Karlsruhe Institute of Technology

Machine Vision

Chapter 5: Color

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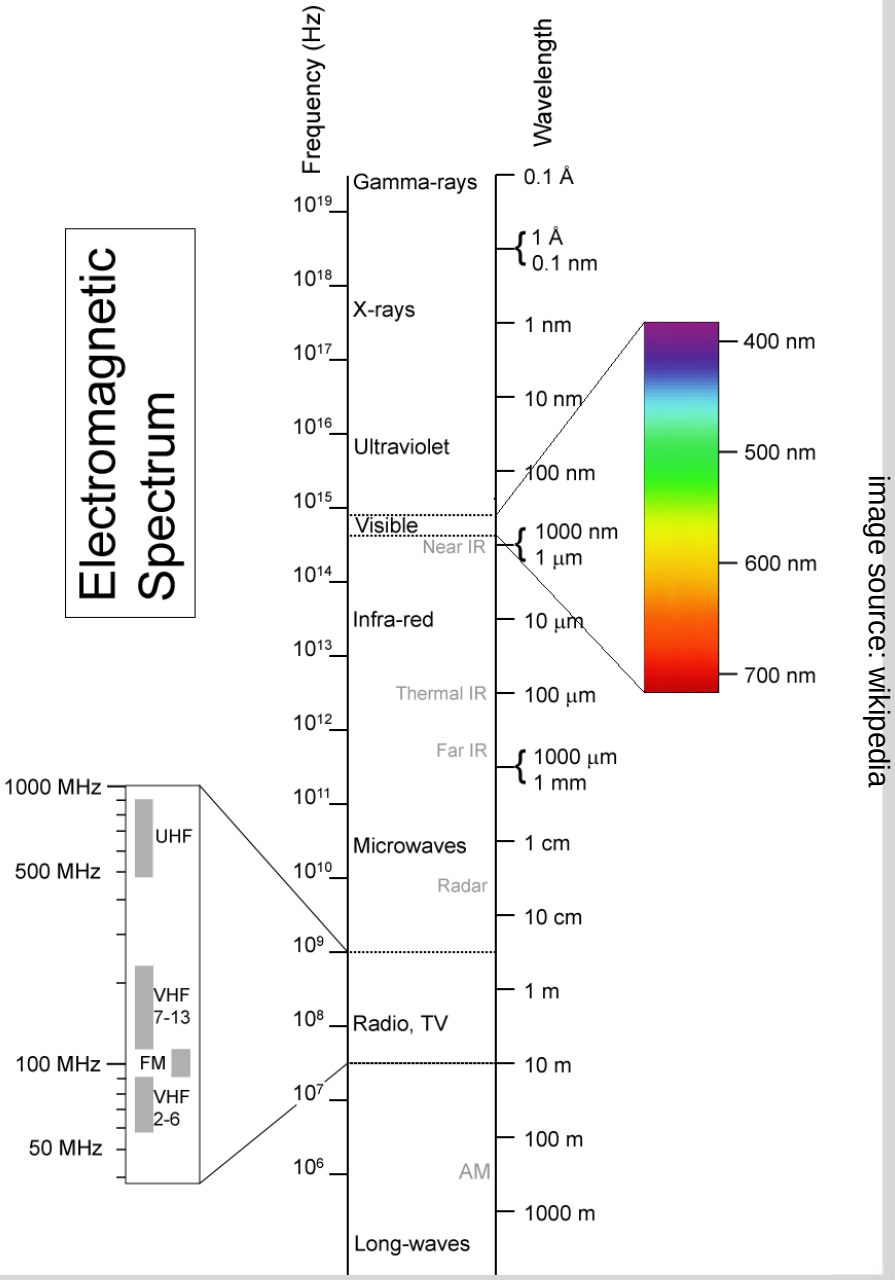
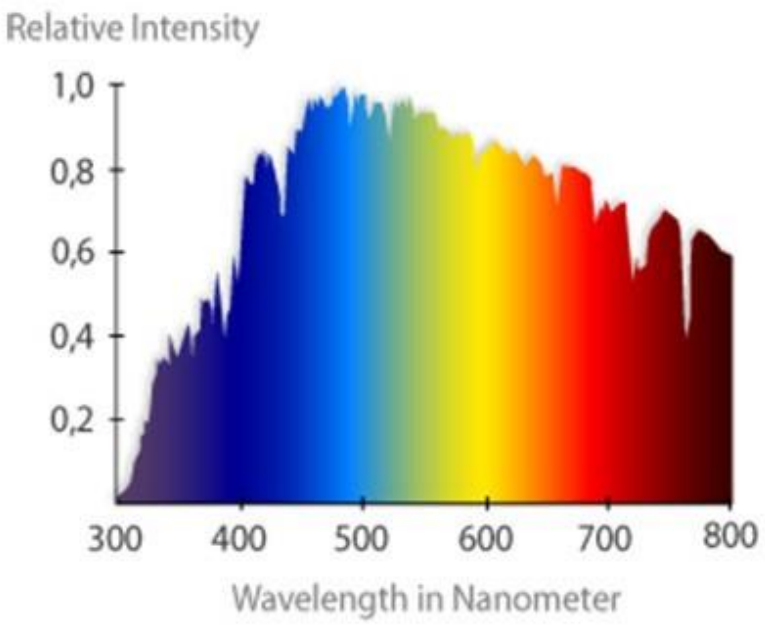
Physics of Color

