SCIENTIFIC AND LARGE DATA VISUALIZATION

December 12, 2020

Applied Perception – Part II (Color)

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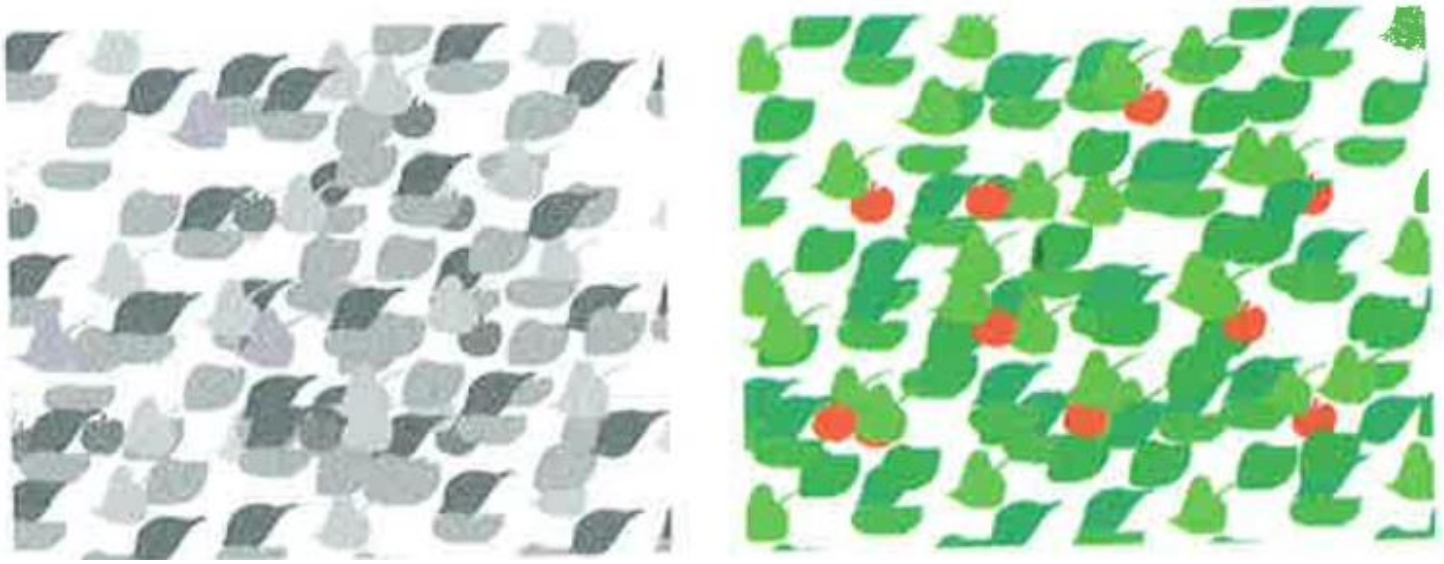
Why color

The function of color vision

Colour vision can be considered as largely superfluous in modern life…

(about 10% of the male population and about 1% of the female population have some form of color deficiency – hunters *vs* gatherers in human evolution)

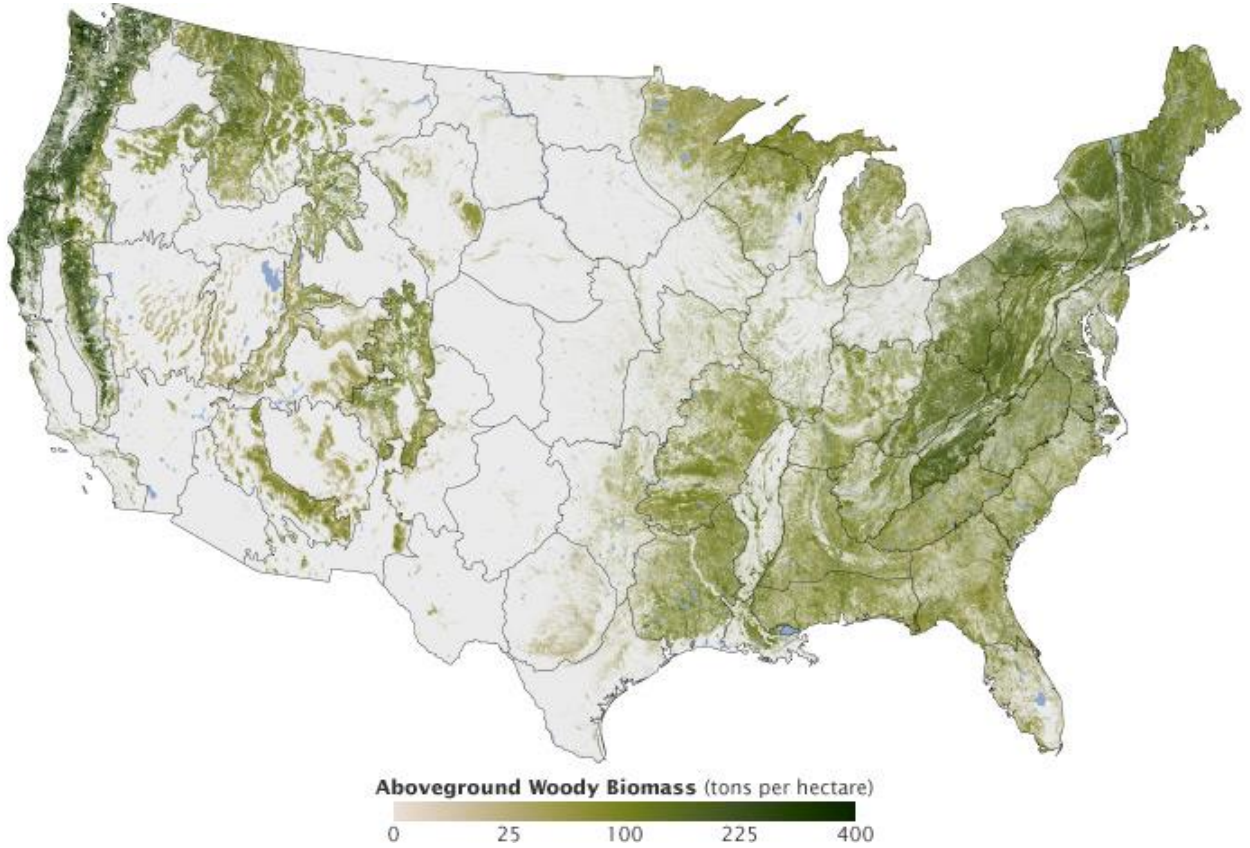


[Breaking camouflage and finding the cherries, from Colin Ware's book Information Visualization – Perception for design]

