

# Lecture 8

# Visual Perception and Colors

[Data Visualization · 1-DAV-105](#)

Lecture by Broňa Brejová

Acknowledgement: materials inspired by lectures from Martina Bátorová in 2021

Why talk about visual perception  
in visualization?

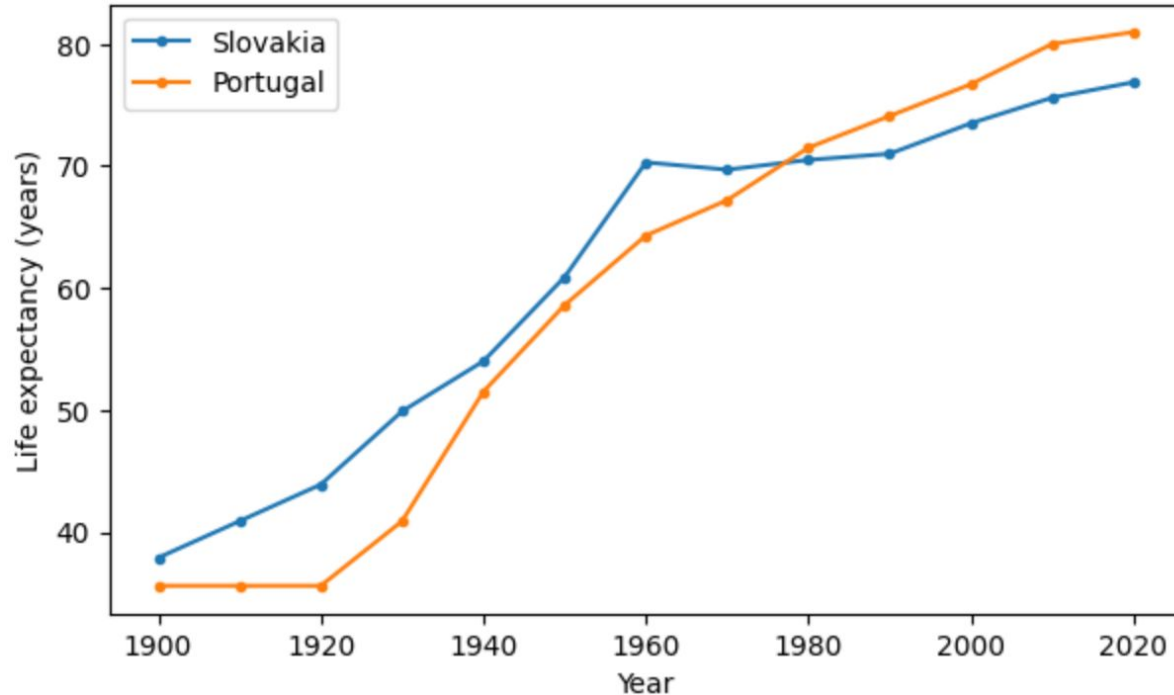
# In which period of time was life expectancy higher in Slovakia than in Portugal?

1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010 2020

Country

<b>Slovak Republic</b>	37.9	40.9	43.9	49.9	54.0	60.9	70.3	69.7	70.5	71.0	73.5	75.6	76.9
<b>Portugal</b>	35.6	35.6	35.6	40.9	51.5	58.6	64.3	67.2	71.5	74.1	76.7	80.0	81.0

In which period of time was life expectancy higher in Slovakia than in Portugal?



# Visual brain, table vs. graph

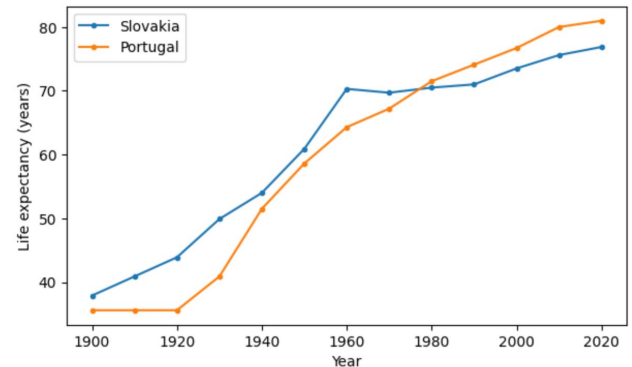
We "read" tables, verbal processing

We "see" plots, visual processing

Visual processing is very parallel and fast, evolved to spot predators

In which situations is a table preferable to a plot?

	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2020
Country													
Slovak Republic	37.9	40.9	43.9	49.9	54.0	60.9	70.3	69.7	70.5	71.0	73.5	75.6	76.9
Portugal	35.6	35.6	35.6	40.9	51.5	58.6	64.3	67.2	71.5	74.1	76.7	80.0	81.0



# Human visual perception

What happens when we look at the figure below?



# Human visual perception

# Human visual perception

What happens when we look at the figure?

