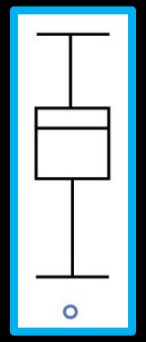
Data, Math and Methods

Week 8, Mapping Color Spaces

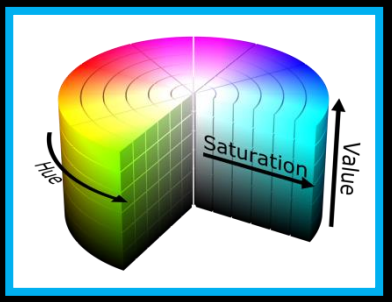
~ Vítek Růžička

Today

- Practical **coding exercise with statistics** (real world data analysis)



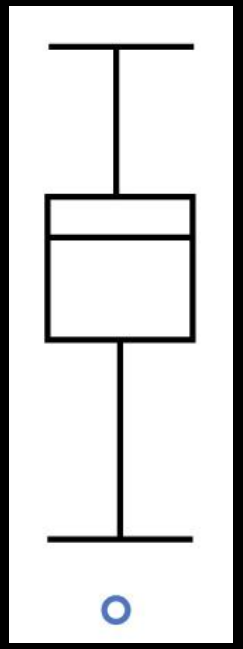
- **Color theories** and representation in **color spaces**



- Practical coding with periodic functions and color spaces

Data Analysis and visualization

Practical coding exercise for data analytics

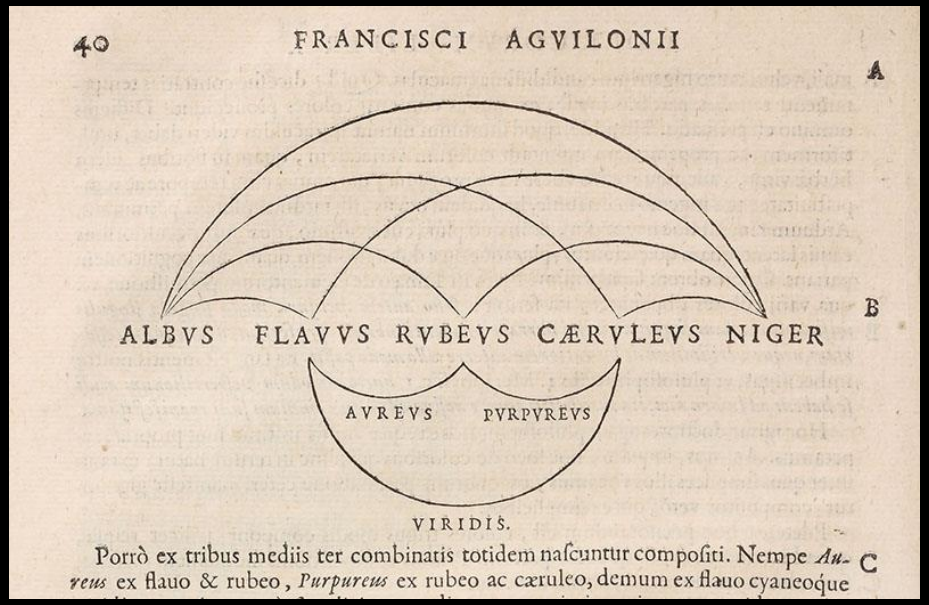


- Load real-world data
- Explore it using **average and standard deviation statistics**
- Visualize it using **box plot**

- Coding together in a notebook:
  w08_practical_data_analysis_starter.ipynb

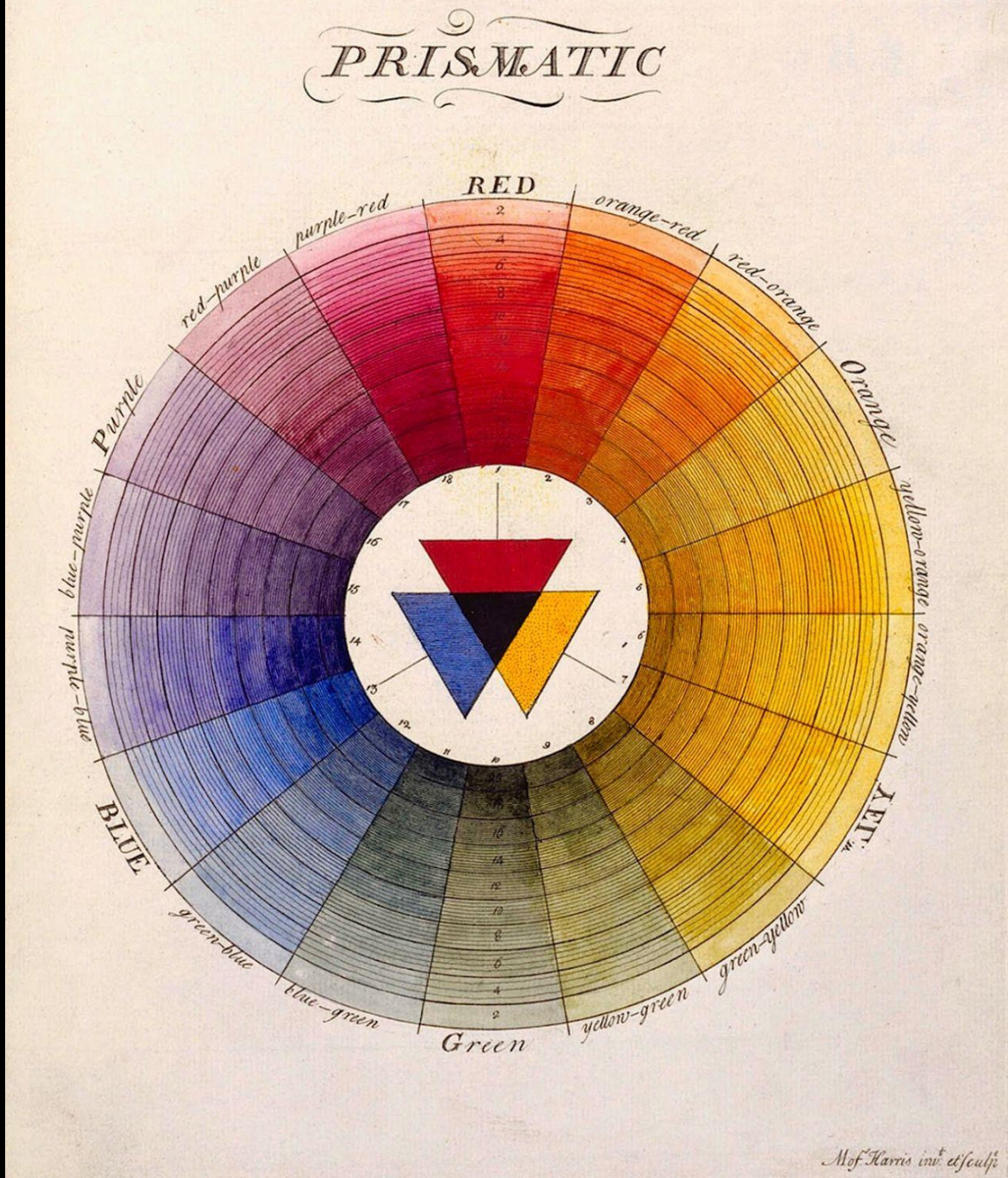
Pause 1

Primary colors



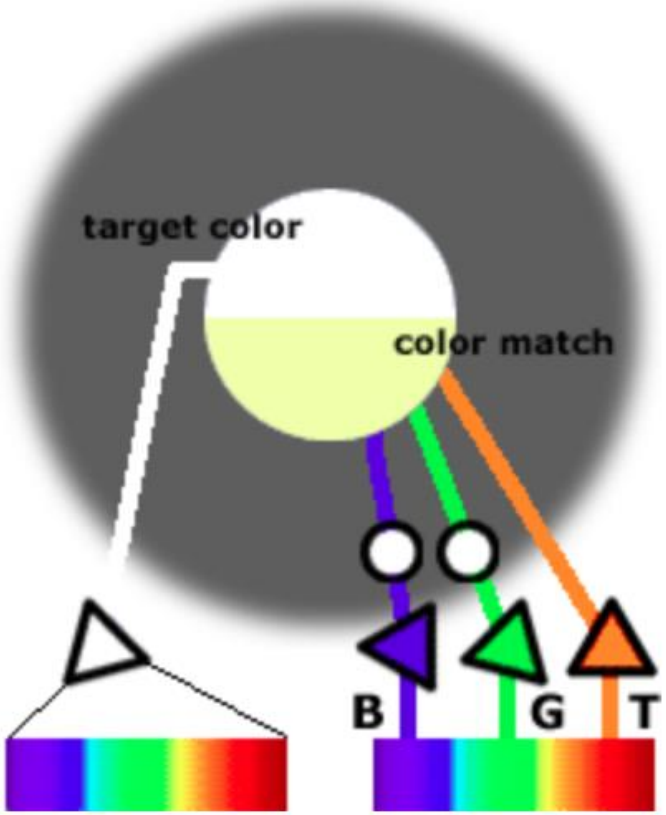
^^ François d'Aguilon's color mixing theory (1613)