The function of color vision

…yet color is extremely useful in data visualization:

- showing patterns
- labeling
- highlighting



[https://earthobservatory.nasa.gov/features/ForestCarbon/page4.php]

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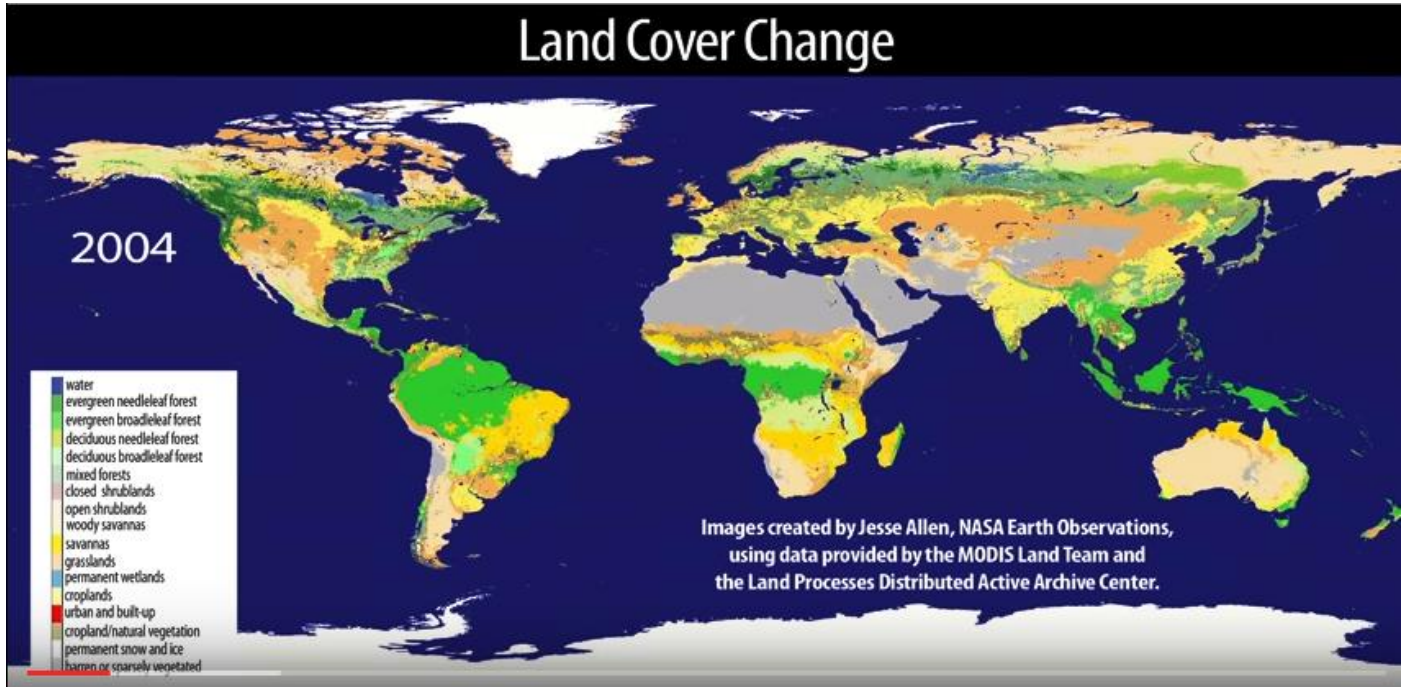

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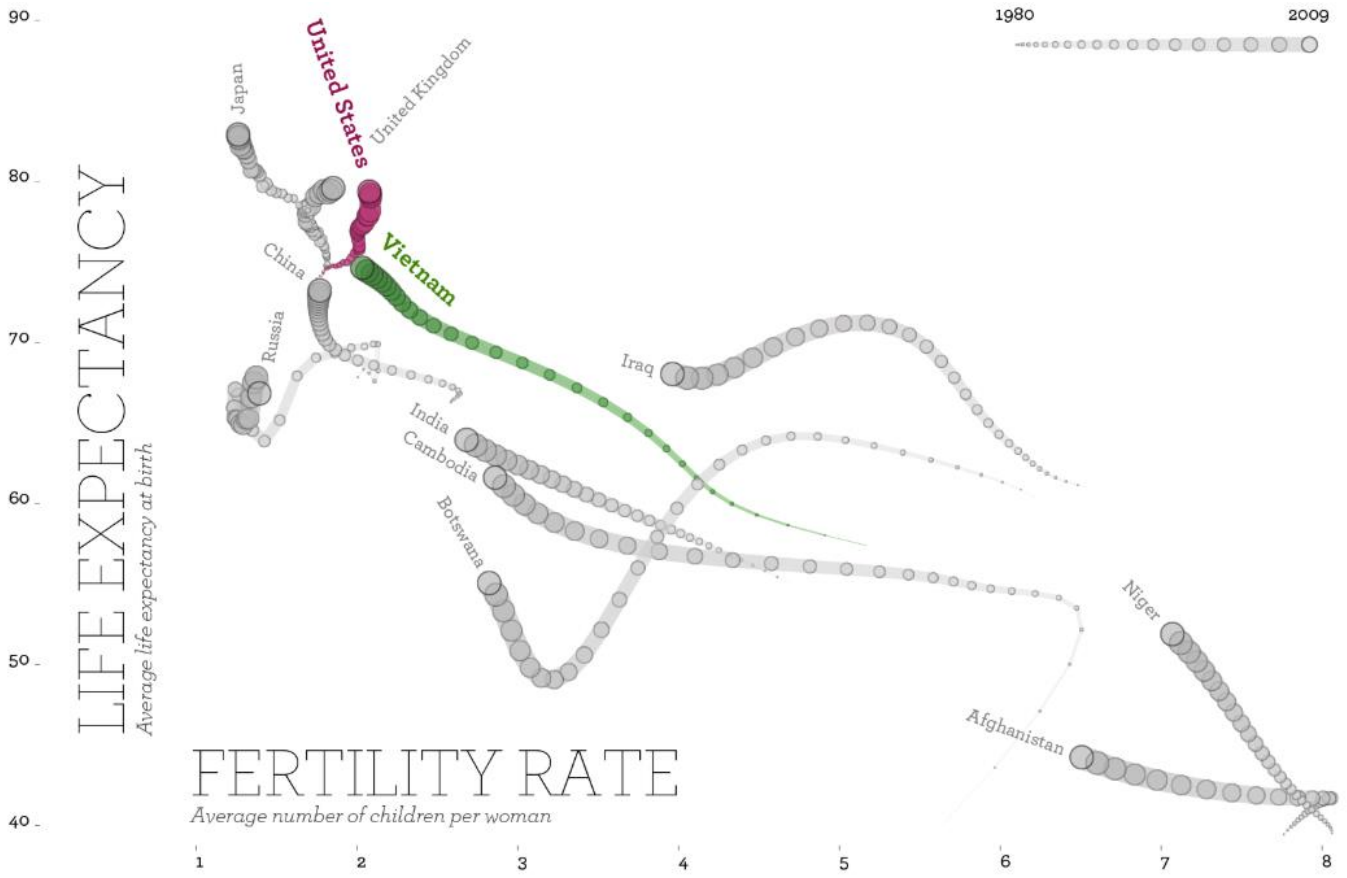