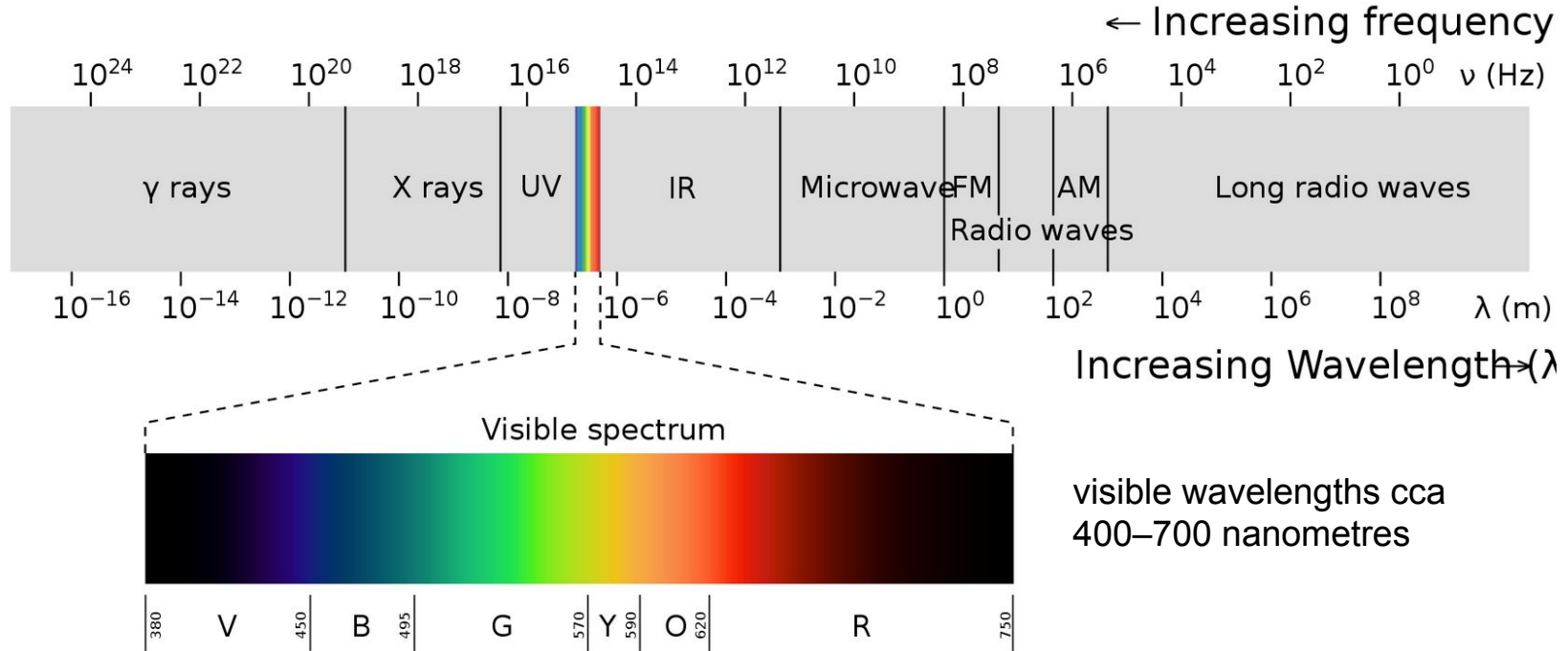


- The **light** from the screen / projector hits the retinas of our **eyes**
- Photoreceptor cells **transduce** (convert) this signal into nerve impulses
- In the brain:
  - detection of **basic features**
  - recognition of **patterns**
  - interpretation, assignment of **meaning**

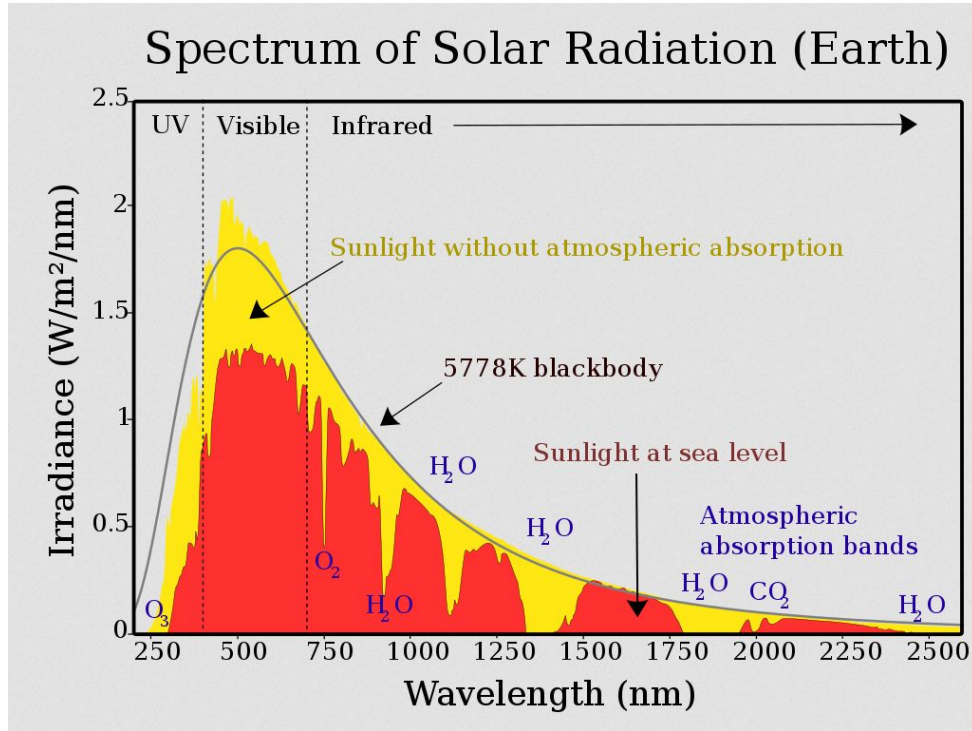
**Today:** Focus on the light, eyes and colors, later stages next week

Light

# Visible light as a part of electromagnetic spectrum



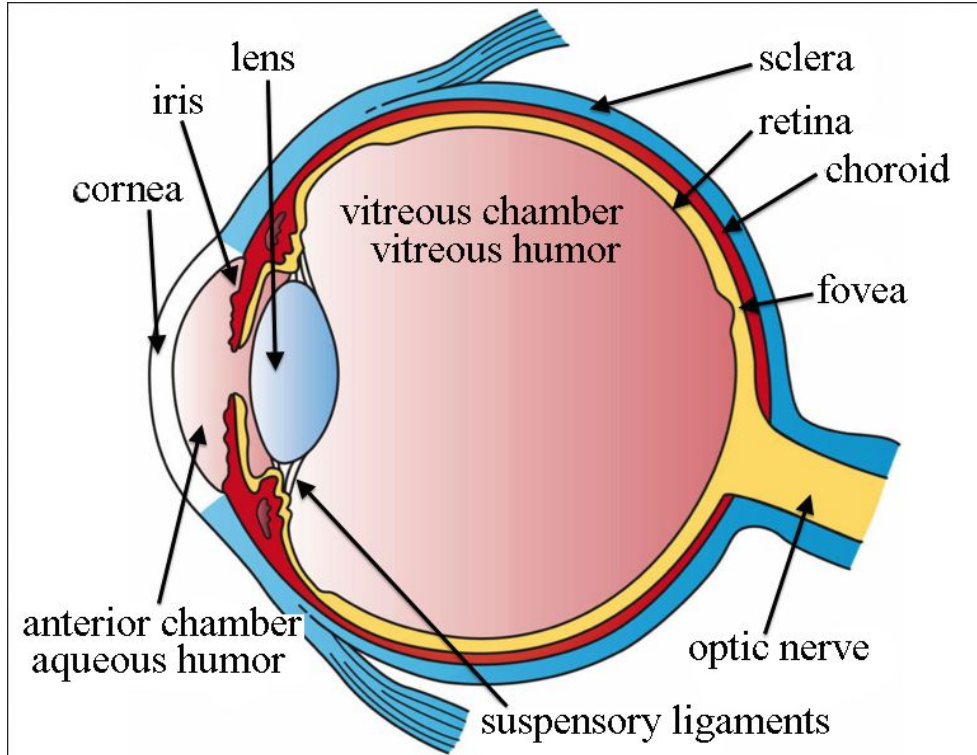
# Sunlight is a mixture of different wavelengths