- visible light is electromagnetic wave in the range between 380nm and 740nm wavelength
- the wavelength of the light specifies its color

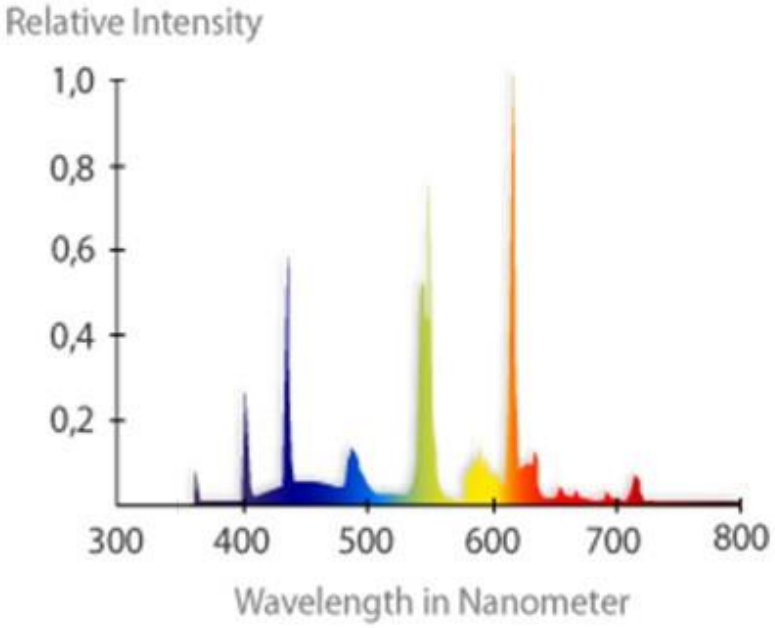


Physics of Color cont.

- light can contain many wavelength' → spectrum
- spectrum depends on light source and filter
- to describe the physics of a light source completely, we must know its full spectrum



sunlight



fluorescent tube

image source: internet (somewhere)

Color in Human Perception

– human eye has four kind of light sensitive cells:
  - rods (not color sensitive)杆状细胞，只检测光的强弱，不检测光的颜色，在光照较弱时提供信息
  - L-, M-, S-cones (color sensitive)