The color wheels of Moses Harris (1766) >>



Colorimetric experiment

- **Can we mix 3 colors to get any color?**
- **Maxwell method of color matching (1857)**
  - The viewer was asked to turn a small knob to **adjust** (…) the beam of **each "primary" light**, **until their mixture**, with the target light, produced a color match to the "white" half.
  - ***Maths it***: First, the **brightnesses of the three primaries** are adjusted until they match the white standard: this identifies their **relative proportions in a white mixture**. **Then one of the three primary lights is replaced by the test color**, such as an orange light or colored paper disk, and the matching is repeated. By subtracting and renormalizing the contribution of the two primaries in the second white mixture from their contribution in the three primary mixture, Maxwell was able to define the test color in terms of the quantity of three primary values it replaced.



Maxwell method of color matching

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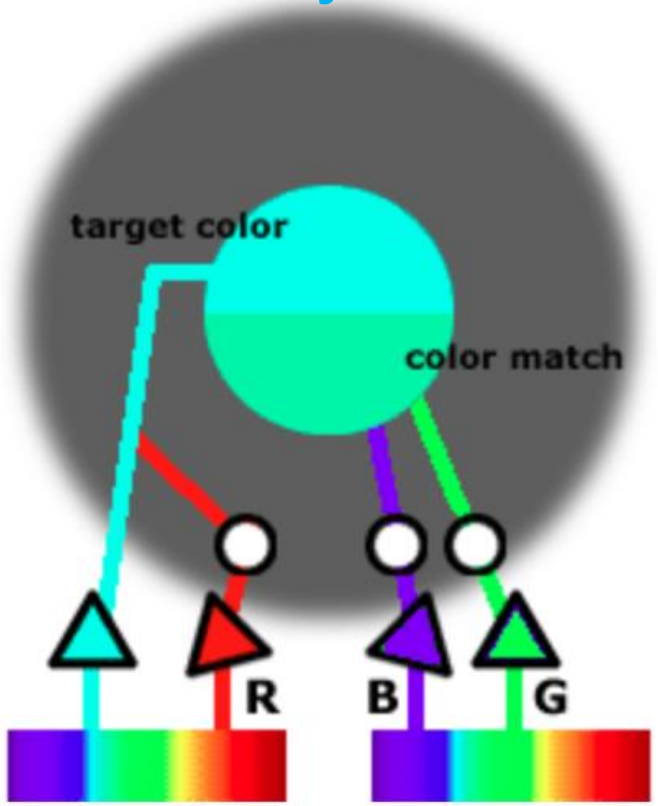
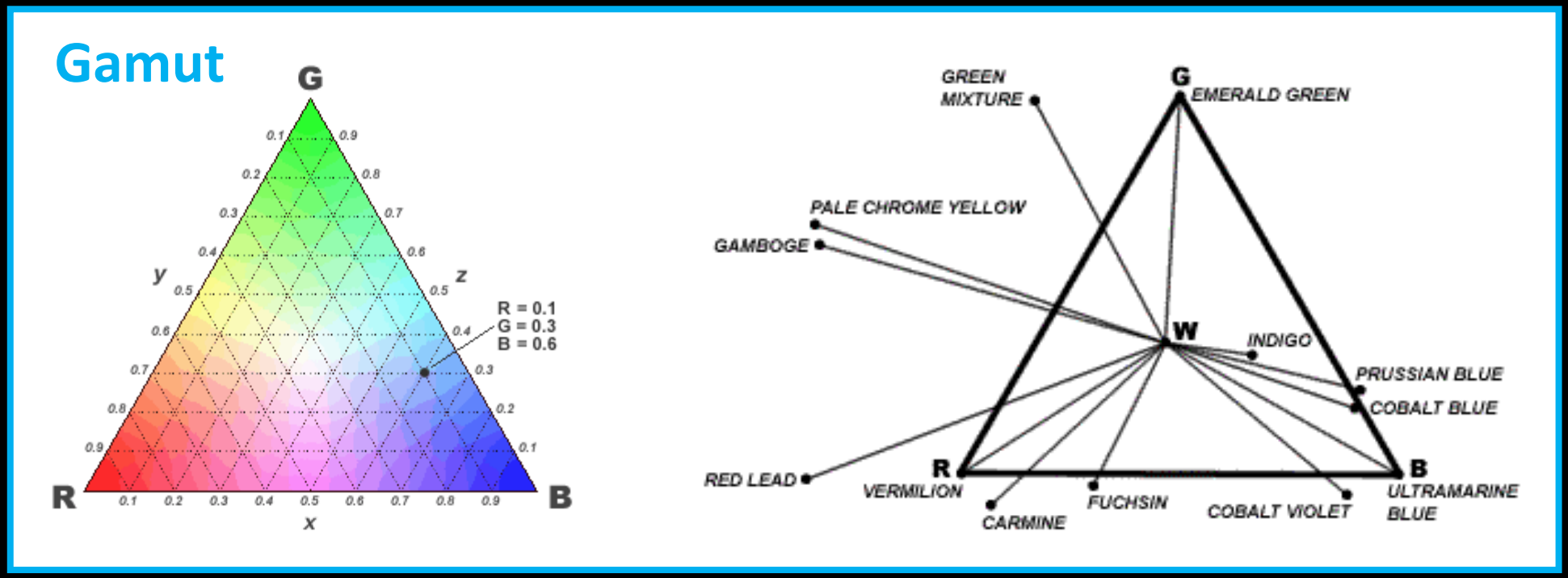
Later adjustment



maximum saturation method of color matching

Problems?