[https://commons.wikimedia.org/wiki/File:Solar\\_spectrum\\_en.svg](https://commons.wikimedia.org/wiki/File:Solar_spectrum_en.svg)  
<https://commons.wikimedia.org/wiki/File:WhereRainbowRises.jpg>

Human eye

# Human eye

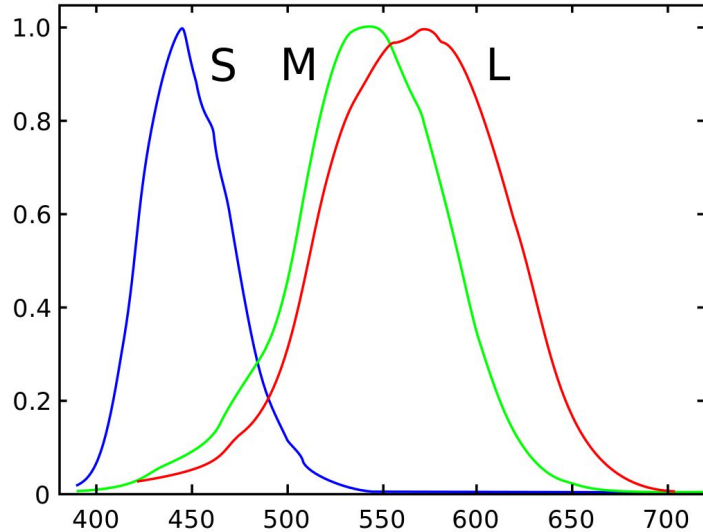


**Retina** (sietnica): light-sensitive layer

**Lens** (šošovka): focus light to retina

**Pupil** (zrenica): hole in iris (dúhovka) where light enters the eye, its size regulated by the amount of light

# Photoreceptor cells in the retina

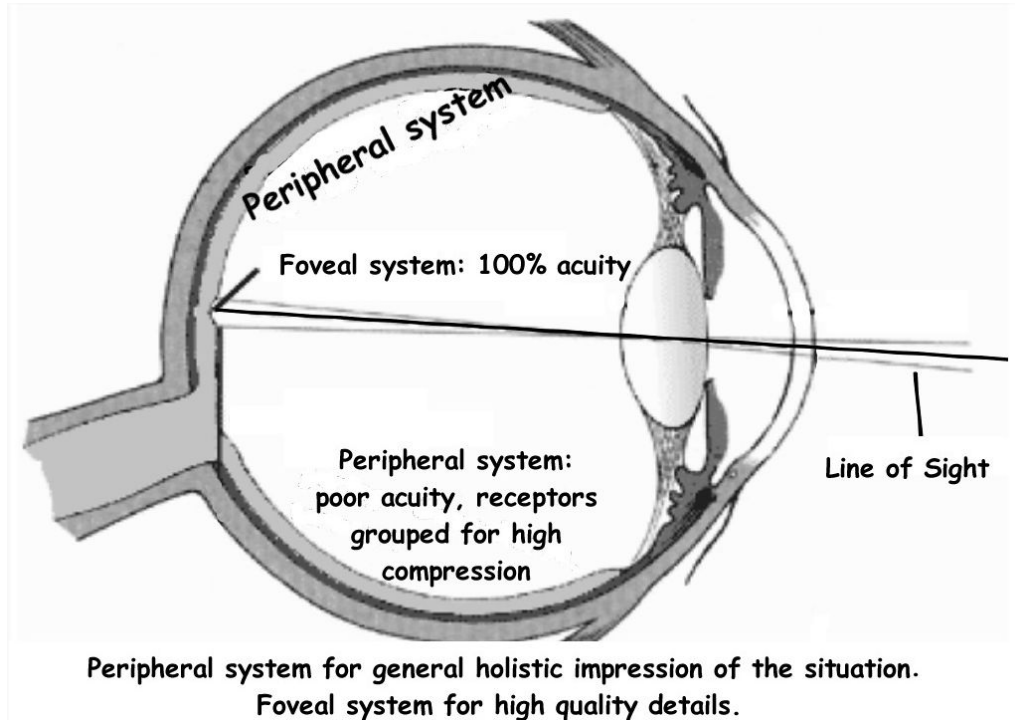


**Rods** (tyčinky): more sensitive to low light, not used for color vision

**Cones** (čapíky): color vision, three different types sensitive to different wavelengths (blue, green, red)

[https://commons.wikimedia.org/wiki/File:Cones\\_SMJ2\\_E.svg](https://commons.wikimedia.org/wiki/File:Cones_SMJ2_E.svg)

# Foveal vs peripheral vision



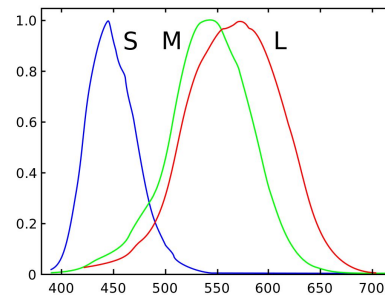
**Fovea:** central zone with many cones, sharp color vision, only about 1-2°