可以和上一页PPT的内容联动：靠LMS细胞完成对色彩的识别，但是会有遗漏（色谱上色彩比重不同）

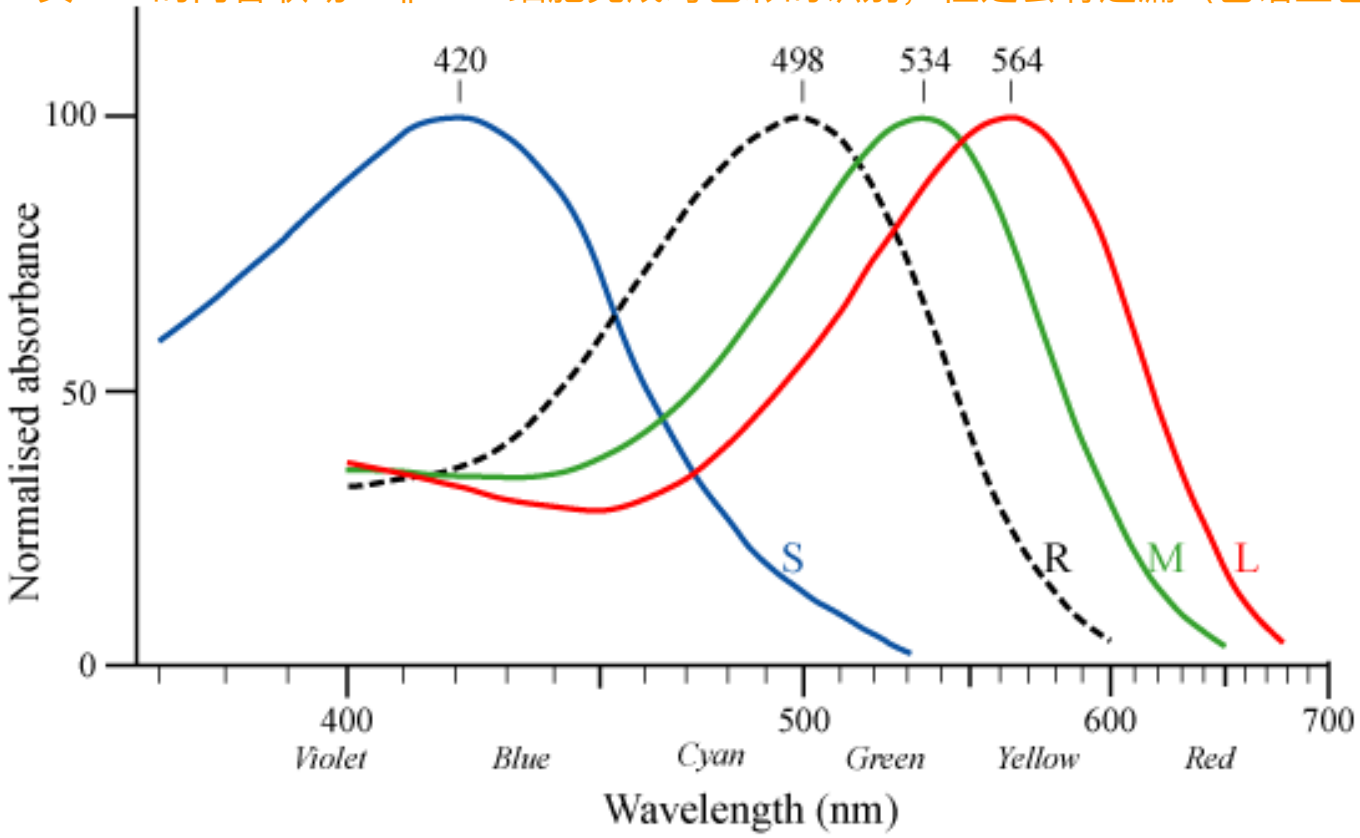


image source: wikipedia

Color in Human Perception

– Young-Helmholtz theory:

The human impression of color can be explained completely by the responses of the S-, M-, and L-cones

- *this does not apply to color blind people*
- *this does not apply to other species*

– assuming monochromatic light the wavelength can be reconstructed from the responses of the cones

假设单色光，波长可以根据视锥细胞的响应重建

images: created using simulation tool from: http://www.vischeck.com/vischeck

Color in Human Perception

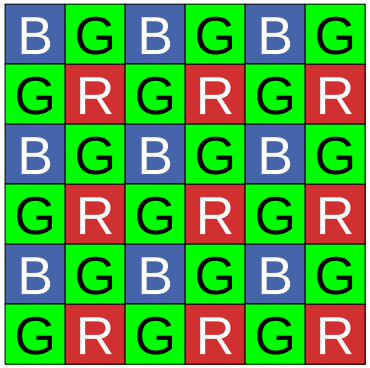
– different light spectra cause the same response of cones

→ color cameras imitate the responses of cones

→ color monitors mix colors from three wavelength’

人眼细胞中，绿色敏感细胞（M细胞）最多，因此对绿色最敏感

Green出现频率最高，白平衡也green通道不变，有关系



arrangement of color sensitive cells in
a color camera (*Bayer pattern*)

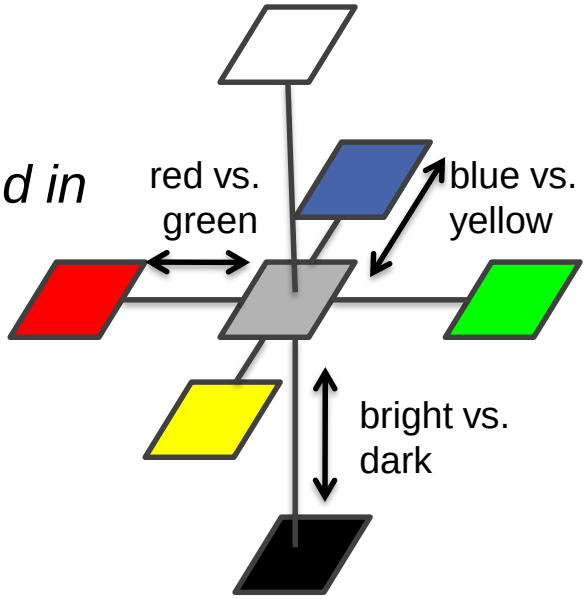
Color Psychology

– the psychological impression of color is not explained by the responses of the cones

– Hering's opponent color theory:

The human impression of color can be described in terms of three scales:

- *bright vs. dark*
- *red vs. green*
- *blue vs. yellow*

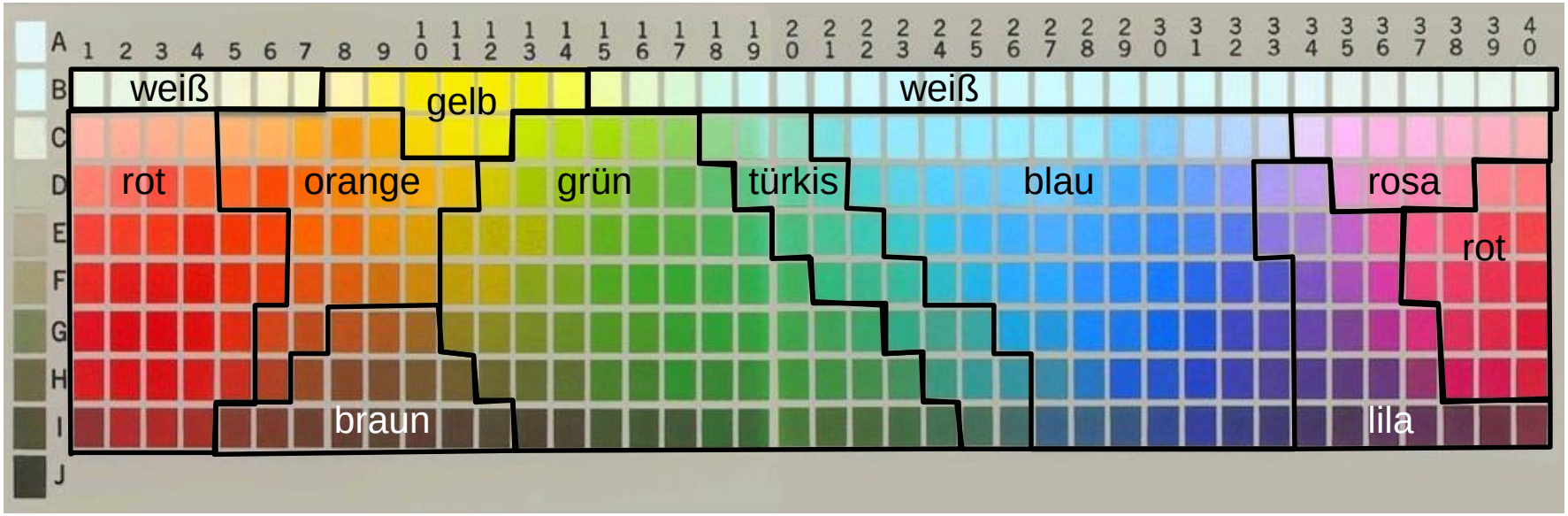


– observations: some "mixed colors" exist, others don't:

- exist: bluish red (violet), yellowish red (orange), bluish green (cyan), yellowish green (citron color)
- do not exist: bluish yellow, reddish green

Color Names

- categorization of colors depends on cultural background
  - e.g. which colors are named as „green“, „blue“, etc.



the lecturer‘s personal impression about colors terms
(German cultural background, categorization done using an LCD monitor)

Color Terms

- luminance, intensity:

  total amount of incident light independent of spectrum

- chrominance:

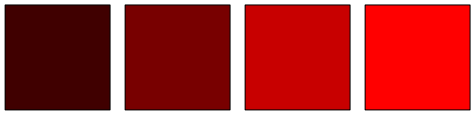
  spectrum of light independent of luminance

- hue:

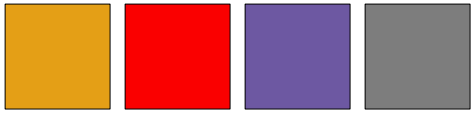
  most dominant wavelength in spectrum

- saturation:

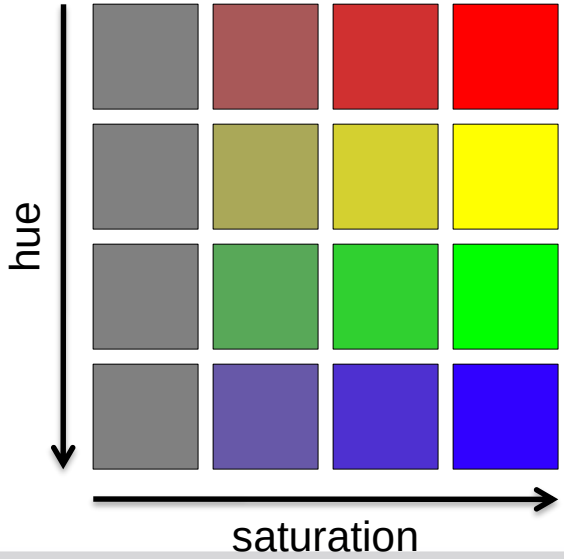
  percentage of energy in most dominant wavelength



same chrominance,
increasing luminance



same luminance,
varying chrominance



Role of Color Processing

- processing of chrominance and luminance in visual cortex follows different pathways
  - luminance is used to recognize shape and texture in the image
  - chrominance is an important cue to control visual attention

This text is hard to read since it has the same luminance as the background

This text is easy to read although it has the same chrominance as the background

Can you read the text?

How many apples do you see?