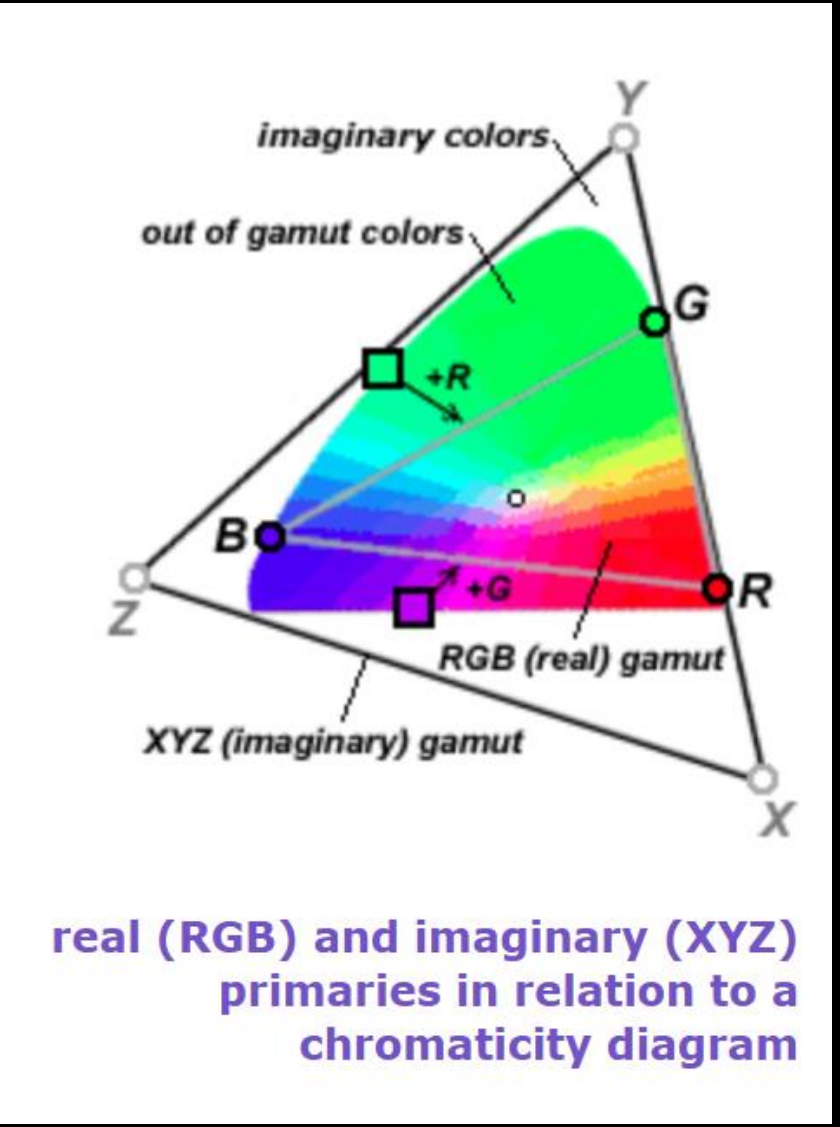


James Clerk Maxwell's "diagram of colors" (1857)

Figure showing the **location of pigments more saturated than any visual mixture of the three primary colors**; (1879)

Gamut

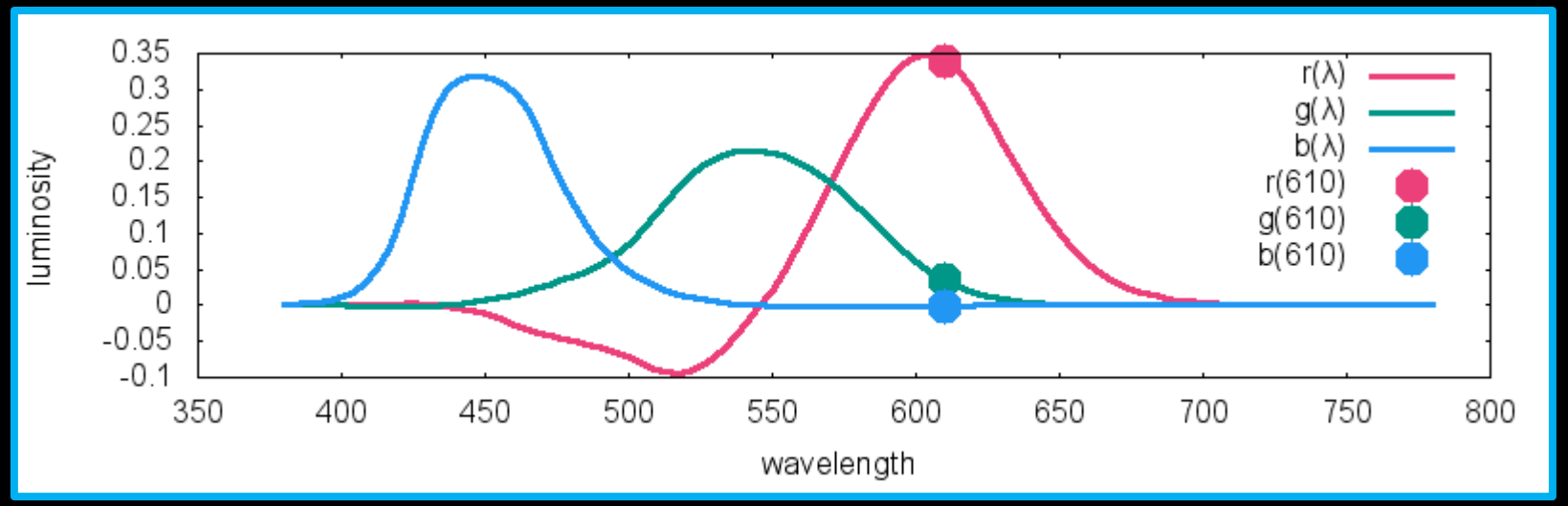
- The diagram shows this solution in a **generic chromaticity diagram**.
- The **RGB** lights, located on the spectrum locus, define a **triangular "real" gamut** that contains all light colors that can be matched by a direct mixture of the RGB lights.
- The **"out of gamut" colors** that are within the chromaticity diagram but outside the RGB mixing triangle (shown as squares) **must be matched by mixing them with one of the RGB primaries, to desaturate them**. (Basically you had to subtract some value from the matched color)



real (RGB) and imaginary (XYZ) primaries in relation to a chromaticity diagram

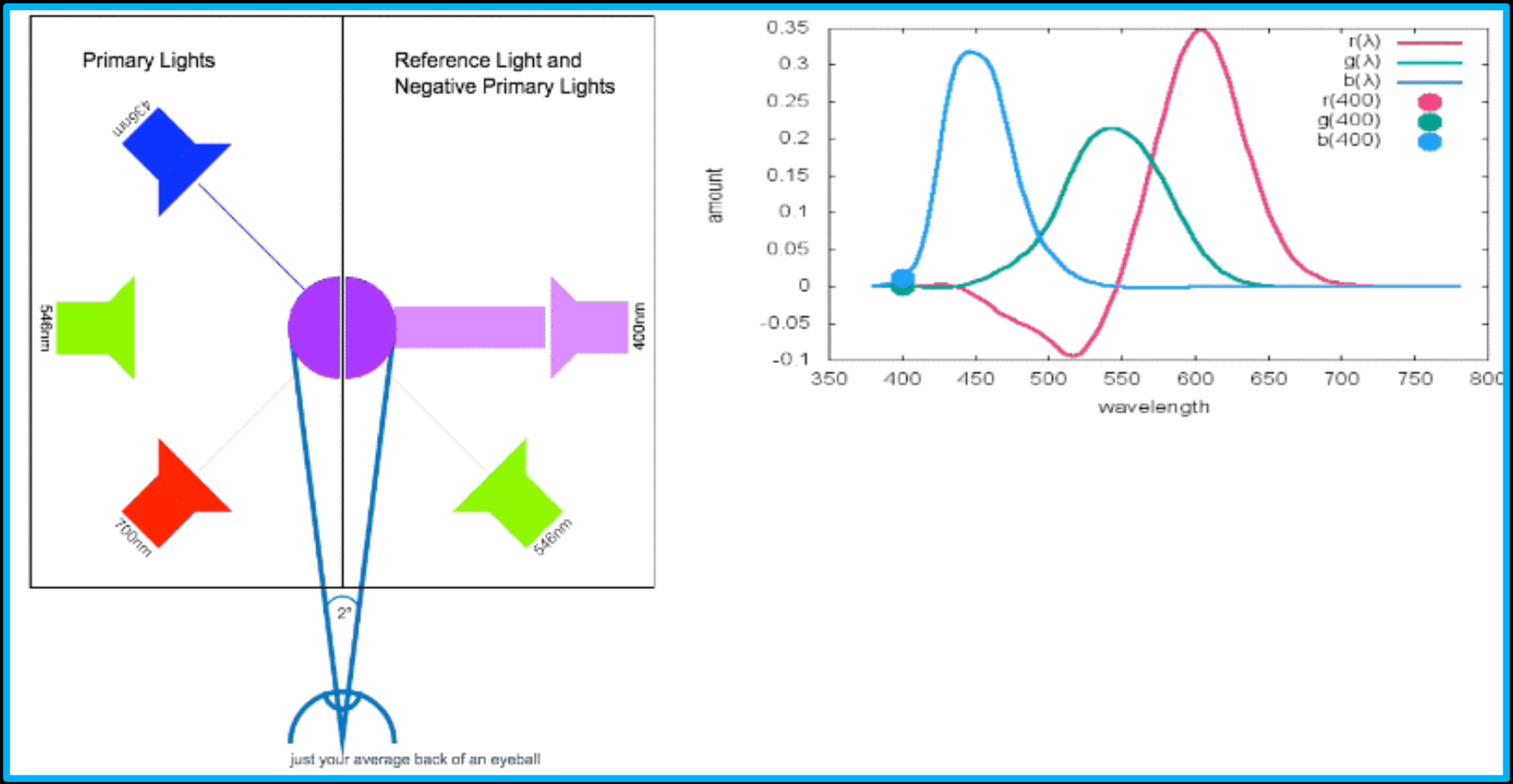
RGB from 1931

- What this means is that for the whole range of colors, you would have to be able to **mix with negative intensities** of primaries!