**Peripheral vision:** mostly rods, fast monochrome vision

The eyes make fast **movements** (saccades) between fixations on different points of interest to create a composite image

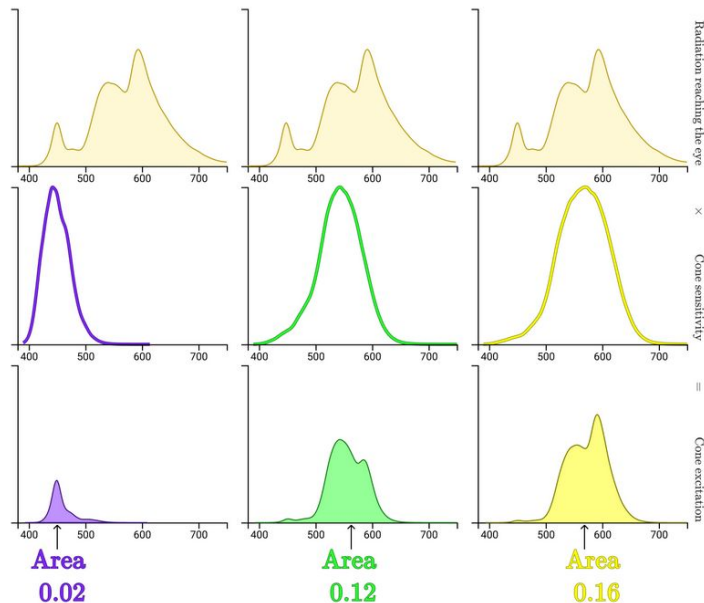
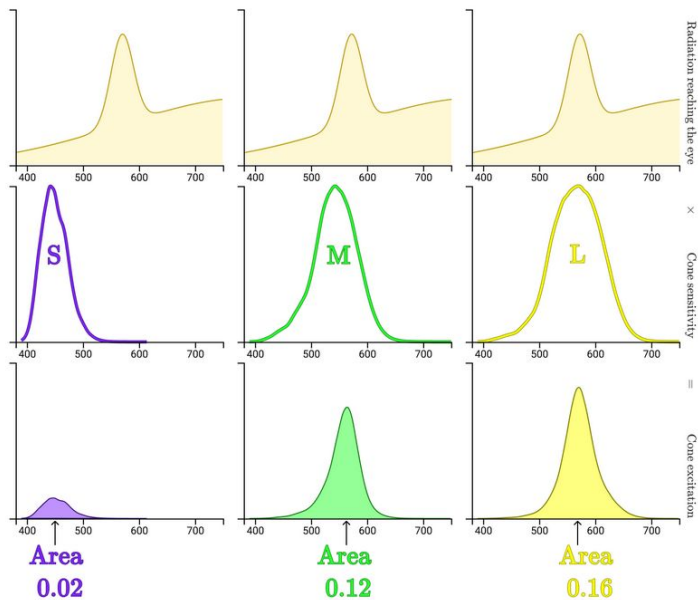
# Colors and color spaces

# Metamers: light with different spectra that appear the same (to typical humans)

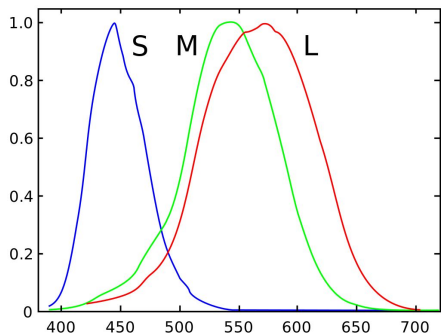
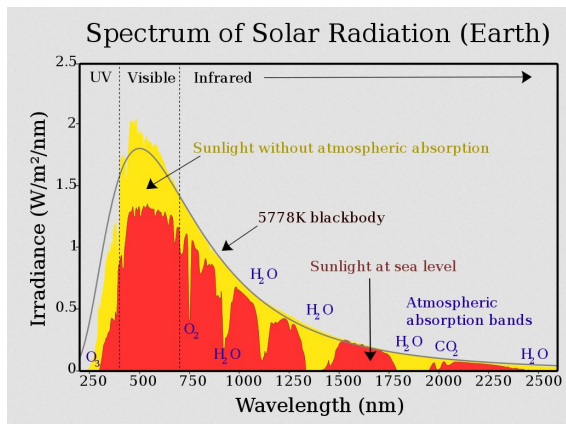


Cone excitation by a point on a lemon

Cone excitation by a pixel of a lemon on a screen



# Color spaces, LMS



A **color space** is an organization of colors.

Our eye projects a full light spectrum into three values: response of the three types of cones.

S (short), M (medium), L (large) wavelength

**LMS** color space uses these three values to represent a color.

Metameric colors have the same values.

Derived models, e.g. CIE with better properties.

[https://commons.wikimedia.org/wiki/File:Solar\\_spectrum\\_en.svg](https://commons.wikimedia.org/wiki/File:Solar_spectrum_en.svg)  
[https://commons.wikimedia.org/wiki/File:Cones\\_SMJ2\\_E.svg](https://commons.wikimedia.org/wiki/File:Cones_SMJ2_E.svg)

Do you know some other color spaces?

# Additive color models, RGB

Monitors, projectors etc.

Component lights in **primary colors**,  
other colors mixtures of these (adding up light).