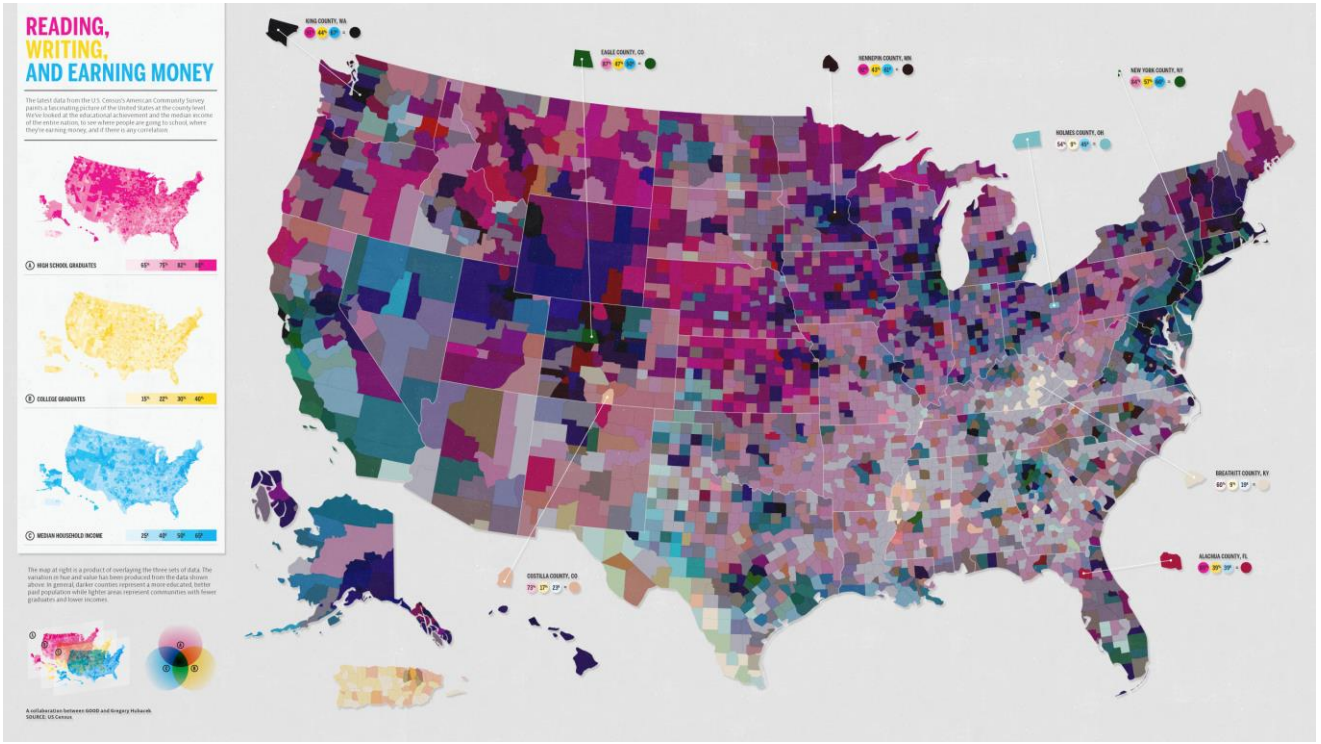
[http://truth-and-beauty.net/projects/remixing-rosling]

The function of color vision

…yet color is easy to misuse

"Above all, do no harm" (*Envisioning Information*, E. Tufte)

"Think of color as an attribute of an object rather than its primary characteristic" (*Information Visualization*, C. Ware)



[https://gis.stackexchange.com/questions/3087/what-makes-a-map-be-classed-as-badly-designed]