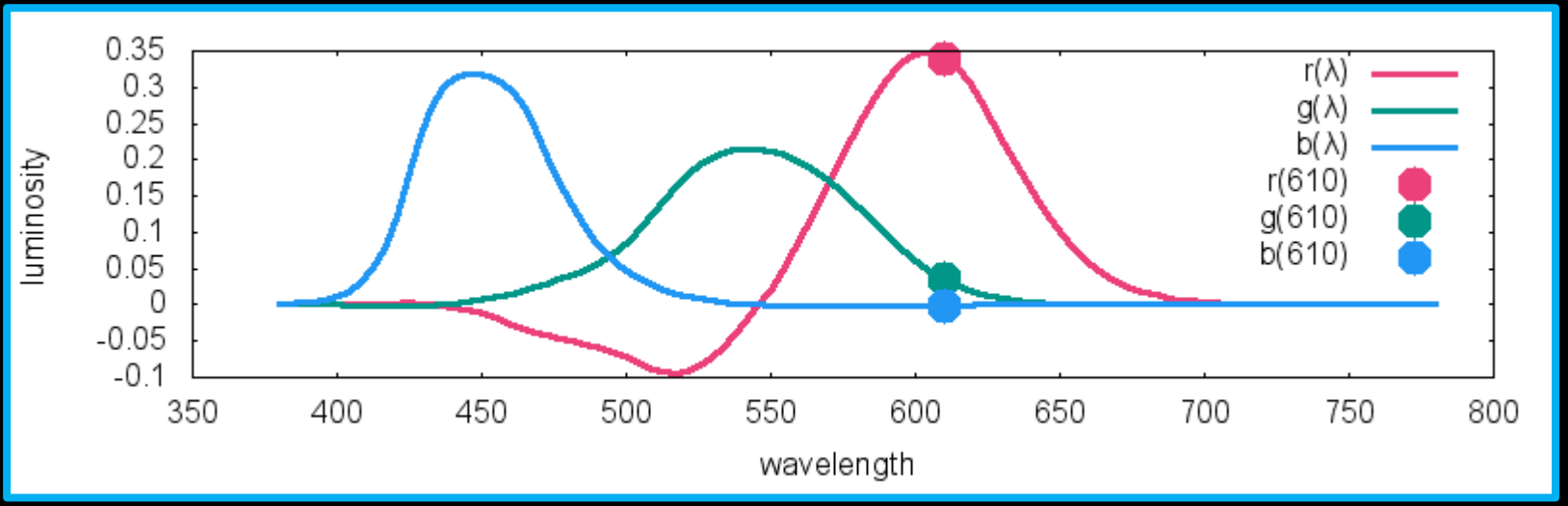
<< **CIE 1931** Standard Colorimetric Observer XYZ functions between 380 nm and 780 nm (at 5 nm intervals)

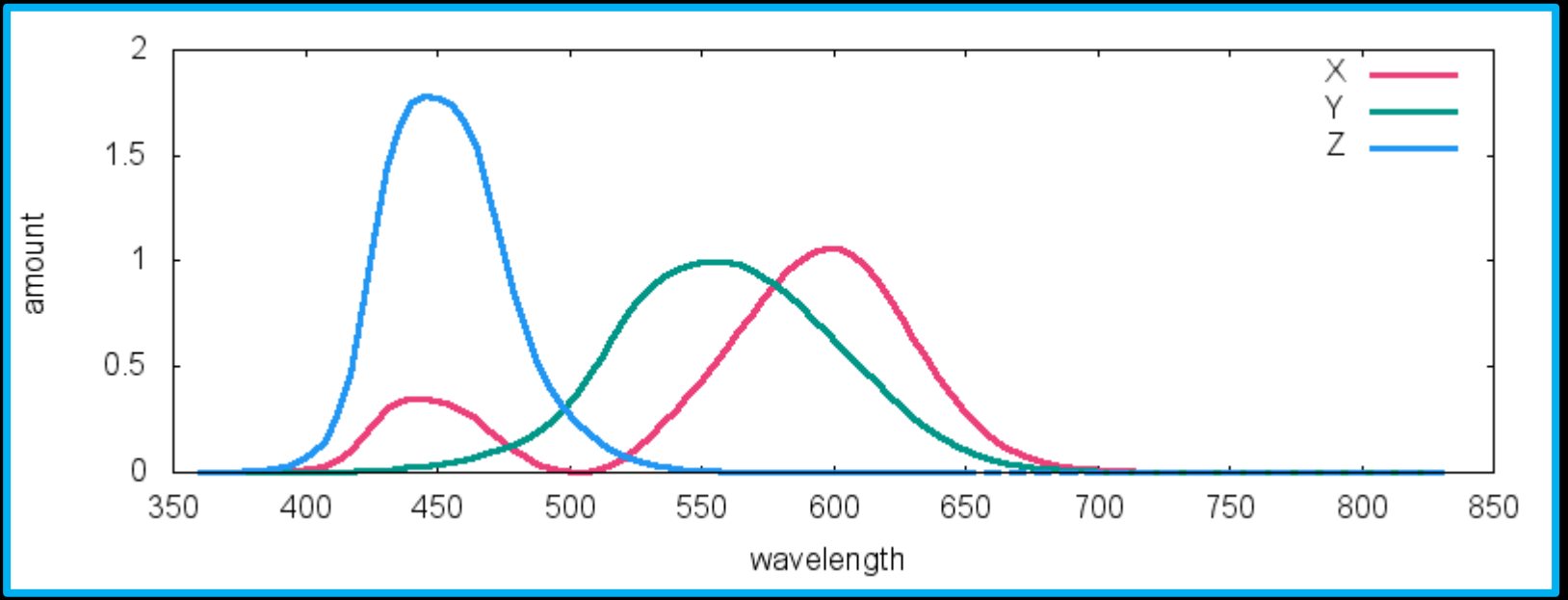
How is that possible?