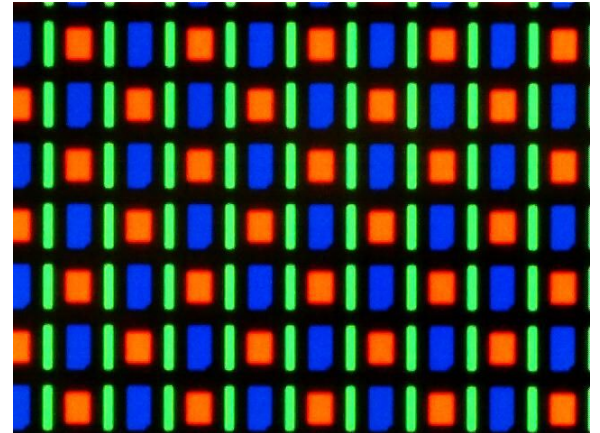
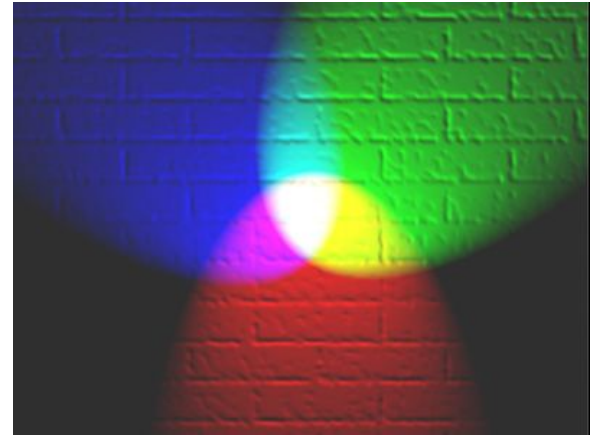
**White** can be achieved by combining colors.

**RGB** uses **red, green, blue** as primary  
(corresponds to LMS peaks).

The **gamut** is the set of colors representable by a  
device, usually a subset of the visible spectrum.

[https://commons.wikimedia.org/wiki/File:RGB\\_illumination.jpg](https://commons.wikimedia.org/wiki/File:RGB_illumination.jpg)

[https://commons.wikimedia.org/wiki/File:Nexus\\_one\\_screen\\_microscope.jpg](https://commons.wikimedia.org/wiki/File:Nexus_one_screen_microscope.jpg)



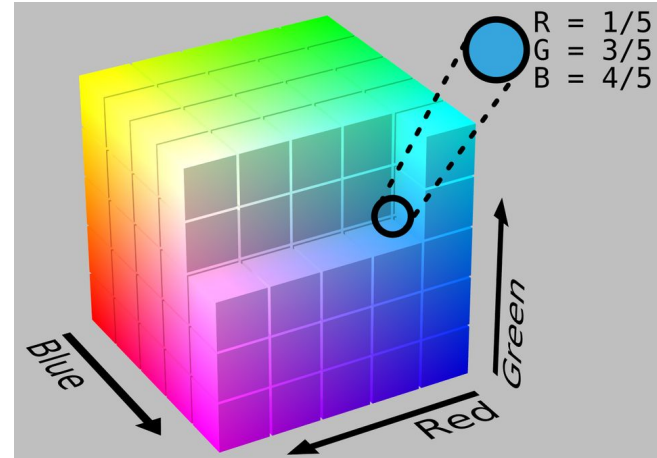
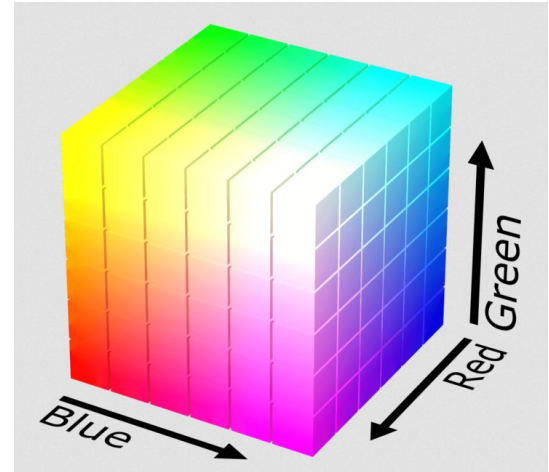
# Colors in RGB space (RGB cube)

RGB is often used to specify colors.

Each coordinate e.g. a real number between 0 and 1 or integer between 0 and 255.

Also hexadecimal notation, e.g. #ff0000 is pure red.

Greytones on the main diagonal (x,x,x).



[https://commons.wikimedia.org/wiki/File:RGB\\_color\\_solid\\_cube.png](https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png)

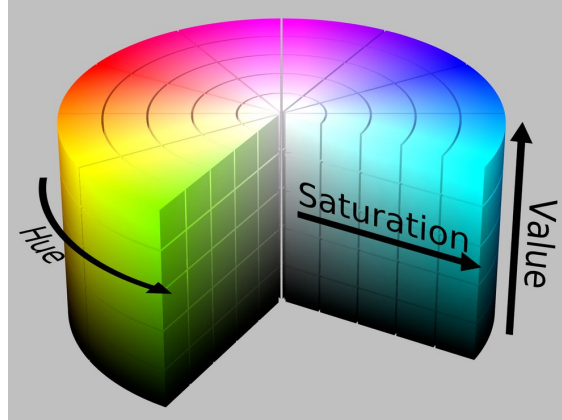
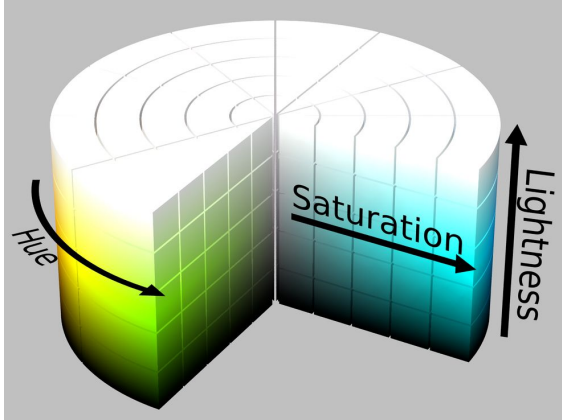
[https://commons.wikimedia.org/wiki/File:RGB\\_Cube\\_Show\\_lowgamma\\_cutout\\_b.png](https://commons.wikimedia.org/wiki/File:RGB_Cube_Show_lowgamma_cutout_b.png)

# HSL and HSV color models

Transformations of RGB model with more intuitive coordinates.

Useful for color pickers, color palettes, image transformations etc.

