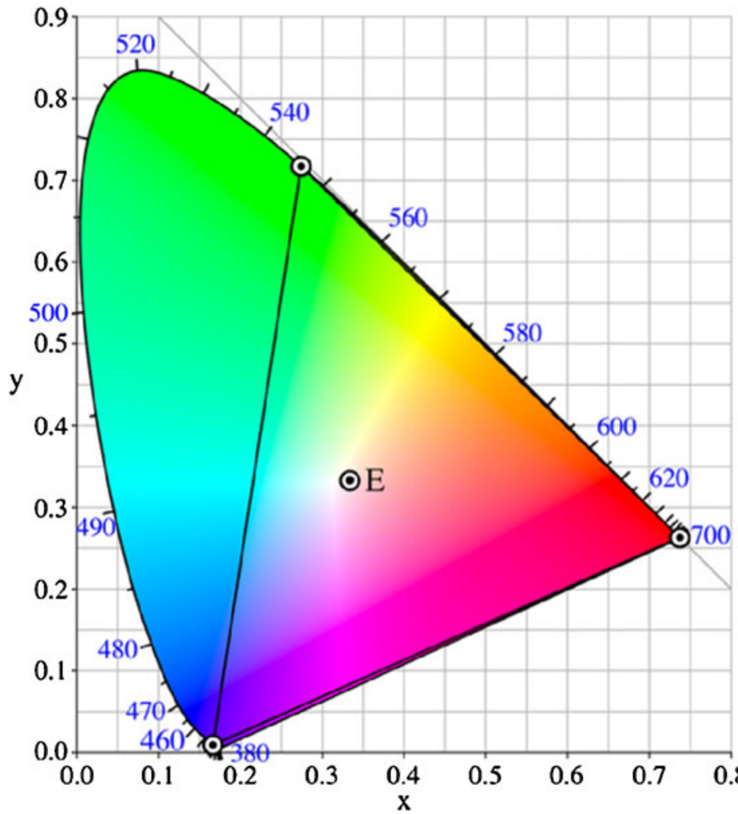
- The *tristimulus values* X, Y and Z define the *normalized xy*-parameters:

$$x = \frac{X}{X+Y+Z} \quad \text{and} \quad y = \frac{Y}{X+Y+Z}$$

- Parameters x and y define the *CIE Color Space*.

Color and Color Images

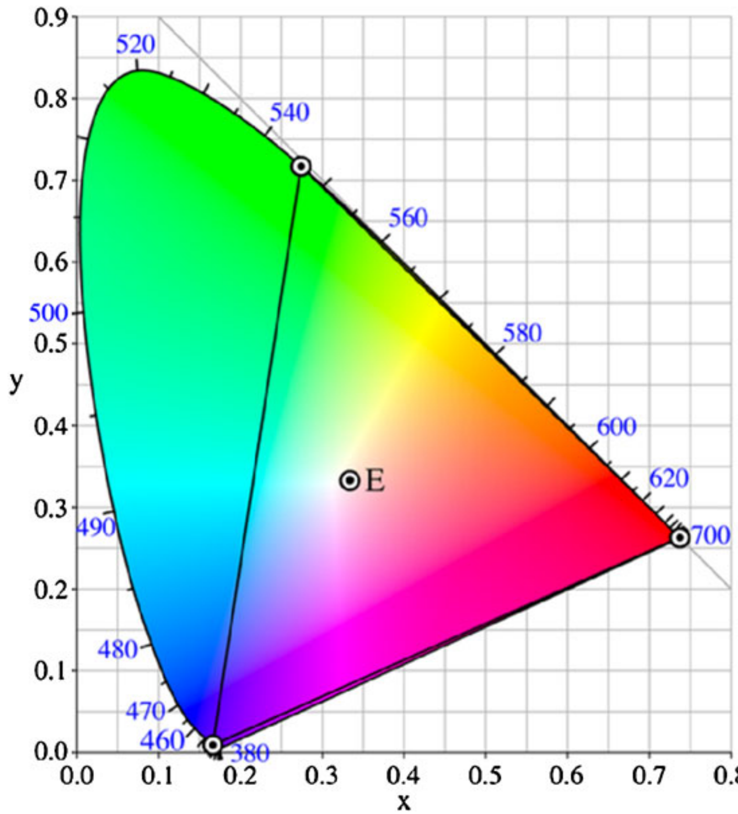
- The *xy* CIE color space is represented by a chromaticity diagram.
- It shows the *gamut* of human vision, i.e. , the colors that are visible to an average person.