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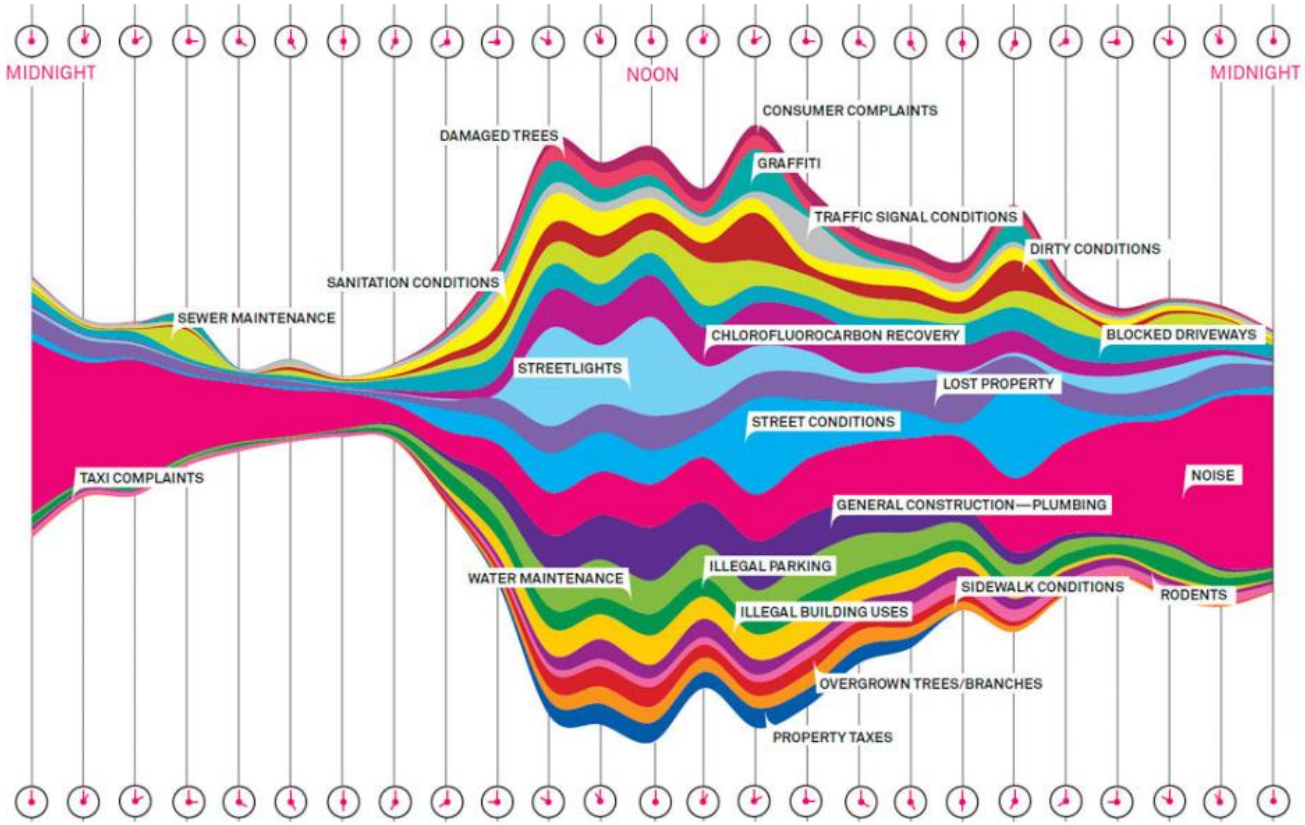


[https://www.wired.com/2010/11/ff_311_new_york/]

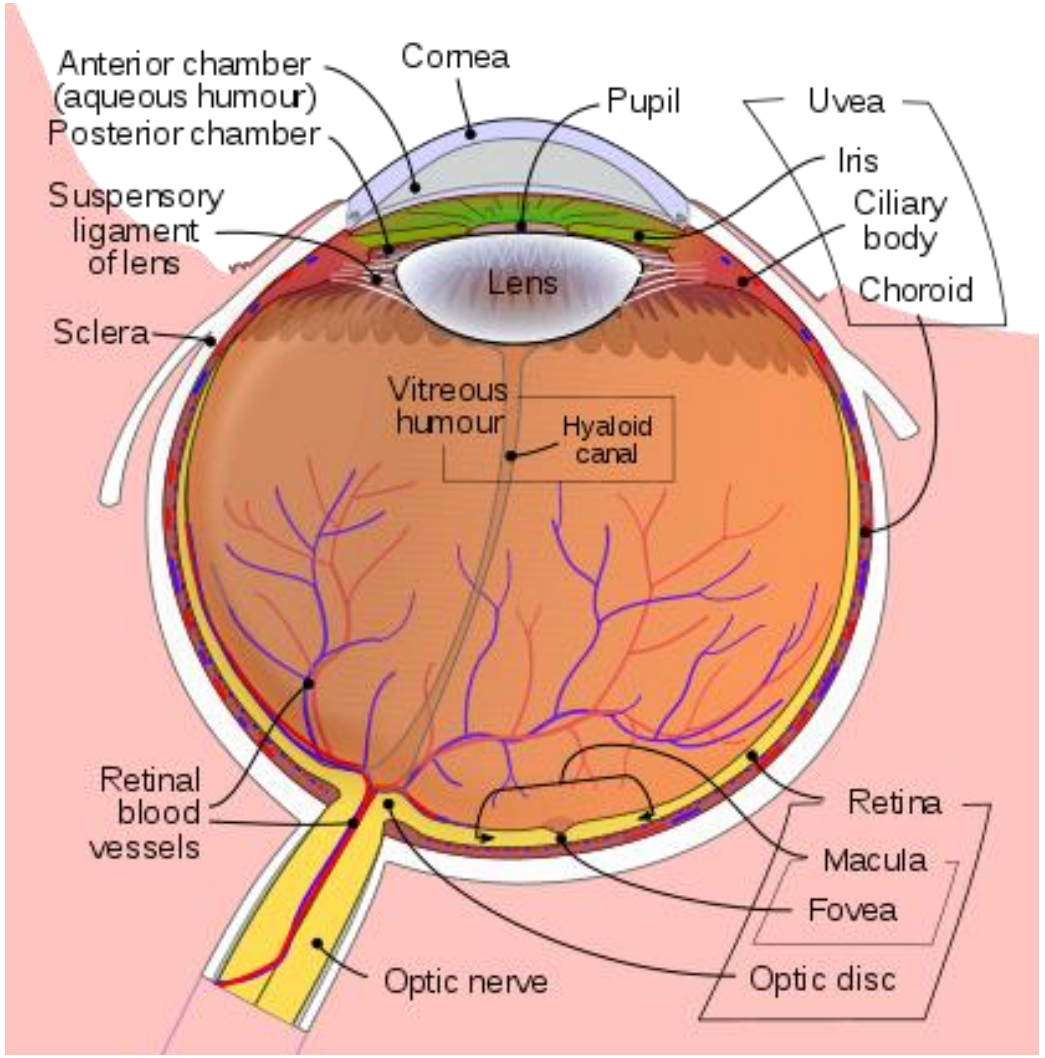
Plan for today

- Basics on color perception
  - trichromacy theory
  - opponent process theory
- Color spaces
  - RGB, HSV/SL, CIE Lab/Luv, CIE LCh/HCL
  - perceptual uniformness, usability
- Color in visualization
  - lightness and saturation
  - categories
  - scales