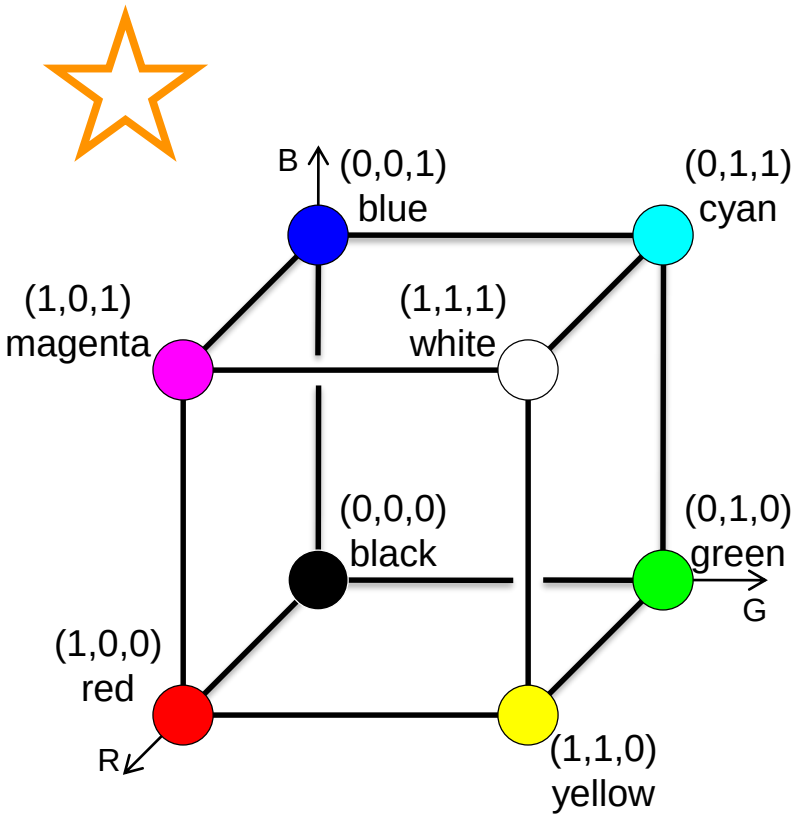
Technical Color Models

- many different models of color, but all use 3 channels
  - models imitating the three cones: RGB, CMY/CMYK
  - models based on color psychology: XYZ, L*a*b*, L*u*v*, HSV, HSL, …
  - other models: YUV, …

RGB：显示器类，发出光，加法
CMY：颜料类，反射光，减法

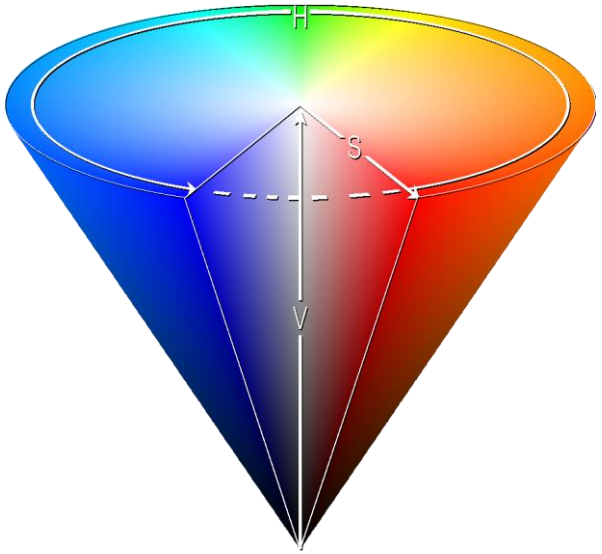
RGB Color Space

- RGB imitates the responses of S-, M-, and L-cones
  - R: red-value (0–1)
  - G: green-value (0–1)
  - B: blue-value (0–1)
  - the color that is displayed on a monitor is device dependent
  - application areas: digital cameras, monitors, image representation



HSV Color Space

- color decomposition into luminance, hue, and saturation
  - H: hue (0–360°)
  - S: saturation (0–1)
  - V: value, luminance (0–1)
  - created by projection of the RGB cube along its diagonal
  - channel have semantics
  - application areas: painting, machine vision



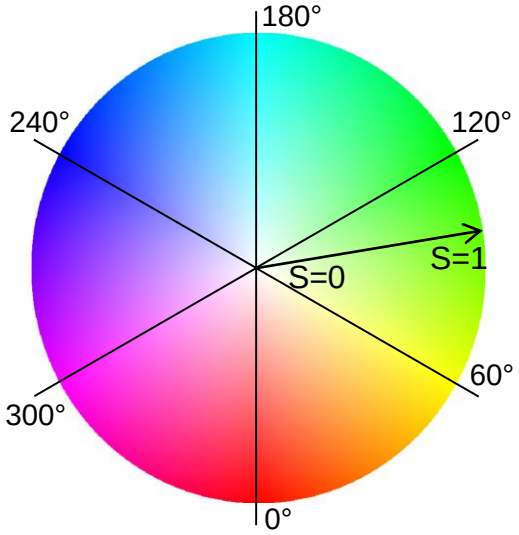


image source: Wikimedia Commons

L*u*v* Color Space and L*a*b* Color Space

- Color spaces based in human color interpretation
  - distances in color space refer to differences in human color interpretation
  - L* axis: luminance
  - u*, v* axis: chrominance
  - a*, b* axis: chrominance
  - application areas: machine vision