Source: R. Klette

Color and Color Images

- The convex outer curve in the diagram contains *monochromatic colors*.
- Inside the gamut, there are less *saturated colors*, with white at the center $E = (0.33, 0.33)$.



Source: R. Klette

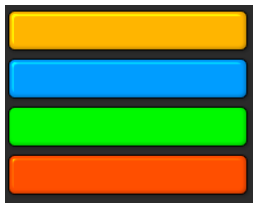
Monochromatic Color

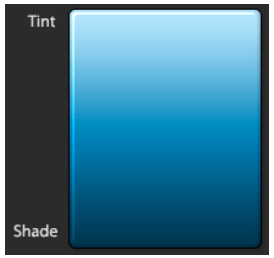
- *Monochromatic color* refers to a color scheme that is comprised of variations of one color.

- You can use any color to create a monochromatic color scheme. Examples: adding white to red creates pink; adding black to red creates maroon.

Monochromatic Color

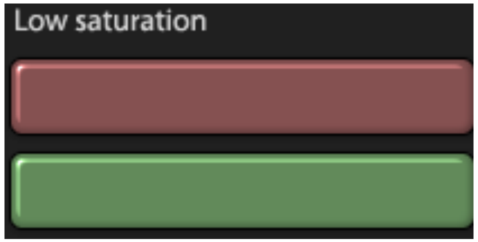
- The three main components of a monochromatic color scheme are:
  - **Hue**: a particular color (base color);
  - **Shade**: a darker version of a particular color;
  - **Tint**: a lighter version of a particular color.





Saturation

- *Color saturation* is used to describe the *intensity* of color. It is a measurement of how different from pure grey, the color is.
- Saturation is not really a matter of light and dark, but rather how pale or strong the color is.



Color Perception

- When designing figures for presentations, it is important to think about a good color scheme.
- The idea is that all of the audience can see best what is supposed to be visualized.
- Color perception varies for people, and it depends on lighting.

Red-Green Color Blindness

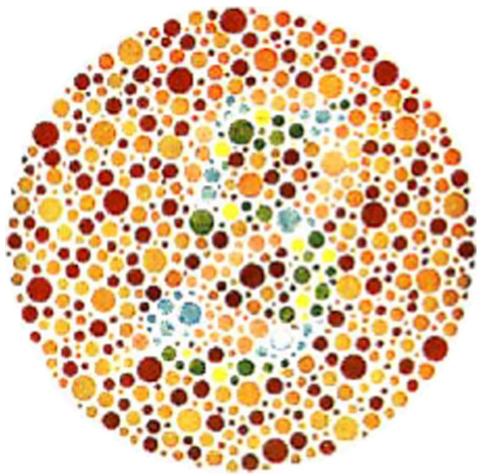
- Color blindness means that some colors cannot be distinguished.

- In about 99 % of cases this is red-green color blindness. Total color blindness is extremely rare (i.e. seeing only shades of grey).

Red-Green Color Blindness

- Estimates for red-green color blindness for people of European origin are about 8-12 % for males and about 0.5 % for females.

Source: R. Klette



- Normal color vision sees a 5 revealed in the dot pattern, but an individual with red-green color blindness sees a 2.

Primary Color Perceptions

- Humans perceive color differently; “color” is a psychological phenomenon.
- But there appears to be agreement that Yellow, Red, Green, and Blue define the four *primary color perceptions*.

Source: R. Klette

Grey Levels

- Grey levels are not colors; they are described by the *luminance* (the physical intensity) or the *brightness* (the perceived intensity).