Where we left off

The Human Visual System

The eye and the brain



The Human Visual System

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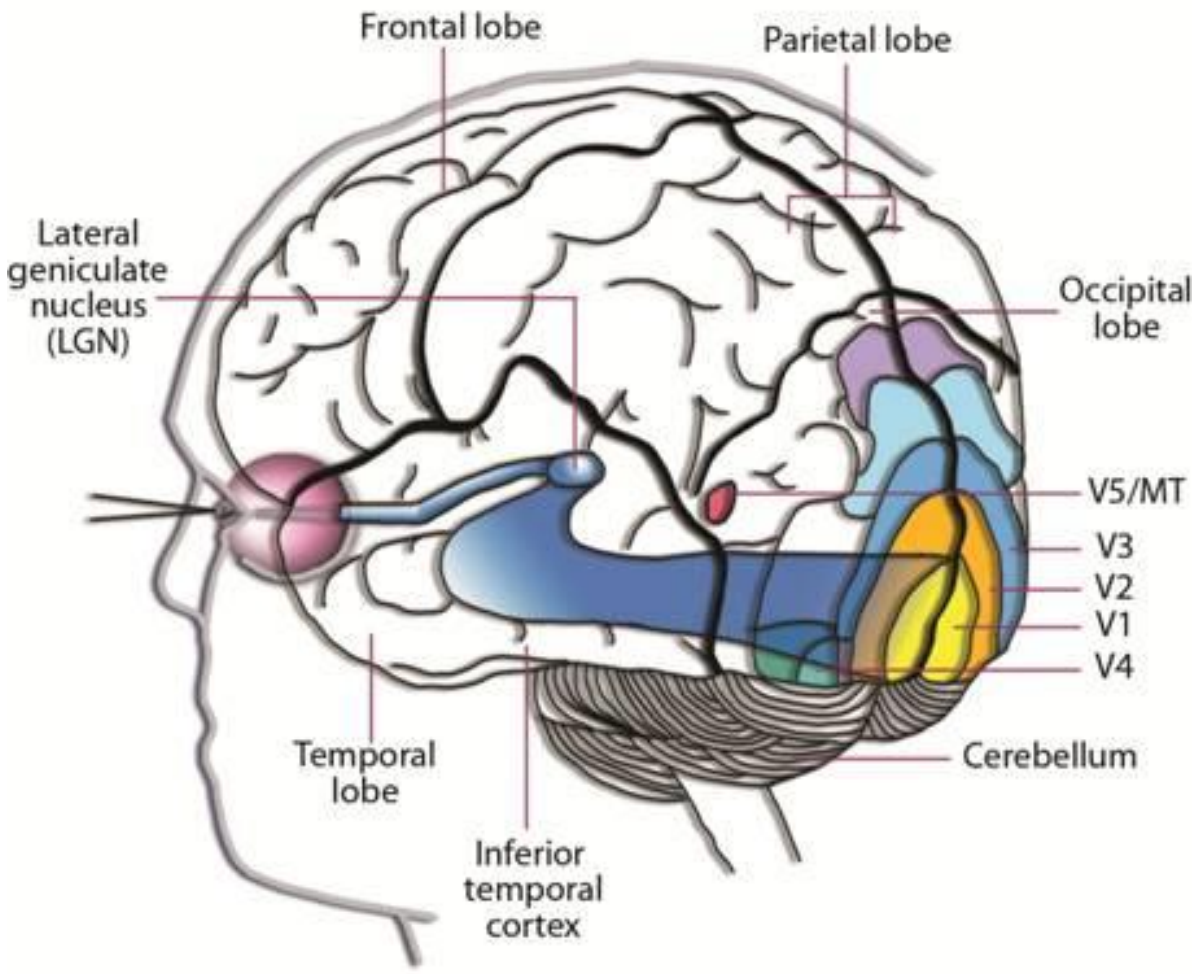
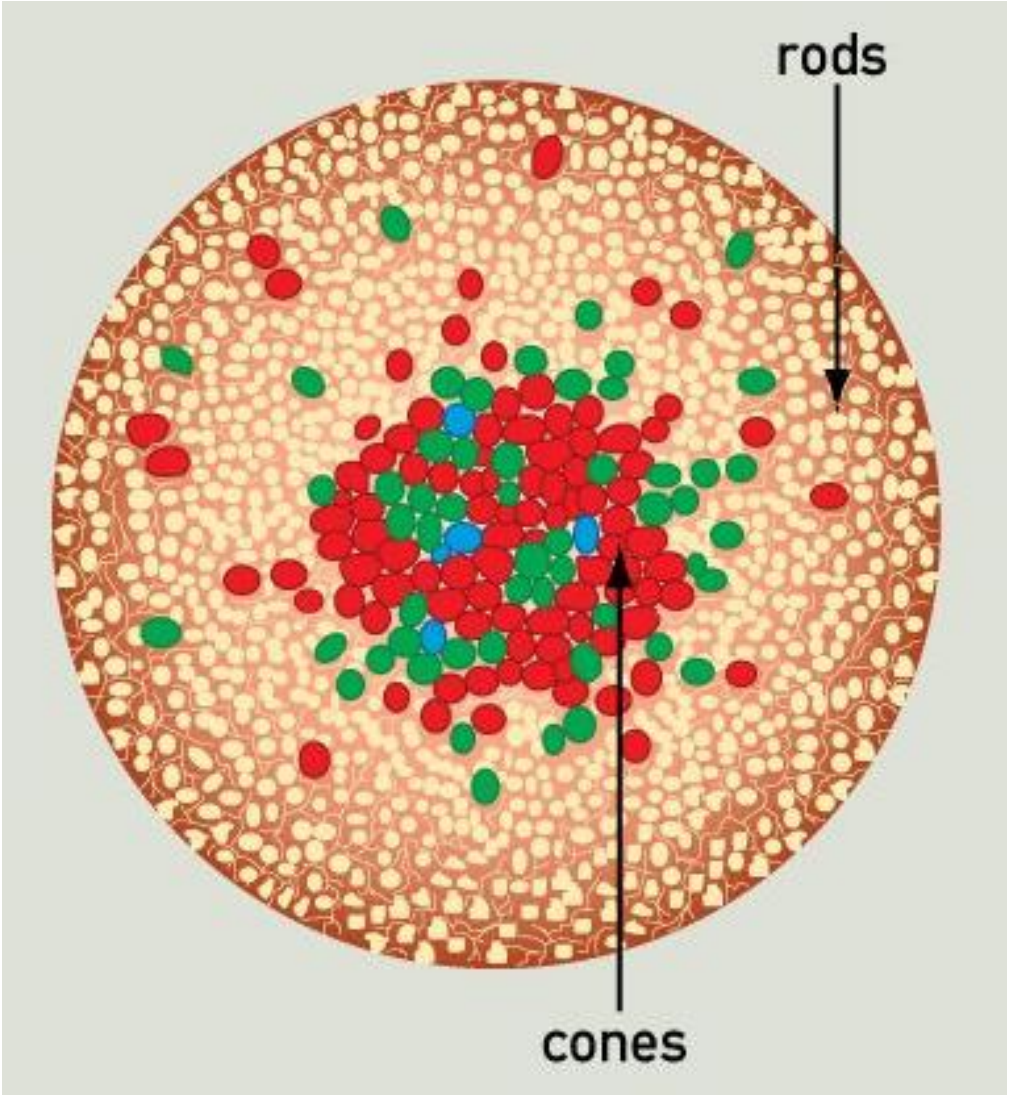