**Hue, saturation, lightness / hue, saturation, value.**



[https://commons.wikimedia.org/wiki/File:HSL\\_color\\_solid\\_cylinder\\_saturation\\_gray.png](https://commons.wikimedia.org/wiki/File:HSL_color_solid_cylinder_saturation_gray.png)  
[https://commons.wikimedia.org/wiki/File:HSV\\_color\\_solid\\_cylinder\\_saturation\\_gray.png](https://commons.wikimedia.org/wiki/File:HSV_color_solid_cylinder_saturation_gray.png)

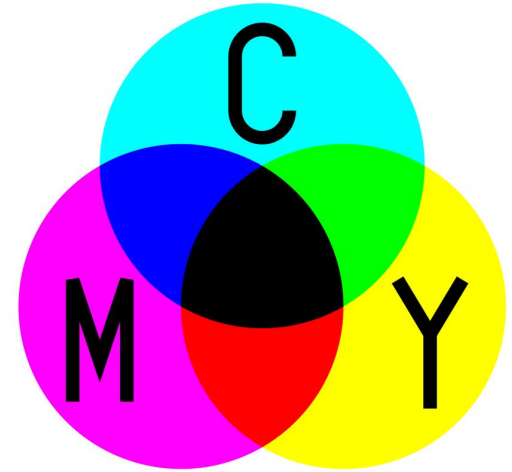
# Subtractive models, pigments

Pigments block part of the light spectrum.

Adding more pigments blocks (subtracts) more light.

**Black** can be achieved by combining colors.

Example: CMY(K) color model used in **printing**.



# CMY(K) color model

Primary colors cyan, magenta and yellow

- **cyan** absorbs red
- **magenta** absorbs green
- **yellow** absorbs blue

**Black (K)** added because

- it is cheaper
- it hides artifacts in dark colors



Conversion from RGB to CMYK is difficult,  
device-dependent.

[https://commons.wikimedia.org/wiki/File:Barns\\_grand\\_tetons.jpg](https://commons.wikimedia.org/wiki/File:Barns_grand_tetons.jpg)

[https://commons.wikimedia.org/wiki/File:CMY\\_separation\\_%E2%80%93\\_no\\_black.jpg](https://commons.wikimedia.org/wiki/File:CMY_separation_%E2%80%93_no_black.jpg)

[https://commons.wikimedia.org/wiki/File:CMYK\\_separation\\_%E2%80%93\\_maximum\\_black.jpg](https://commons.wikimedia.org/wiki/File:CMYK_separation_%E2%80%93_maximum_black.jpg)

# Color wheel, RYB model

Subtractive model developed in art,  
for mixing pigments

Dates back to 17th century

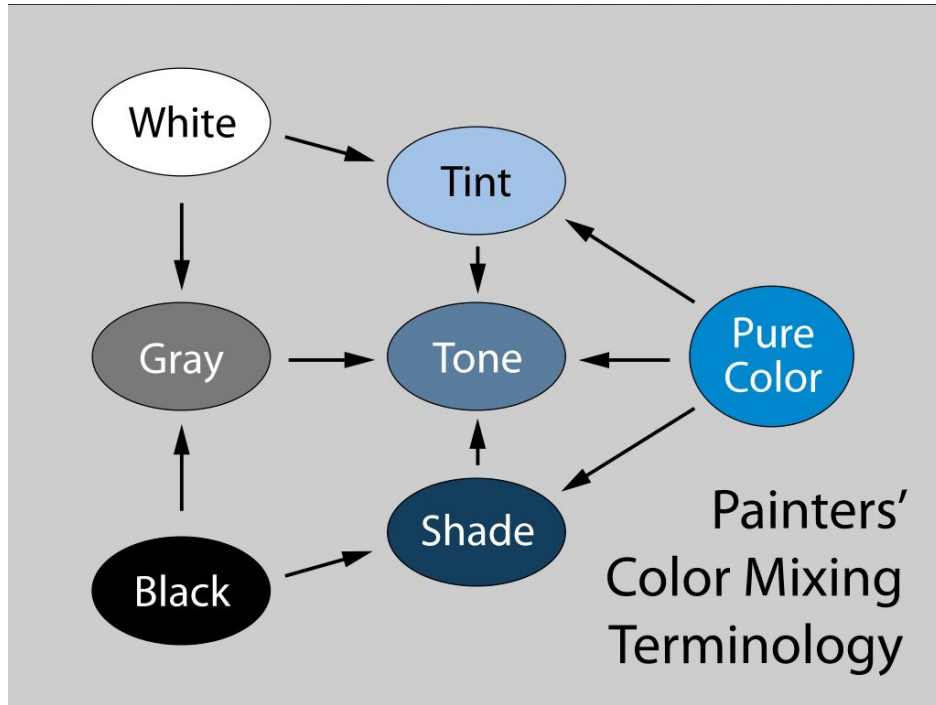
**Primary colors** red, yellow, blue

**Secondary** orange, green, purple  
(each a mix of two primaries)



[https://www.w3schools.com/colors/colors\\_wheels.asp](https://www.w3schools.com/colors/colors_wheels.asp)

# Tint, tone, shade - more painter terminology



# Examples of color schemes

**Monochromatic:** tints / tones / shades of the same hue

**Complementary:** 2 colors opposite on the color wheel  
(e.g. orange and blue)

**Split complementary:** color and 2 neighbors  
of its complement (e.g. orange and blue-green, blue-purple)

**Analogous:** 3-5 adjacent colors on the wheel

Each of these can be desaturated (tints / tones / shades)

See also <https://color.adobe.com/create/color-wheel>



# Color and meaning, cultural differences

Colors often symbolize different things both within and between cultures:

- for example red: blood, love, passion, life, anger, violence, danger, emergency, speed, heat ...
  - China: good luck, prosperity vs. Europe: warning
  - "in the red" mean losses in English, what about China?
- mourning color is black in Europe, white in the East

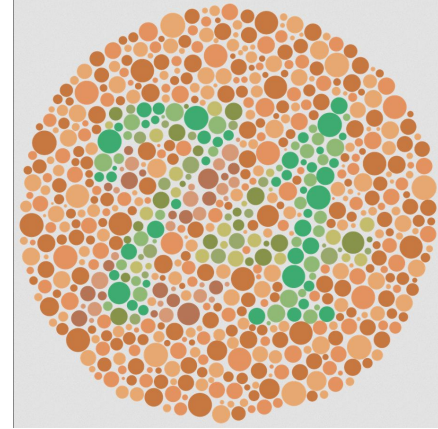
# Colors in data visualization

# Not everybody will be able to see your colors

## Color blindness or color vision deficiency

Various forms and causes

Most often genetic red–green color blindness, where L or M opsin gene is mutated (8% of males)