- A uniform scale of grey levels or intensities is common, such as:

$$u_k = k/2^a \quad \text{for } 0 \le k < 2^a$$

Grey Levels

- Look at this effect: both squares below have the same constant intensity. Human vision perceives the ratio of intensities.

Source: R. Klette

Color Representations

- The figure below shows an RGB color image and its representation in three scalar channels (Red, Green, and the Blue components).

Source: R. Klette

Color Representations

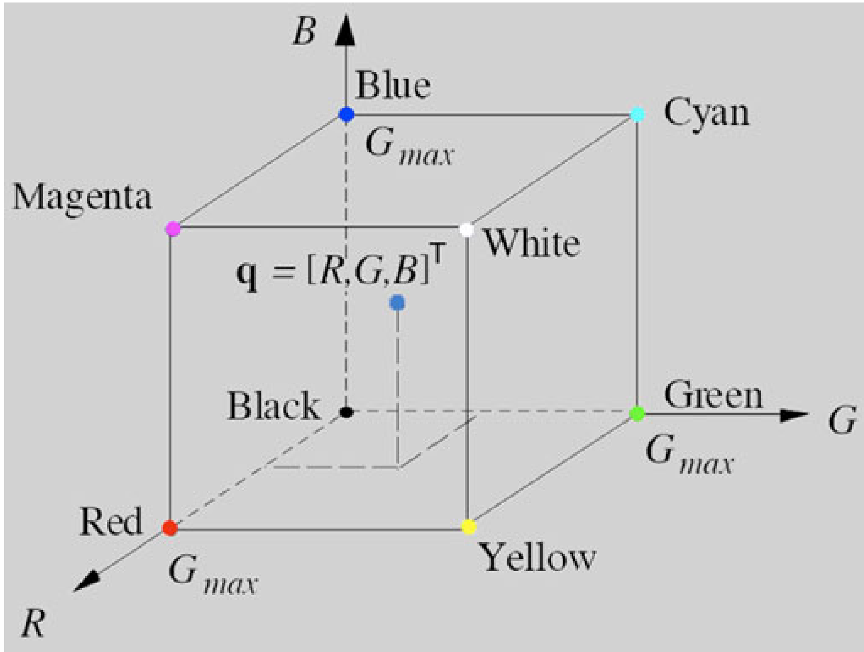
- The used RGB color representation model is *additive*.
- That is, adding to a color, which means increasing values in its scalar representation, contributes to going towards White.
- This is the common way for representing colors on a screen.

The RGB Space

- Assume that $0 \leq R, G, B \leq G_{\max}$ and consider a multi-channel image with pixel values $\mathbf{u} = (R, G, B)$.
- If $G_{\max} = 255$, then we have 16,777,216 different colors, such as $\mathbf{u} = (255, 0, 0)$ for Red, $\mathbf{u} = (255, 255, 0)$ for Yellow, and so forth.
- The set of all possible RGB values defines the RGB cube.

The RGB Space

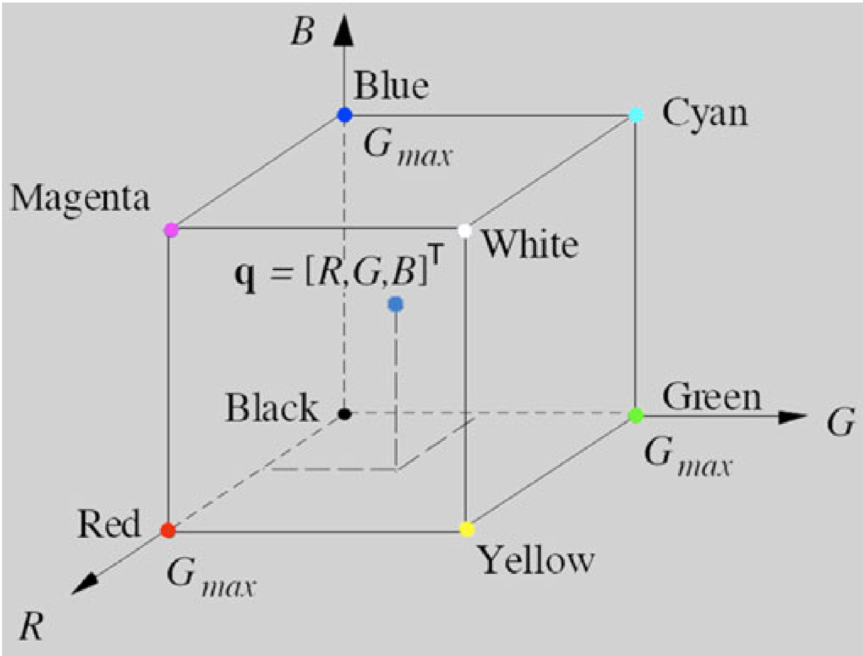
- The diagonal in this cube, from White to Black, is the location of all grey levels (u,u,u), which are not colors.