The Human Visual System

We have three distinct color receptors on the retina, the *cones*, which are active at normal light levels

The influence of *rods* on color perception can be ignored



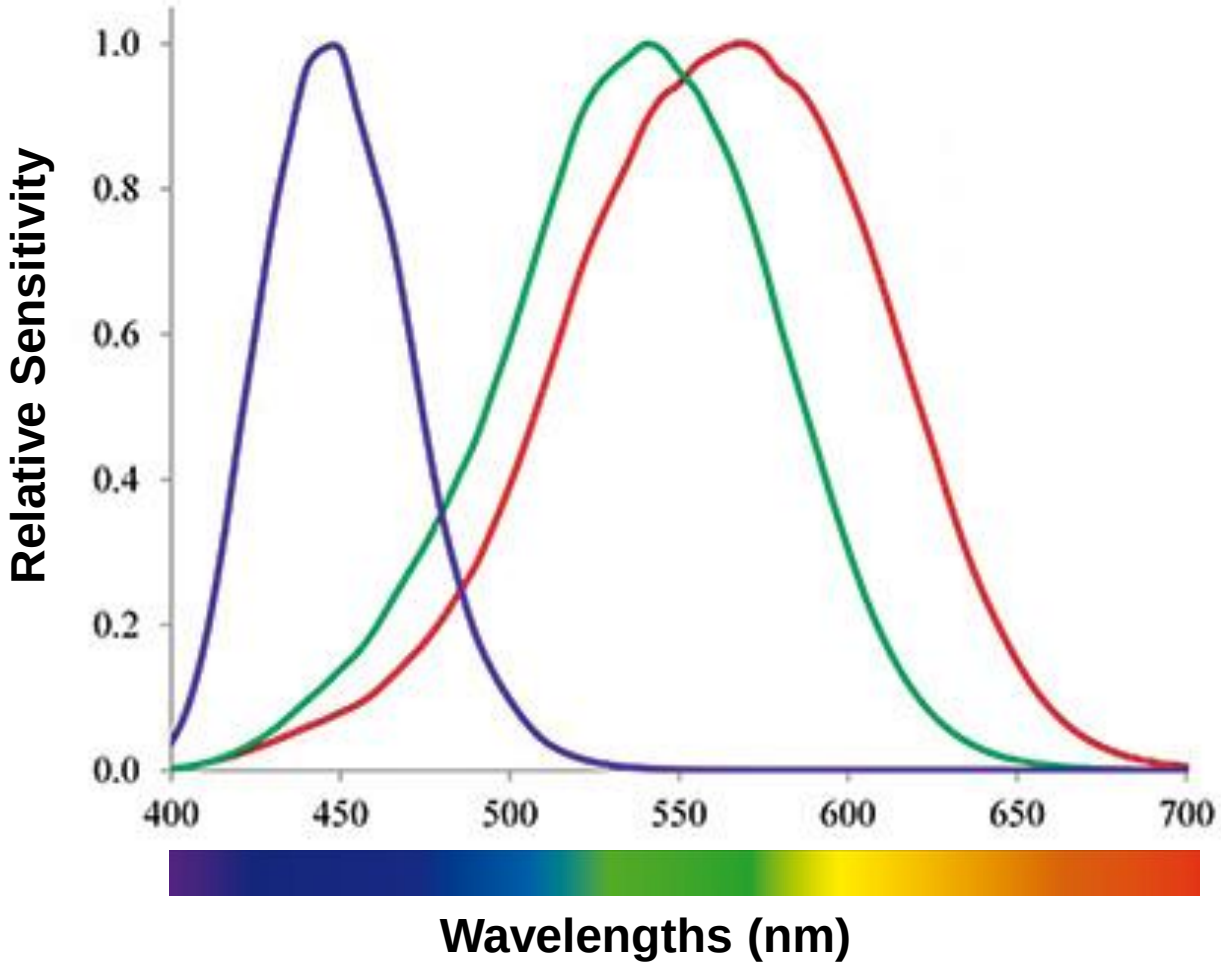
Trichromacy and Opponent process theories

Trichromacy theory

Cones are sensitive to different wavelengths (short, medium, long)