## Technical problems

- Projectors often distort colors
- Black-and-white printing

[https://commons.wikimedia.org/wiki/File:Ishihara\\_9.svg](https://commons.wikimedia.org/wiki/File:Ishihara_9.svg)

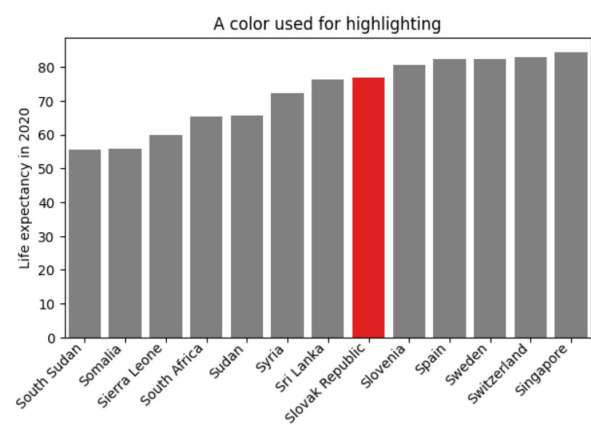
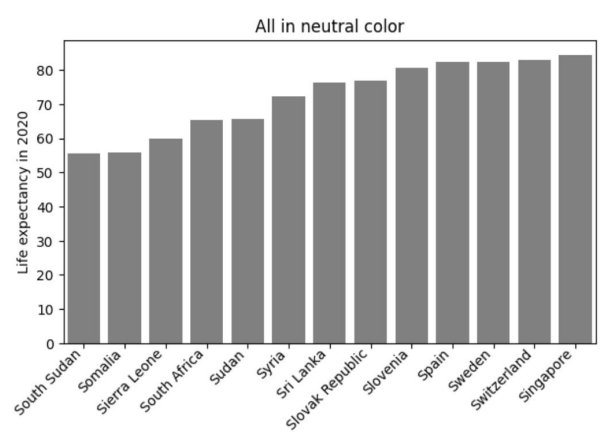
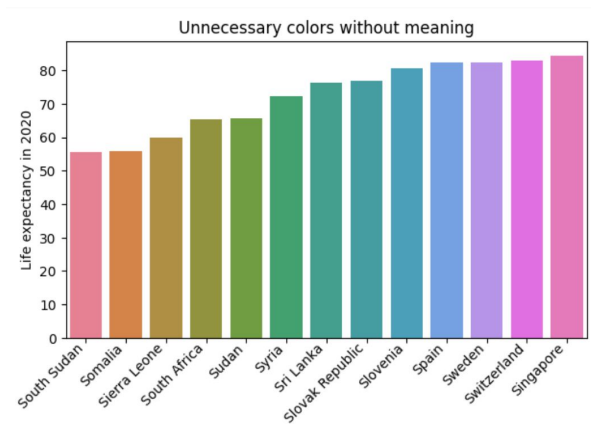
**Choose your colors wisely to avoid these problems as much as possible**

# Color draws attention, use it sparingly

Rely on neutral tones

Use color sparingly, avoid unnecessary colors

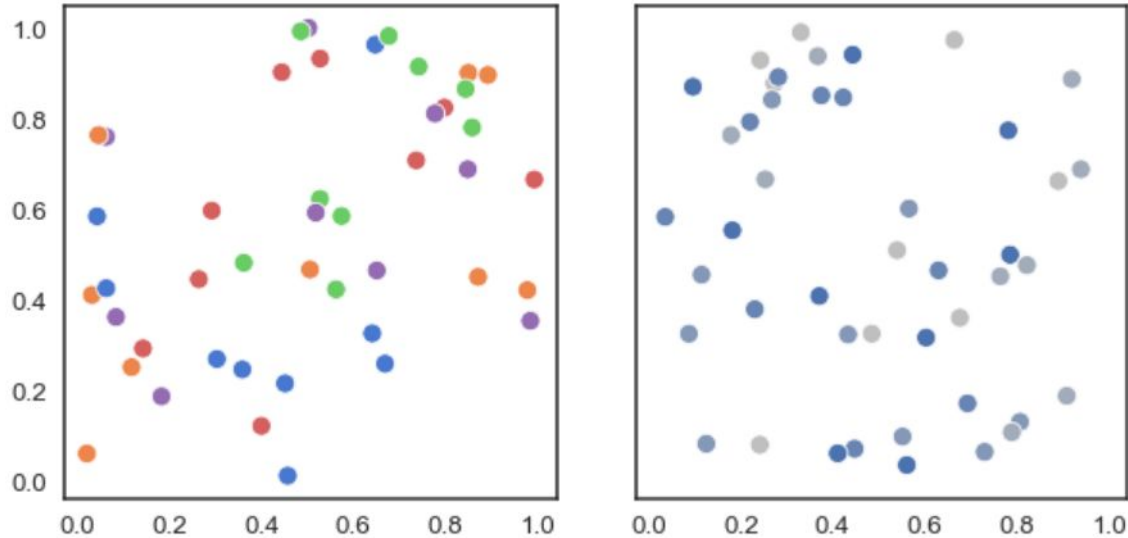
Colors are great for highlighting points of interest