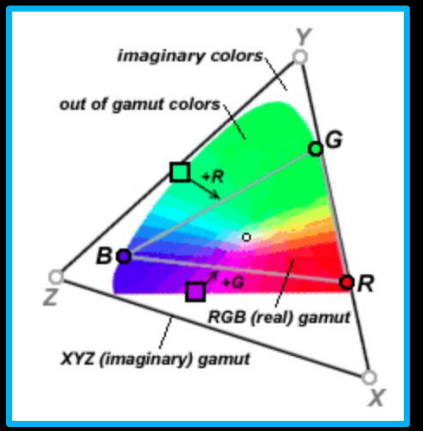


Source: article, gif

XYZ vs. 1931's RGB







Mixing from three real colors (R,G,B) -> to target everything we **have to subtract intensity**

Or we can **mix from the three imaginary colors (X,Y,Z)** and theoretically cover the whole gamut. But these imaginary colors don't exist …

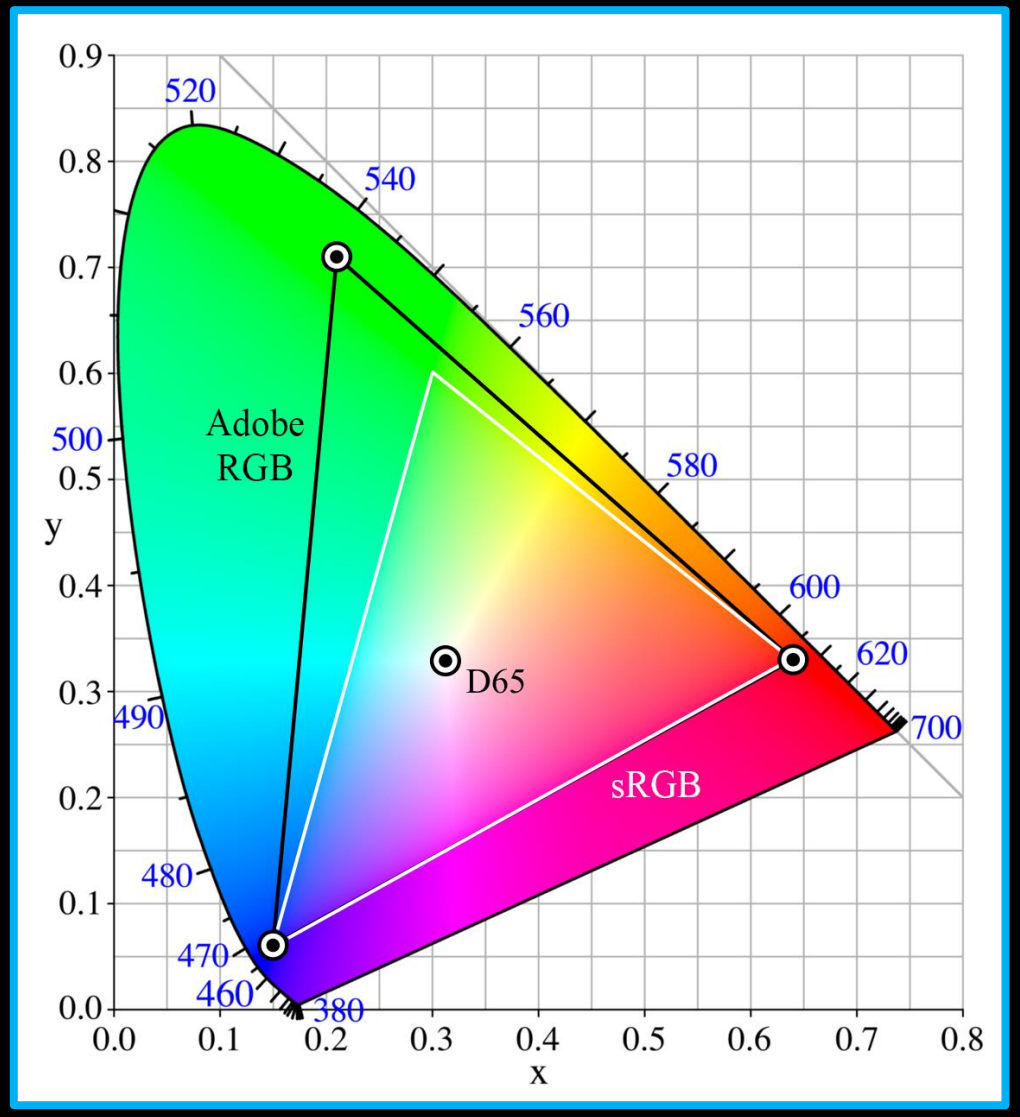
Practically …

- **We can’t mix with XYZ!**
- When using RGB values we are not mixing from the primaries used in 1931’s RGB. We are instead (usually) using the **sRGB** (made by Microsoft in 1996).
- There are other selections of the three primaries which will create their own gamuts – such as **Adobe RGB**.

Practically …

- But finally … each one of these systems specifies their primaries as mixed color in the XYZ coordinates.
- So we can show them on a plot together using the XYZ system

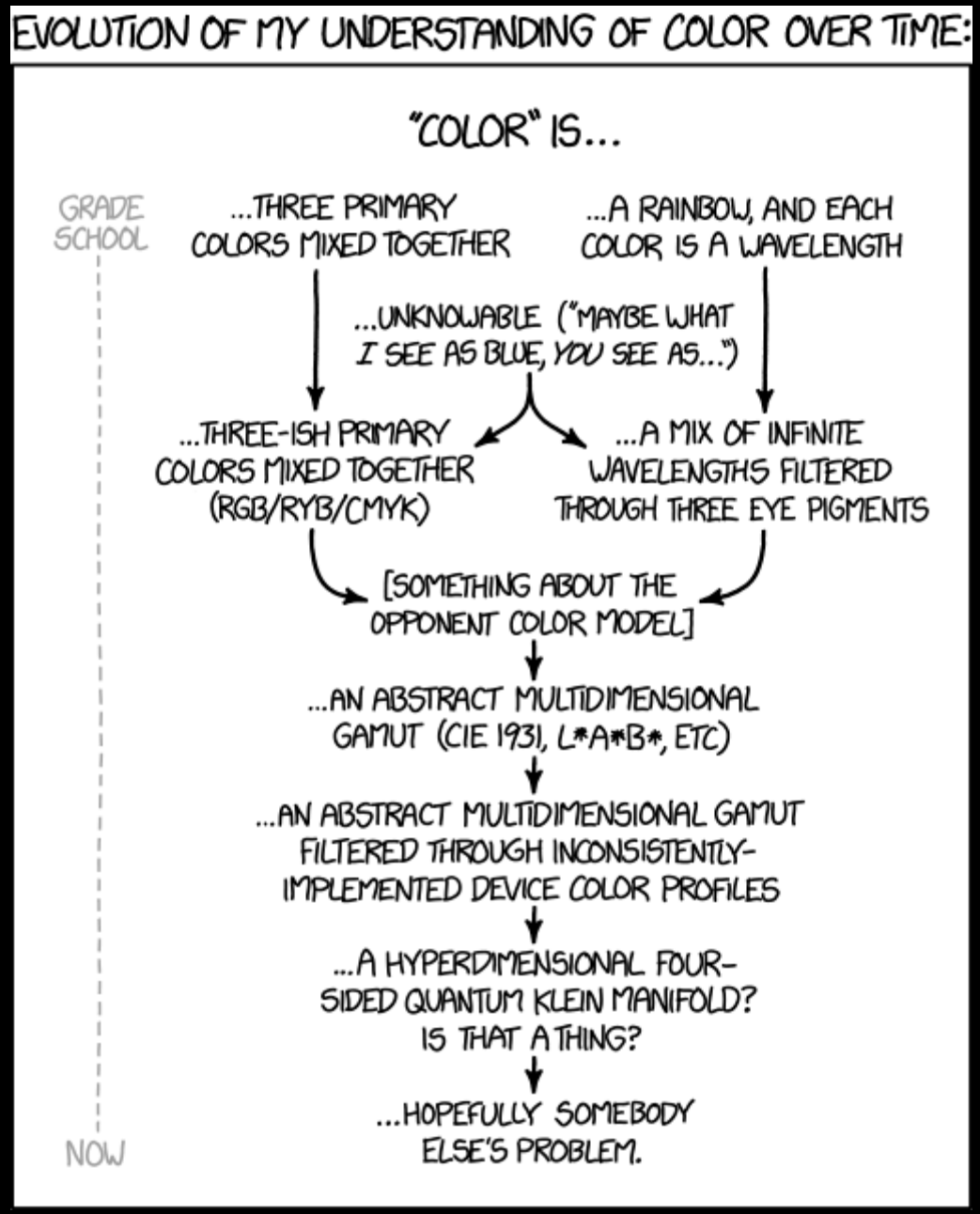
- *PS: Notice that neither sRGB or the Adobe RGB gamut can express all the colors which humans can perceive*



Furthermore …

- None of these gamuts can match whole human perception spectrum ...
- None of the systems *usually* used to **scan** the information (aka a **camera**) is exact
- None of the system *usually* used to **show** the information (aka a **display**) is exact
- Every human's **perception is different** (CIE experiments are done averaging some sample of population …)

- *Still we all live with this just fine :D*



xkcd.com/1882/

More?