Hence they absorb light around the spectrum of blue, green, and red

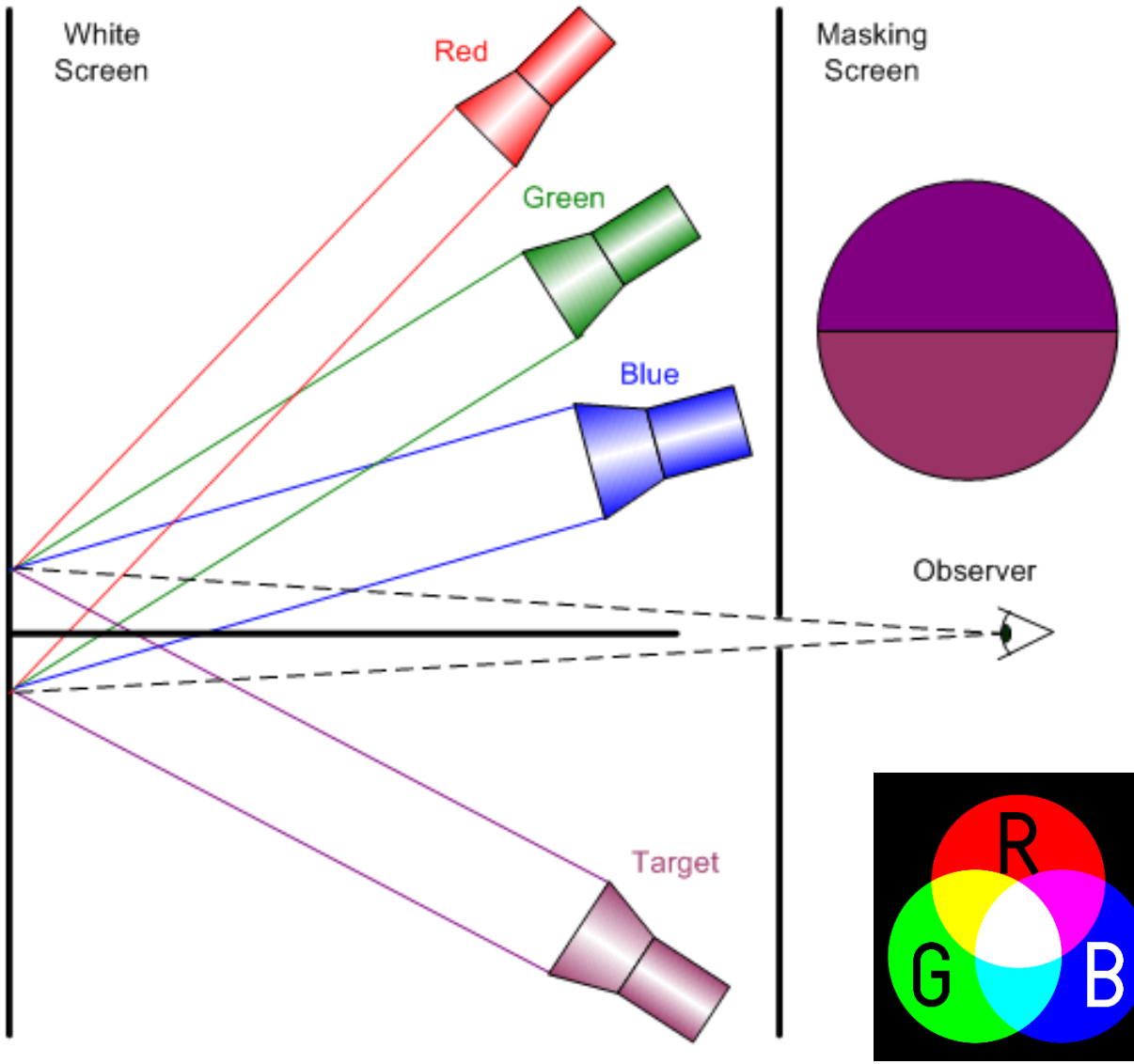
The theory says that we perceive color as a three-channel system. All color spaces, even if designed to different purposes, are three-dimensional



Colour measurement and specification

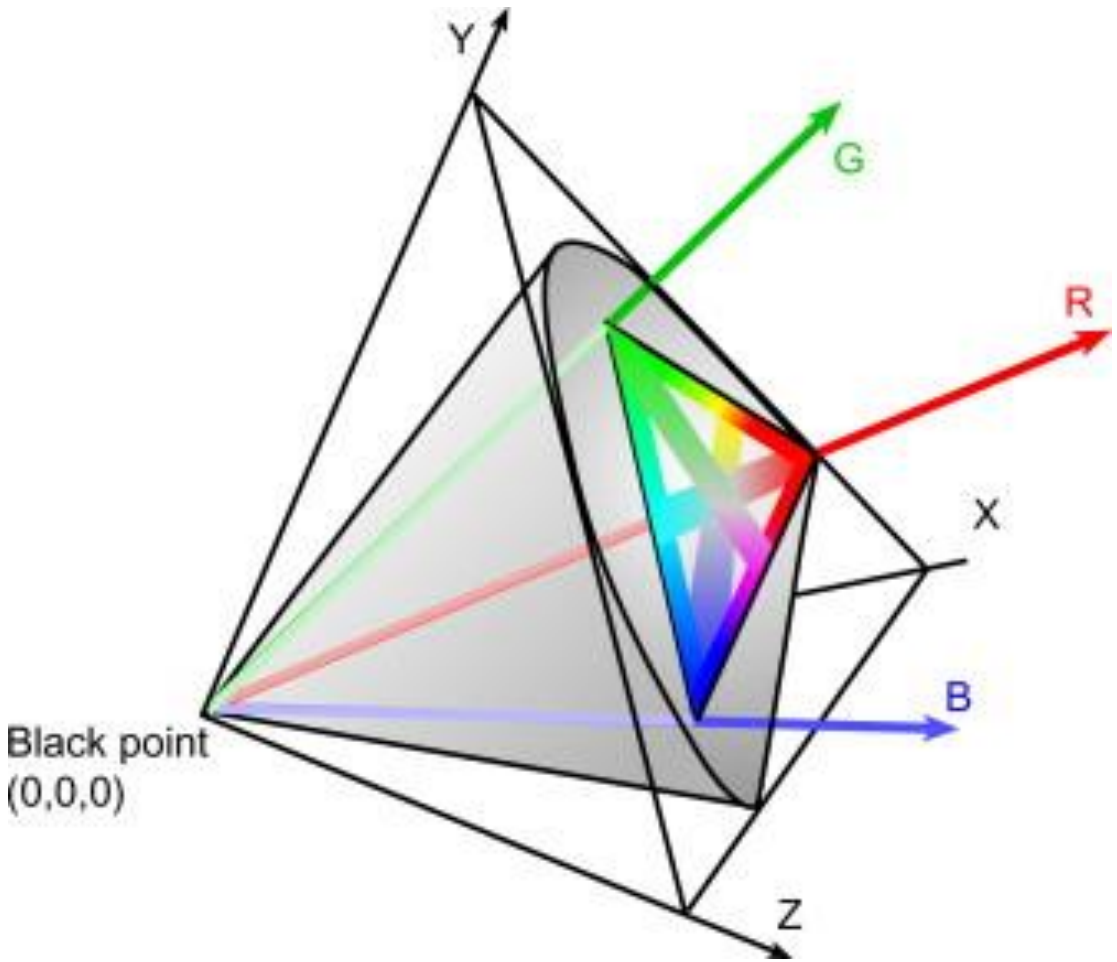
Since only three different receptors are involved in color vision, it is possible to match a patch of color light using a mixture of three color lights, called *primaries*

Given a standard set of primaries, one can use a transformation to create the same color on different output devices