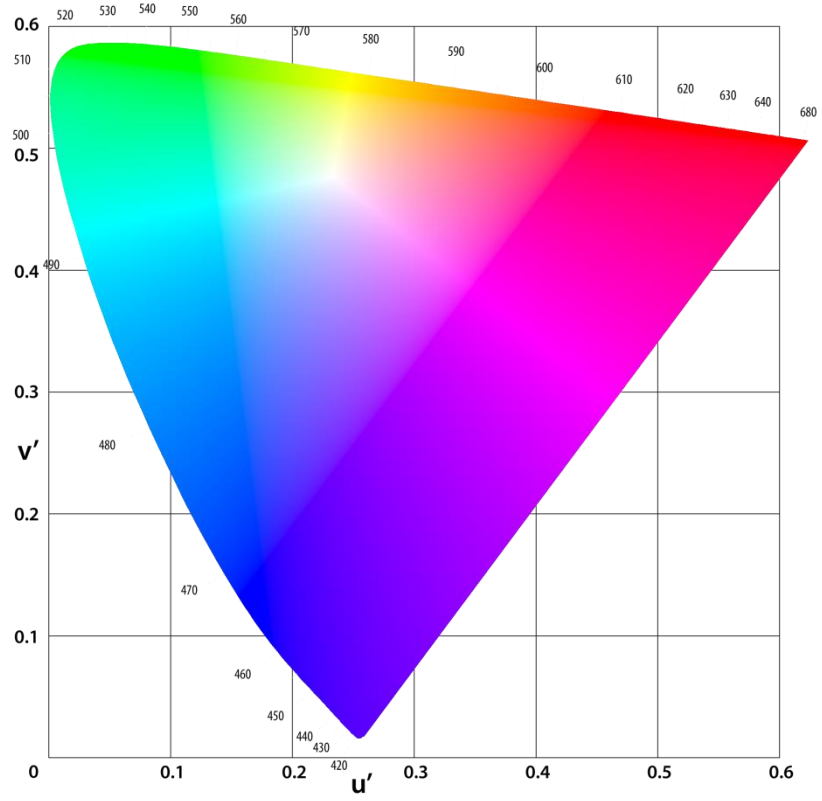


image source: Wikimedia Commons

Color Constancy

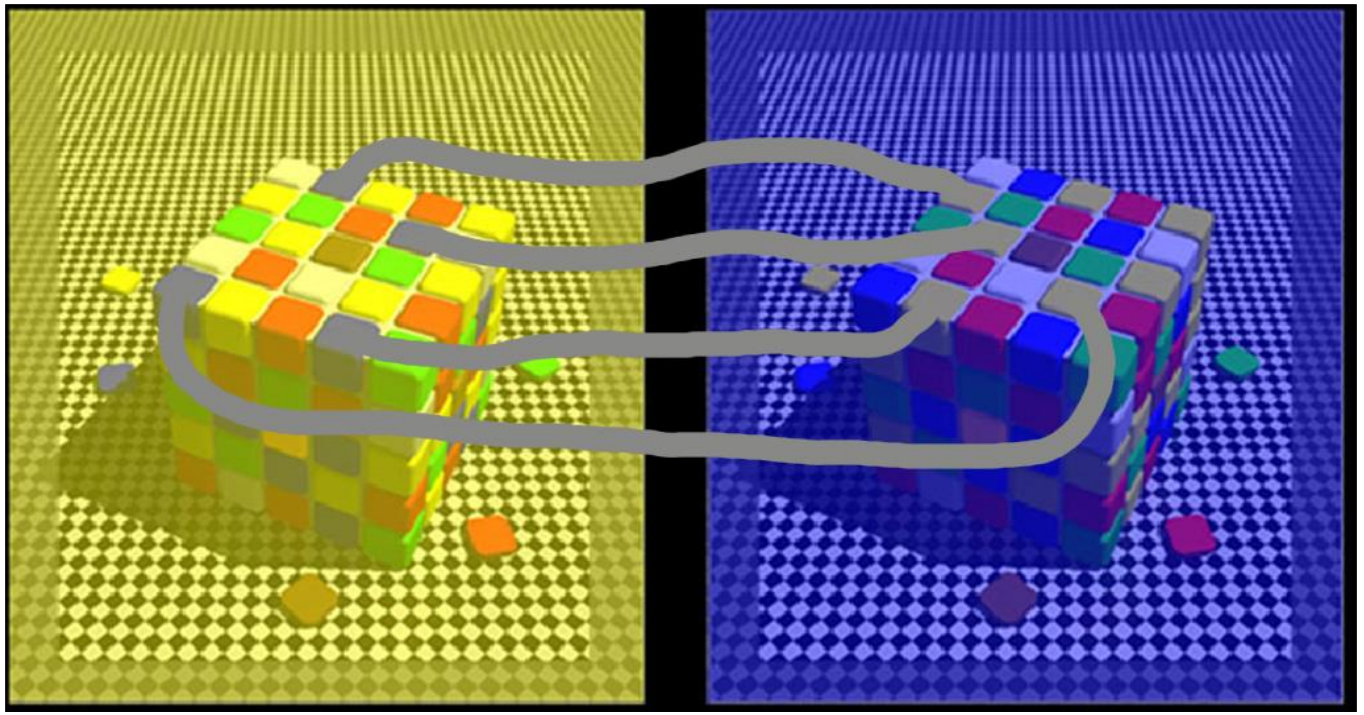


image source: www.lottolab.org, www.echalk.co.uk

the blue tiles on top of the left cube are of the same color as the yellow tiles on top of the right cube!

如果是使用RGB的屏幕呢？是否还会收到照明条件的影响

- color perception depends on lighting conditions, i.e. on spectrum of light that is used to illuminate objects

色彩感知取决于照明条件，即取决于用于照亮物体的光频谱

Color Constancy cont.

image source: wikipedia

- artificial light causes color shift
- white balance for color correction

Color Constancy cont.

- white balance:
  - changes R and B channels of RGB