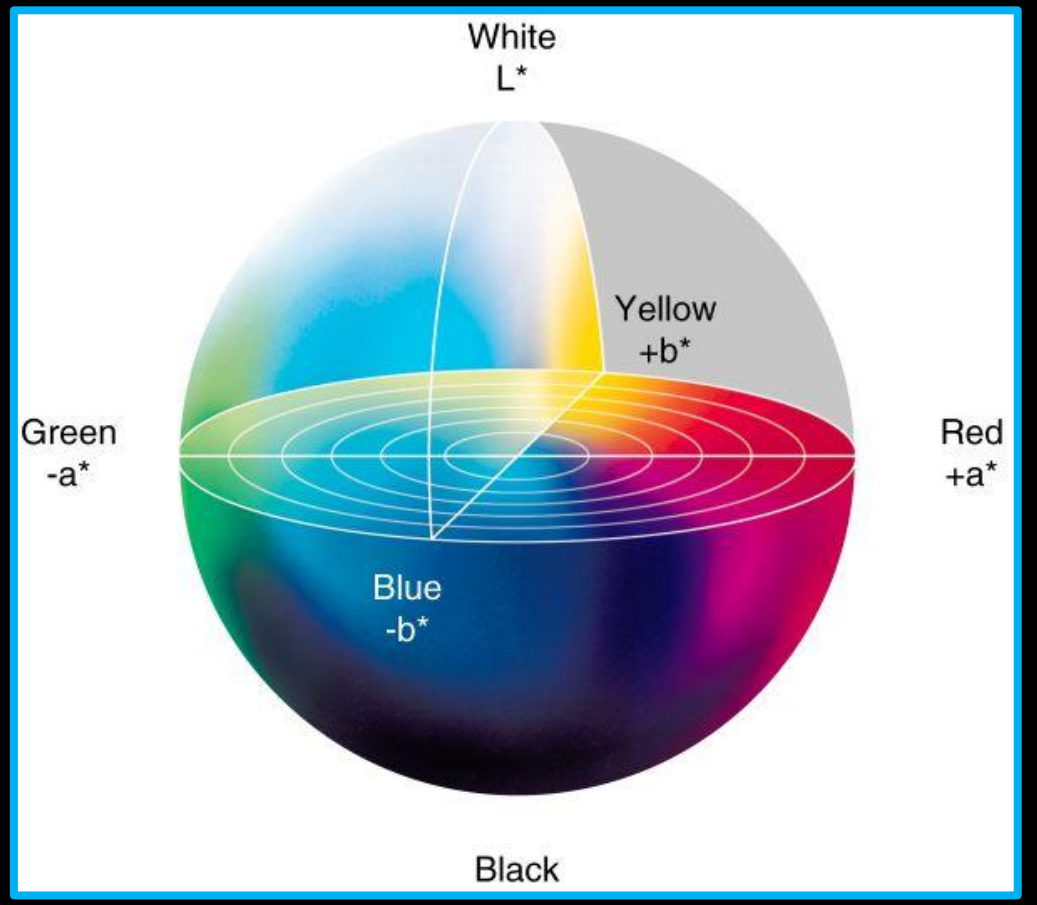
Representations

- Programmatically, if you can save your numbers into 3 channels, what you might **want to do?**
  - Have the relative differences on each of these channels **have the same relative effect** on the perceived change (+- some relativity)
  - Map some channels into easy to understand responses

- **Color spaces** such as: RGB –> HSV, Lab, LUV, …

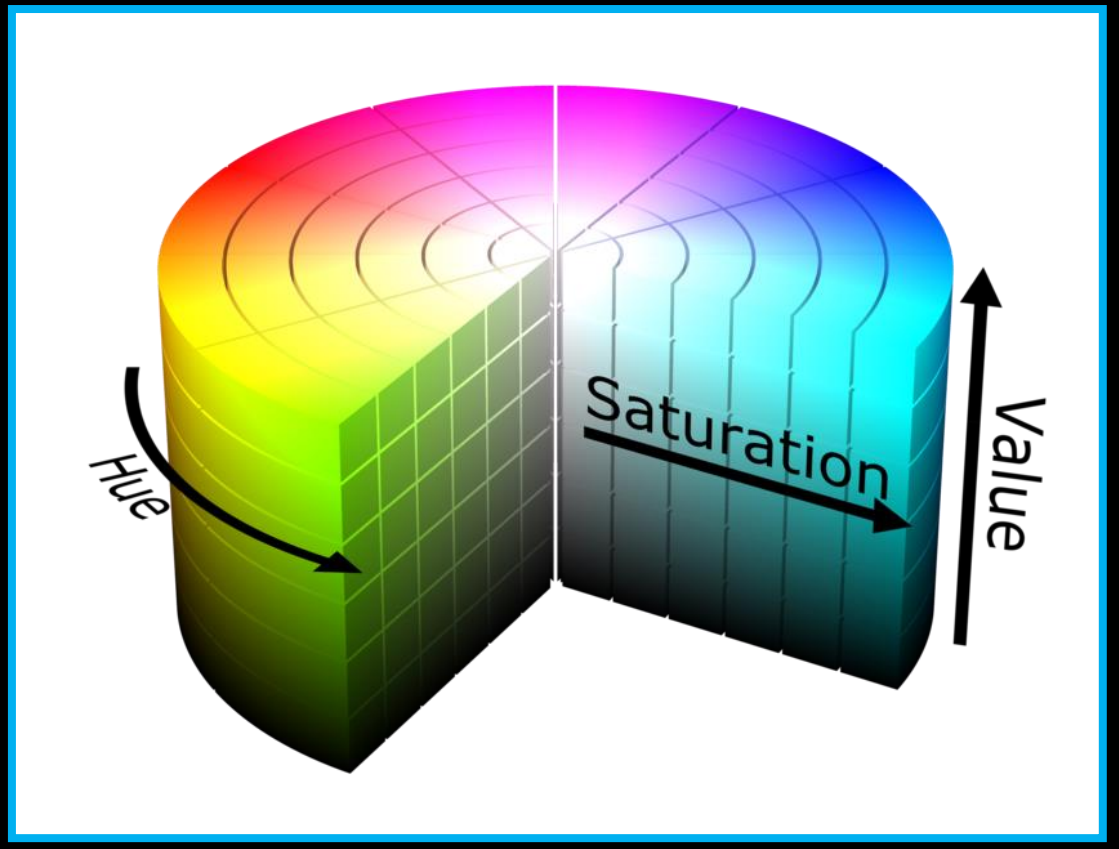
Color spaces

- **LAB** – Mapped from XYZ.
  - Color space that is **more perceptually linear than other color spaces**. Perceptually linear means that a change of the same amount in a color value should produce a change of about the same visual importance.
  - **Device-independent**—it defines colors independently of how they are created or displayed. (Depends on the *white point*)
  - The CIELAB color space is typically used when graphics for print have to be **converted from RGB to CMYK**, as the CIELAB gamut includes both the gamuts of the RGB and CMYK color models