Source: R. Klette

The RGB Space

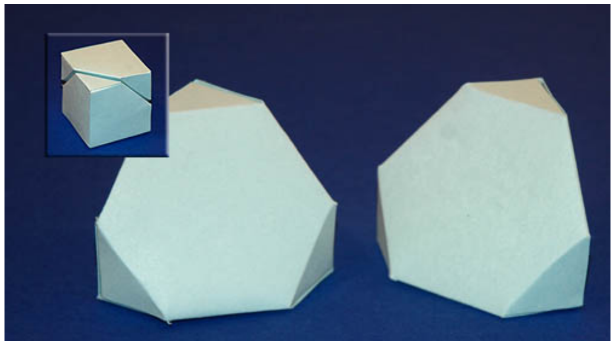
- In general, a point $\mathbf{q} = (R, G, B)$ in this RGB cube defines either a color or a grey level, where the mean $M = (R + G + B)/3$ defines the *intensity* of color or grey level $\mathbf{q}$.

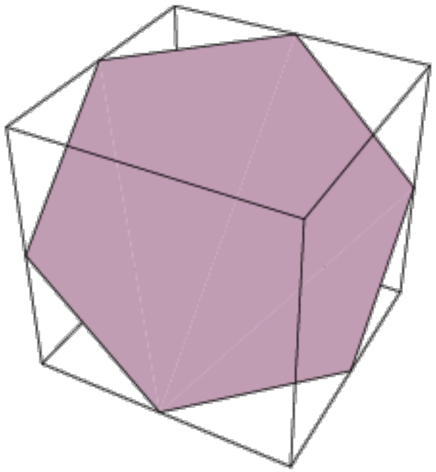


Source: R. Klette

The HSI Space

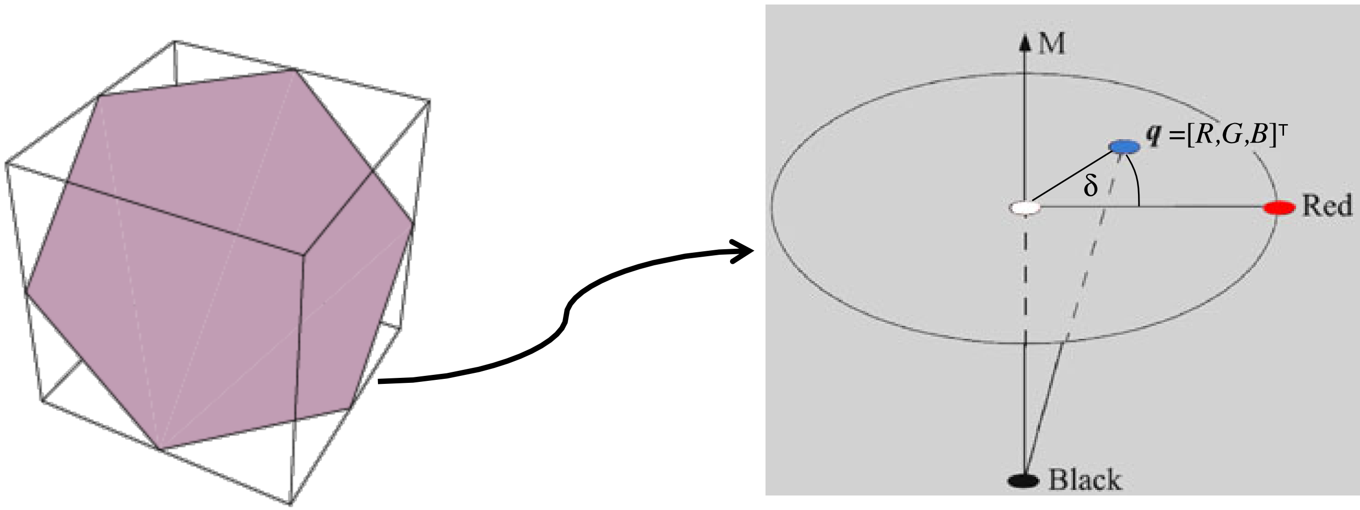
- Consider a plane that cuts the RGB cube orthogonally to its diagonal, with $\mathbf{q} = (R, G, B)$ incident with this plane but not on the diagonal.