  - need a grey or white reference area
  - calculate average RGB values for reference area
  - calculate correction factors for R and B
  - multiply R and B values of image pixels with correction factors

average RGB values are:
$R_{average}=0.69$
$G_{average}=0.59$
$B_{average}=0.51$

correction factors:
$c_R=G_{average}/R_{average}$
$c_B=G_{average}/B_{average}$

Color Constancy cont.

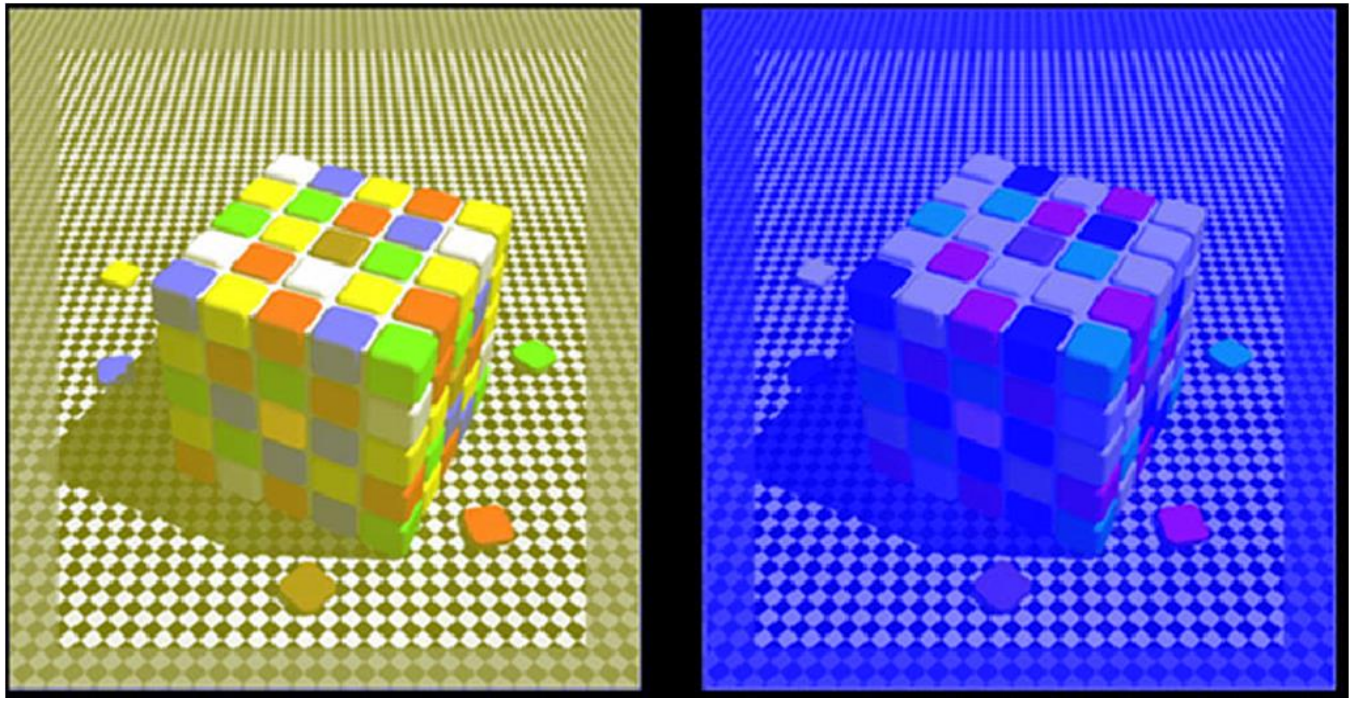


image source: www.lottolab.org, www.echalk.co.uk

- white balance on right image
  RGB of white reference pixel: (137,137,255)
- white balance on left image
  RGB of white reference pixel: (255,254,136)