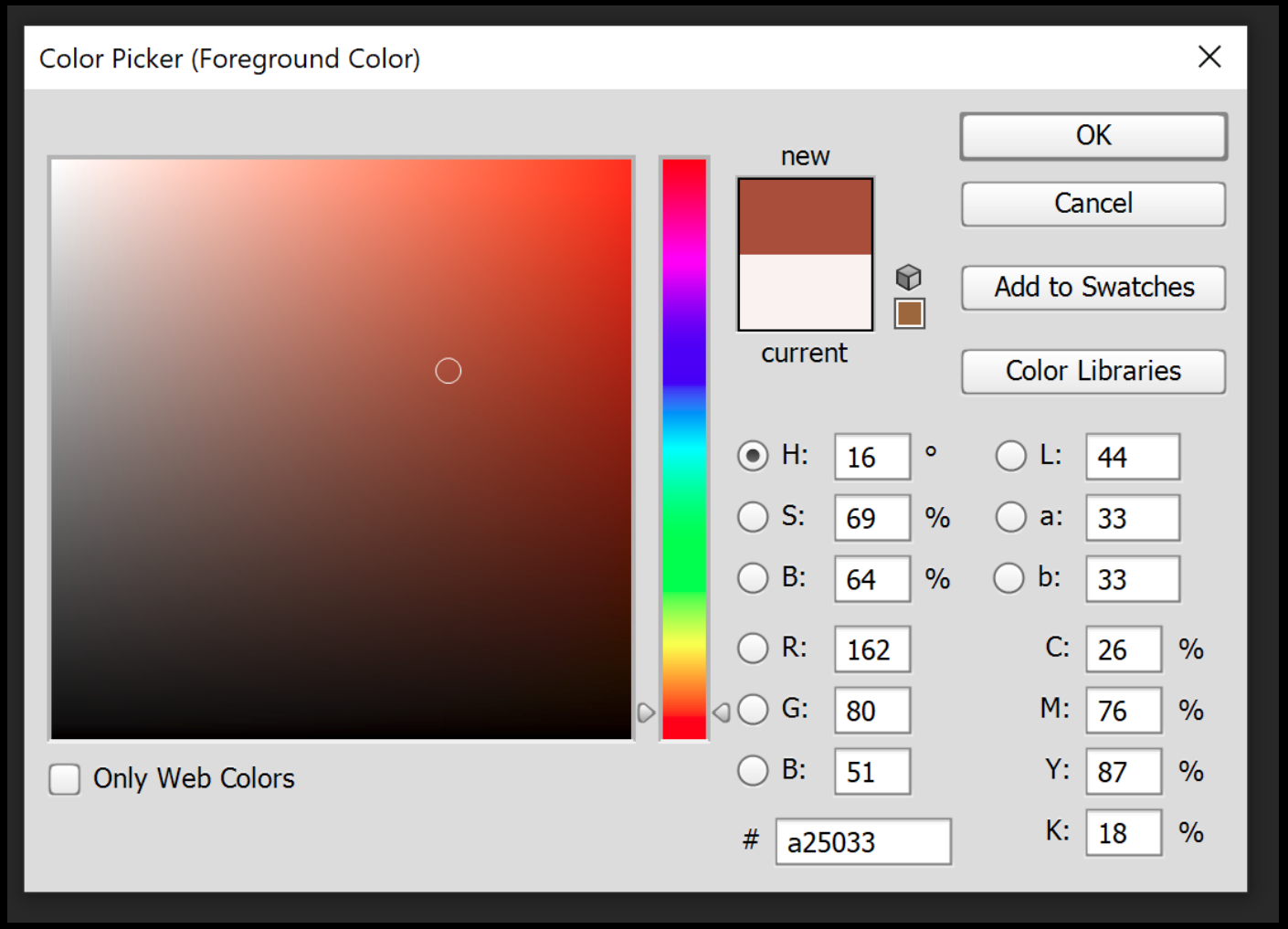


Color spaces - HSV

- **HSV** – sRGB re-mapped as **(hue, saturation, value=brightness)**, is often used by artists because it is often more natural to think about a color in terms of hue and saturation than in terms of additive or subtractive color components.



Color picker



HSV (=HSB)

Lab

RGB

In python?

- Using several libraries – *colorsys, skimage*

- Mapping from RGB:
  - **HSV**: colorsys.rgb_to_hsv(r, g, b) *# here we have single color*
  - **Lab**: lab = skimage.color.rgb2lab(rgb) *# here we have a whole image*

PS: inside probably RGB -> XYZ -> LAB

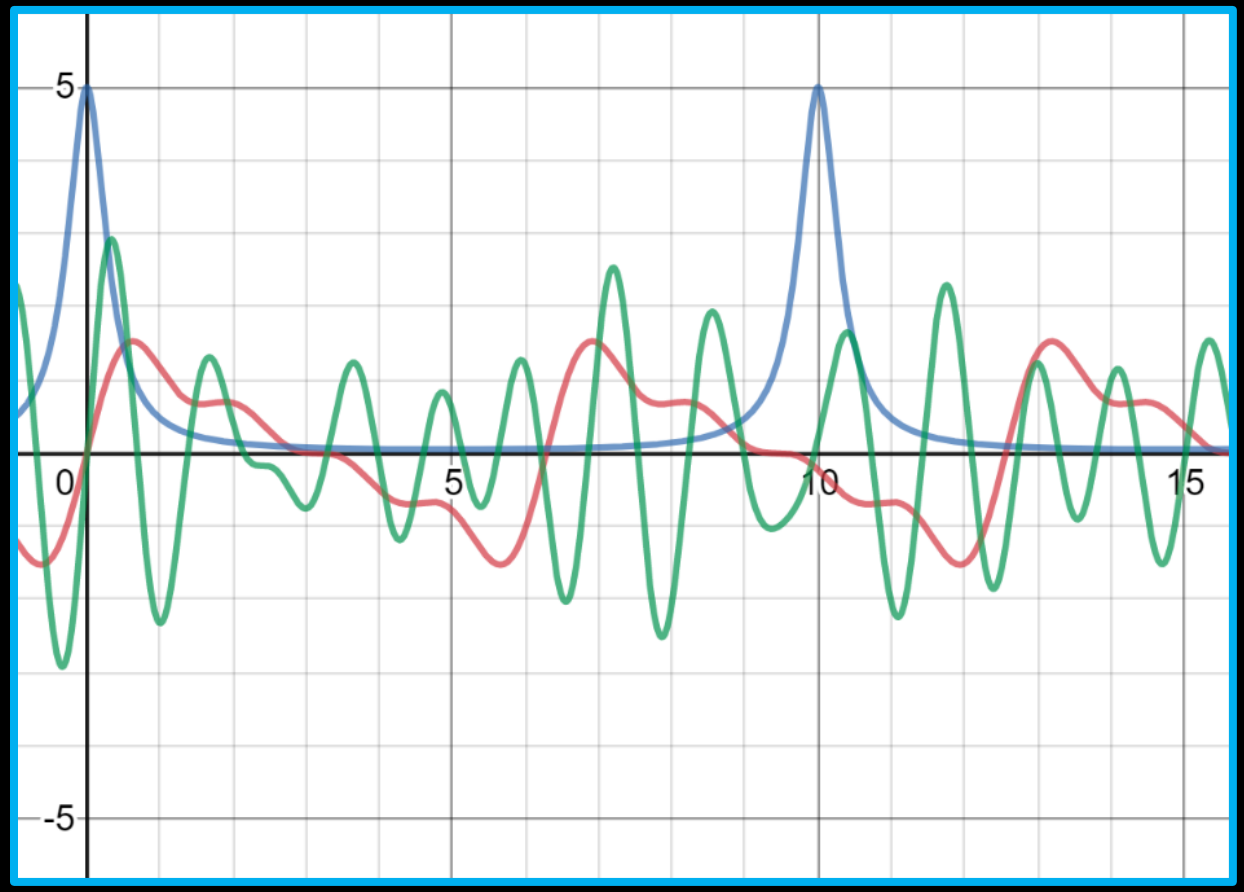
Short recap of periodic functions

Trigonometry and periodic function

- In the said task, we will want to **map numbers into one channel of a non-RGB color systems** …
- Periodic functions can help is with getting the value we want to translate into numbers.

Short recap

- Some fun examples of sums of periodic functions:
  - desmos.com/calculator/b978bw7w3l
  - Or anything else you'd like!