# Qualitative palettes (for categorical variables)

Typically vary hues, easier to distinguish than lightness of the same hue

Try to keep the number of colors low



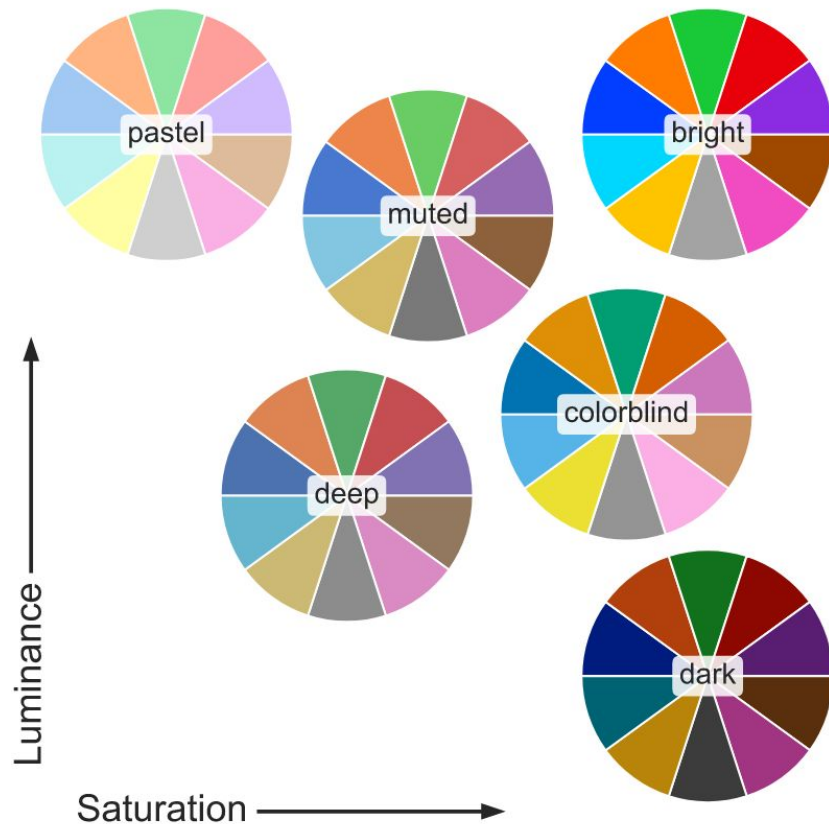
# Qualitative palettes (for categorical variables)

Examples from Seaborn library  
on the right:

[Color Brewer](#) tool:



[https://seaborn.pydata.org/tutorial/color\\_palettes.html](https://seaborn.pydata.org/tutorial/color_palettes.html)



# Quantitative sequential palettes (for numerical variables)

Vary lightness rather than (just) hue (hue is circular, hard to interpret)

**Discrete vs continuous:**



[https://seaborn.pydata.org/tutorial/color\\_palettes.html](https://seaborn.pydata.org/tutorial/color_palettes.html)

# Quantitative diverging palettes

For numerical variables with a special midpoint, often 0  
(such as increase / decrease)

Midpoint displayed as a special neutral color, e.g. grey



[https://seaborn.pydata.org/tutorial/color\\_palettes.html](https://seaborn.pydata.org/tutorial/color_palettes.html)

# Summary

Visual perception:

- light on the retina, transduction on photoreceptor cells
- feature detection, pattern formation, interpretation

Light and color:

- Visible light as a part of electromagnetic spectrum
- Three types of cones sensitive to different wavelengths of light

Color spaces (LMS, RGB, HSL, HSV, CMYK, RYB)

Colors in visualization (qualitative and quantitative palettes, color blindness, sparing use of colors)

# Graphics file formats (for exporting graphs)

**Raster formats:** store your plot as pixels at some resolution

- resolution leads to tradeoff between size and quality
- prefer lossless compression (PNG rather than JPEG)
- transparent background may be also a good idea

**Vector formats:** store your plot as geometric objects (SVG, PDF, EPS)

- can be arbitrarily enlarged, editable
- can be large if many points / lines (subsample data?)
- vector formats usually preferable unless not supported by software
- it is a good idea to include fonts in the file
- beware that these file formats may include bitmaps

# Data analysis project phases

# Data analysis / visualization project phases

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis (many tables and graphs for your use)
- Formation of **hypotheses**
- **Testing** hypotheses (careful reanalysis, new data, other sources)
- **Explanatory** visualizations for the final report / presentation (best views selected for the audience)

# Details: obtaining data

- Obtaining data
  - This course: we download whole datasets in a tabular form
  - But often also web scraping, manual collection of data, measurements, surveys,...
  - Requires careful planning
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis
- Formation of **hypotheses**
- Testing hypotheses
- **Explanatory** visualizations for the final report / presentation

# Details: preprocessing data

- Obtaining data
- Data preprocessing, **checking**, cleaning
  - Try to understand how (and why) the data was obtained and processed
  - Convert them to a convenient format
  - Check for missing values and suspicious outliers
  - Very important phrase: "Garbage in, garbage out"
- **Exploratory** analysis
- Formation of **hypotheses**
- Testing hypotheses
- **Explanatory** visualizations for the final report / presentation

# Details: exploratory analysis

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis
  - Try many analyses
  - This course: visualizations and simple statistics
  - Later you learn advanced statistical and machine learning models
  - Less successful attempts may suggest new directions
- Formation of **hypotheses**
- Testing hypotheses
- **Explanatory** visualizations for the final report / presentation

# Details: Formation of hypotheses

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis
- Formation of **hypotheses**
  - Select visualizations showing interesting trends / exceptions in the data
  - Formulate possible relationships  
(but remember, correlation does not imply causation)
- Testing hypotheses
- **Explanatory** visualizations for the final report / presentation

# Details: Testing hypotheses

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis
- Formation of **hypotheses**
- Testing hypotheses
  - Recheck your code and data, try other related analyses
  - Try to find other relevant data or existing analyses by other people
  - If important decisions will be based on your result, test it particularly thoroughly (what would happen if our plot was all wrong?)
- **Explanatory** visualizations for the final report / presentation

# Details: Explanatory visualizations

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis
- Formation of **hypotheses**
- Testing hypotheses
- **Explanatory** visualizations for the final report / presentation
  - Formulate your conclusions
  - Support them with your analysis and visualizations
  - Do not include all exploratory analyses  
(but do not hide data contradicting your conclusion)
  - Polish visualizations that you selected

# Data analysis / visualization project phases

- Obtaining data
- Data preprocessing, **checking**, cleaning
- **Exploratory** analysis (many tables and graphs for your use)
- Formation of **hypotheses**
- **Testing** hypotheses (careful reanalysis, new data, other sources)
- **Explanatory** visualizations for the final report / presentation (best views selected for the audience)