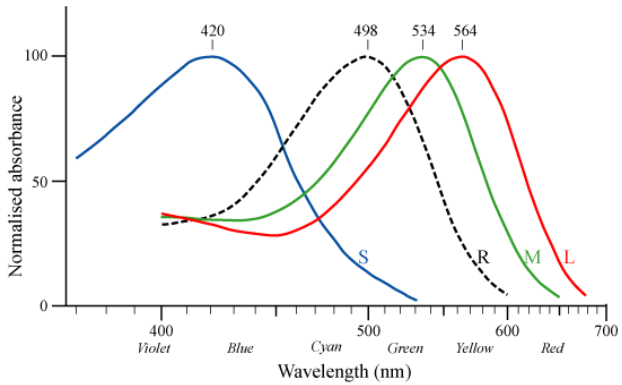
Color Constancy cont.

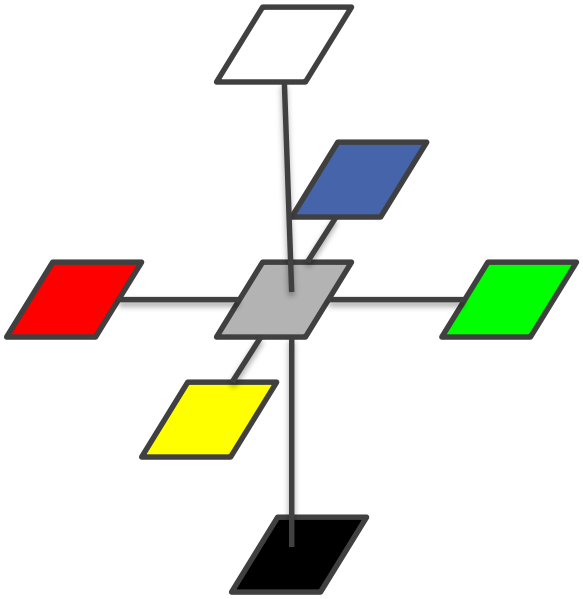
- white balance:
  - built in feature in many digital cameras
  - alternative strategies to determine reference color:
    - color of brightest pixel
    - average color in the image
  - example: robot soccer
    - put white paper into the field of view of the camera
    - do white balance using this area as reference

SUMMARY: COLOR

Summary

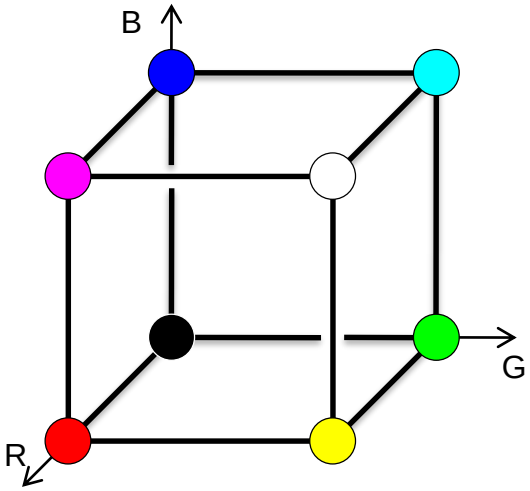
- **nature of color**
  - spectrum of light
  - Young-Helmholtz theory
  - Hering's opponent color theory
  - cultural influence in naming
  - role of color processing
- **color models**
- **color constancy**

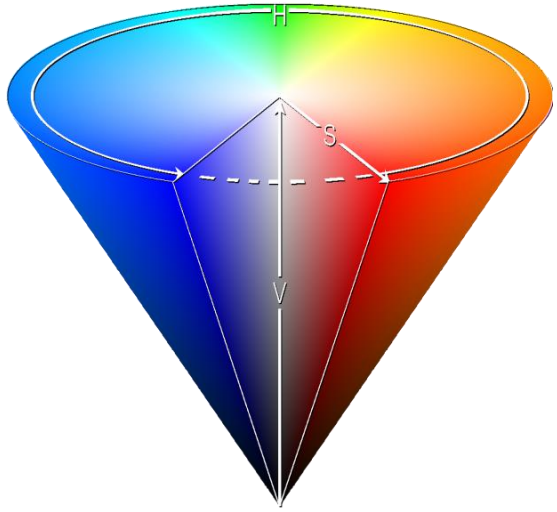




Summary cont.

- **nature of color**
- **color models**
  - RGB
  - HSV
  - L*u*v*
- **color constancy**





Summary cont.

- **nature of color**
- **color models**
- **color constancy**
  - chrominance depends on color of incident light
  - white balance