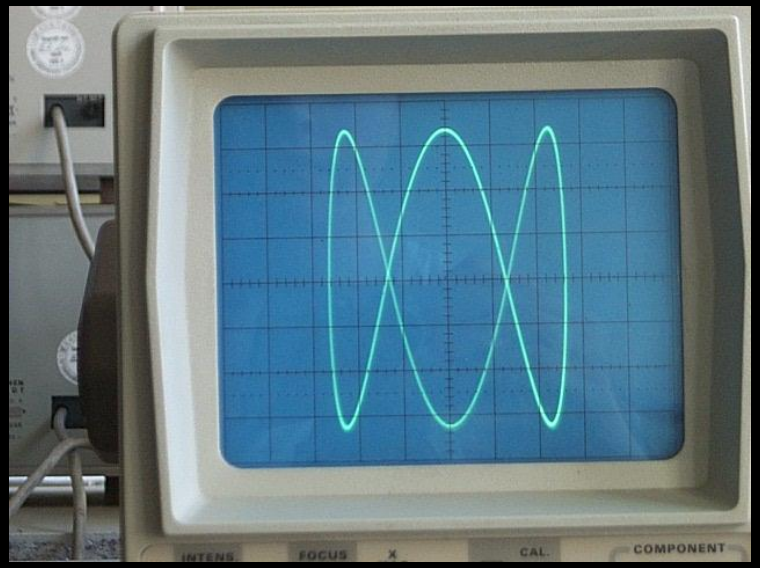


Bonus: Lissajous curves

- Lissajous curves mathematically
  - Lissajous figure is the graph of a system of parametric equations:

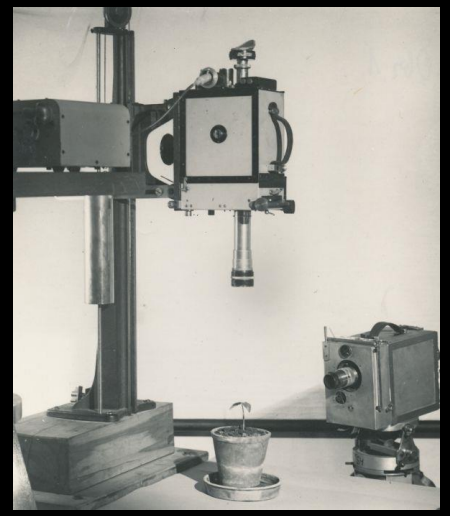
$$x = A\sin(at + \delta), \quad y = B\sin(bt),$$

youtube.com/watch?v=t6nGiBzGLD8

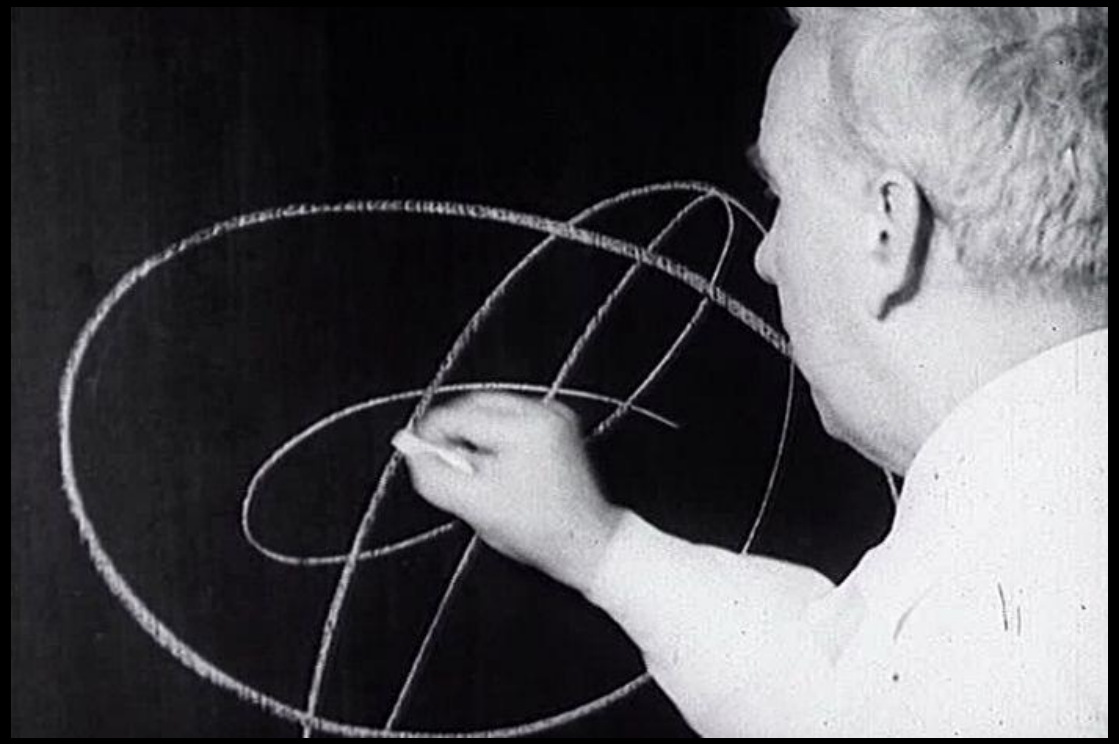


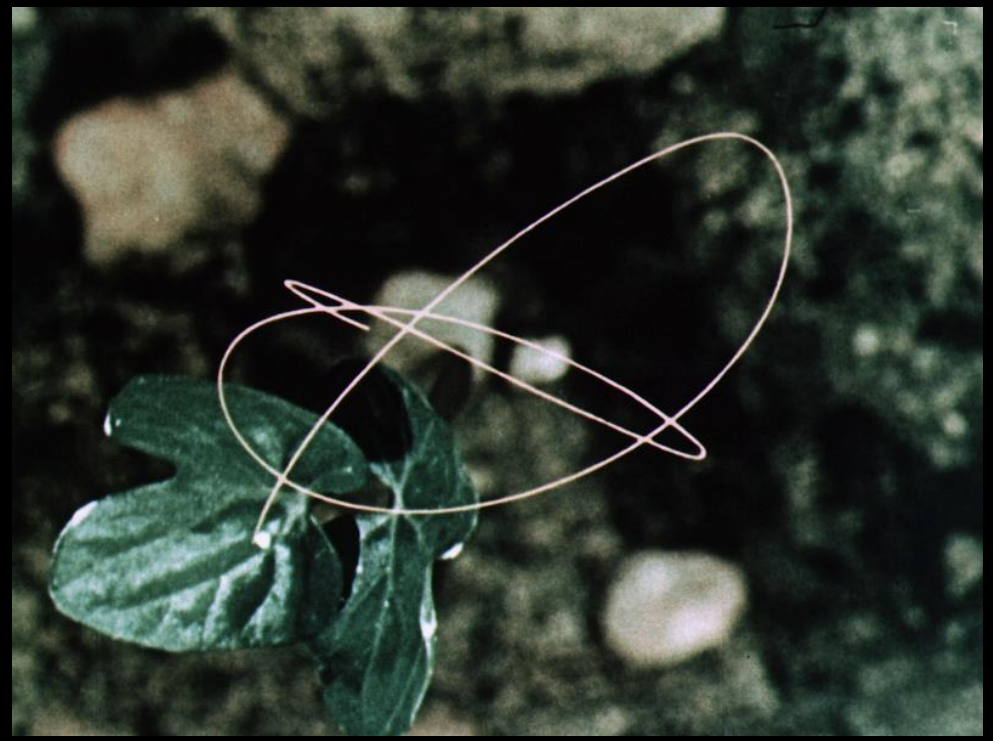
- The appearance of the figure is highly sensitive to the ratio a / b . For a ratio of 1, the figure is an **ellipse**, with special cases including circles (A = B, δ = π / 2 radians) and lines (δ = 0). Another simple Lissajous figure is the **parabola** (b / a = 2, δ = π / 4). Other ratios produce more complicated curves, which are closed only if a / b is rational.

Lissajous curves



- Studies of plant movements





Lissajous curves

- Also demo at: desmos.com/calculator/tyjkpwuotb

Pause 2

Programming task

- **Mapping a periodic function onto chosen color space**.
- Task: Select a coordinate from a **non-RGB color system**.

- Starter code:
  - w08_color_spaces.ipynb

Next class?

- **Path finding**
  - Algorithms for searching in map environments

Links?

Primary colors

- (History/) Story of primary colors (in very readable form!) www.handprint.com/HP/WCL/color6.html

The End