The HSI Space

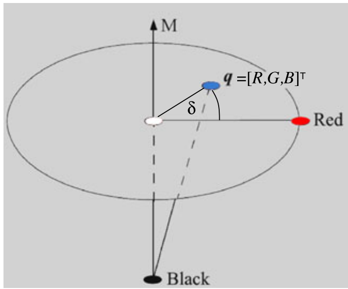
- In an abstract sense, we represent the resulting cut by a *disk*, ignoring the fact that cuts of such a plane with the cube are actually simple polygons.



Source: R. Klette

The HSI Space

- For the disk, we fix one color for reference; for instance the Red color.
- The location of $\mathbf{q}$ in the disk is uniquely defined by an angle H (the *hue*) and a distance S (the *saturation*) from the grey-level diagonal of the RGB cube.



Source: R. Klette

The HSI Space

- Formally, we have:

$$H = \begin{cases} \delta & \text{if } B \leq G \\ 2\pi - \delta & \text{if } B > G \end{cases} \quad \text{with}$$

$$\delta = \arccos \frac{(R-G)+(R-B)}{2\sqrt{(R-G)^2+(R-B)(G-B)}} \quad \text{in } [0, \pi)$$

$$S = 1 - 3 \cdot \frac{\min\{R, G, B\}}{R+G+B}$$

The HSI Space

- Grey levels (u,u,u) with $u \neq 0$ have the intensity $M = u$ and the saturation $S = 0$, but the hue H remains undefined because δ is undefined (division by zero).
- In the case of Black $(0,0,0)$, the intensity is $M = 0$, and the saturation and hue remain undefined.
- So, in the case of White, what do we have?

The HSI Space

- Besides these cases of points in the RGB cube representing non-colors, the transformation of RGB values into HSI values is one-to-one.
- That is, we can also transform HSI values uniquely back into RGB values.
- The hue and saturation may represent RGB vectors with respect to an assumed fixed intensity.

The HSI Space

- Some examples:
  - Red (Gmax,0,0)
    - Intensity?
    - Saturation?
    - Hue?

$$M = G_{\max}/3$$
$$S = 1$$
$$H = 0$$

  - Green (0,Gmax,0)
    - Intensity?
    - Saturation?
    - Hue?

$$M = G_{\max}/3$$
$$S = 1$$
$$H = \arccos(-0.5) = 2\pi/3$$

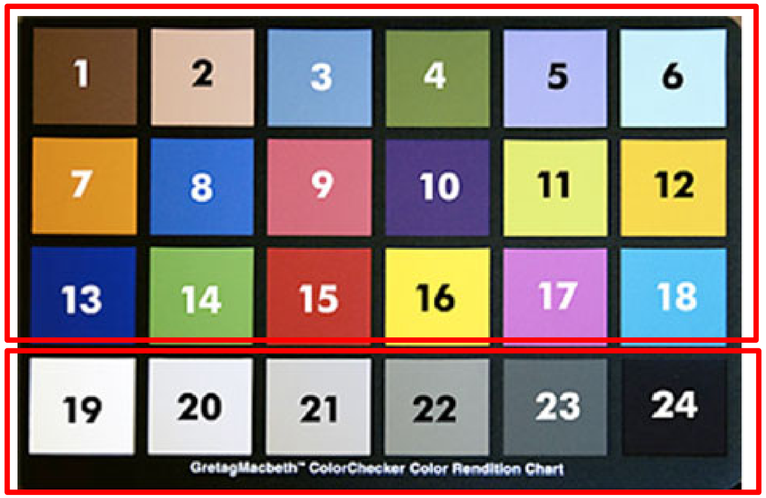
Color Checker

- The figure below shows one of the *color checkers* used for testing color accuracy of a camera, to be used for computer vision applications.

Source: R. Klette

Color Checker

- There are three rows of very precisely (uniform) colored squares numbered 1 to 18 and one row of squares showing grey levels.

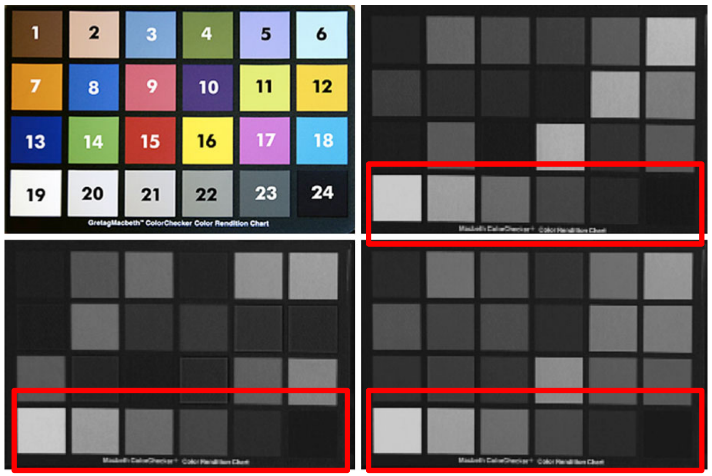


Source: R. Klette

Color Checker

- Assuming monochromatic light, all the grey-level squares should appear equally in the channels for Red, Green, Blue, and intensity.

Blue Channel



Green Channel

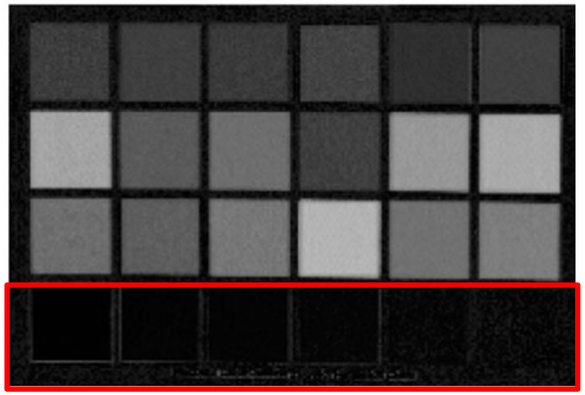
Intensity

Source: R. Klette

Color Checker

- The image of the saturation channel illustrates that grey levels have the saturation value zero assigned in the program.

Source: R. Klette

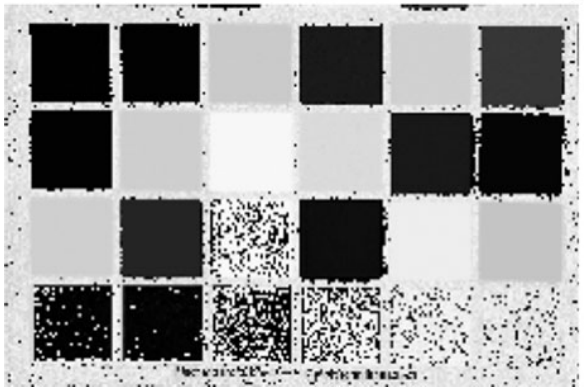


Saturation

Color Checker

- Note that the hue value for reference color Red (Square 15) also “jumps” from white to black, as expected.

Source: R. Klette



Hue

Next Lecture

- Point, Local and Global Operators

Gradation Functions. Local Operators. Fourier Filtering.

- Suggested reading

  - Section 2.1 of textbook.