Colour measurement and specification

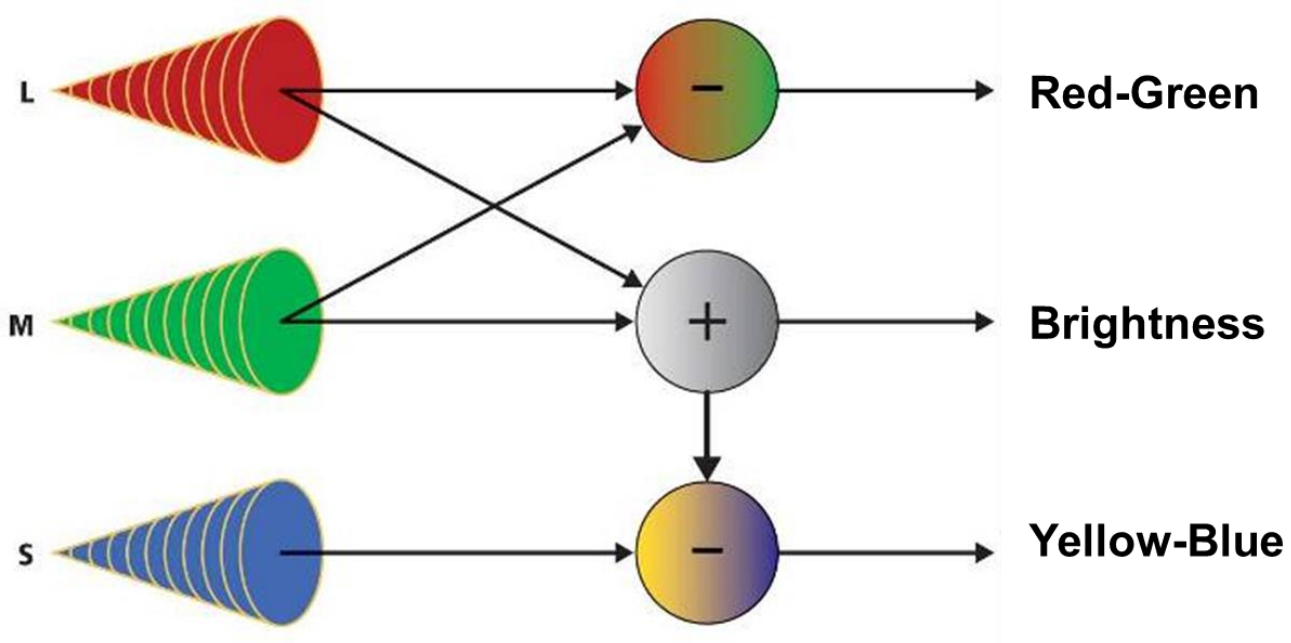
CIE *(Commission Internationale de l'Eclairage)* performed measurements (prior to 1931) to collect color matching functions from observers, and transformed them to have a set of abstract primaries called the *XYZ tristimulus* values



[The CIE XYZ standard virtual primaries. The gray solid is the gamut of perceivable colors. The pyramid represents the colors that can be created by means of R, G, B monitor primaries. From C. Ware, Information for Visualization]

Opponent process theory

In the late 19th century, German psychologist e. Hering proposed the theory (later supported by experimental evidence) that there are six elementary colors, and that these colors are arranged perceptually as opponent pairs along three axes: black-white, yellow-green, and yellow-blue

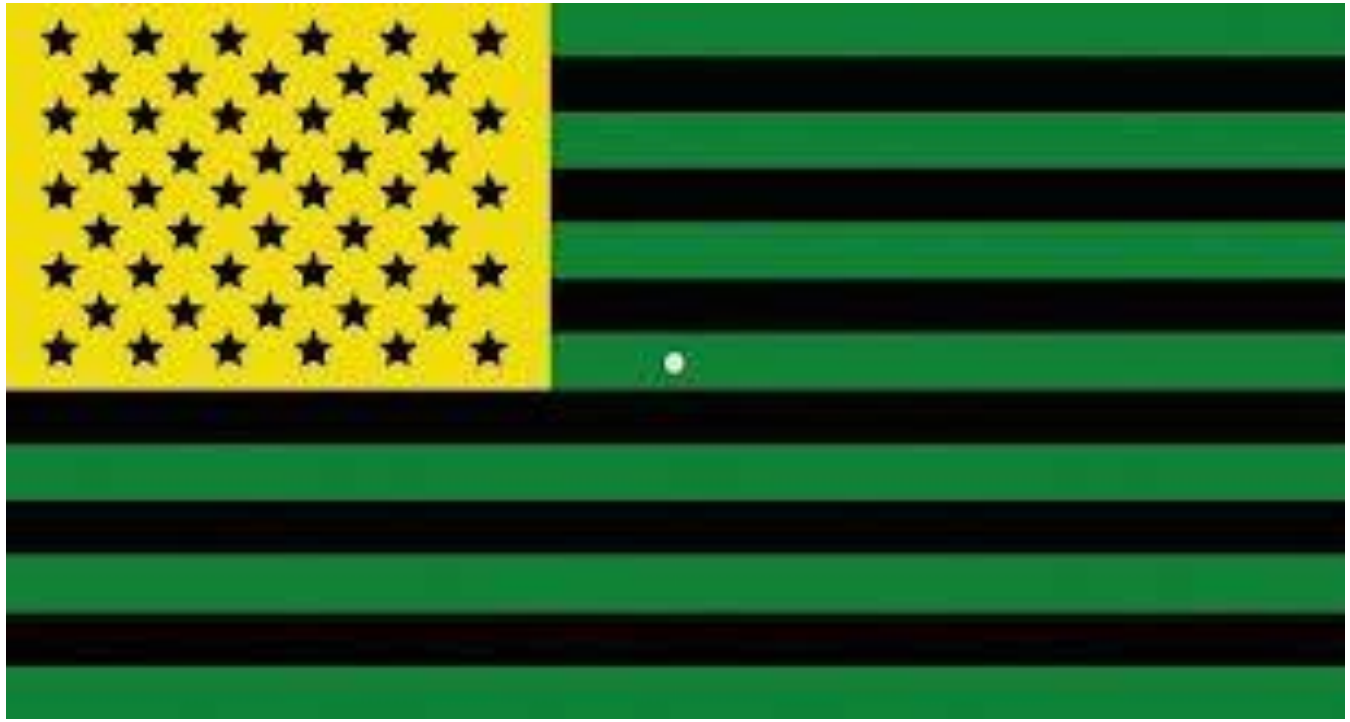


Opponent process theory

Scientific evidence

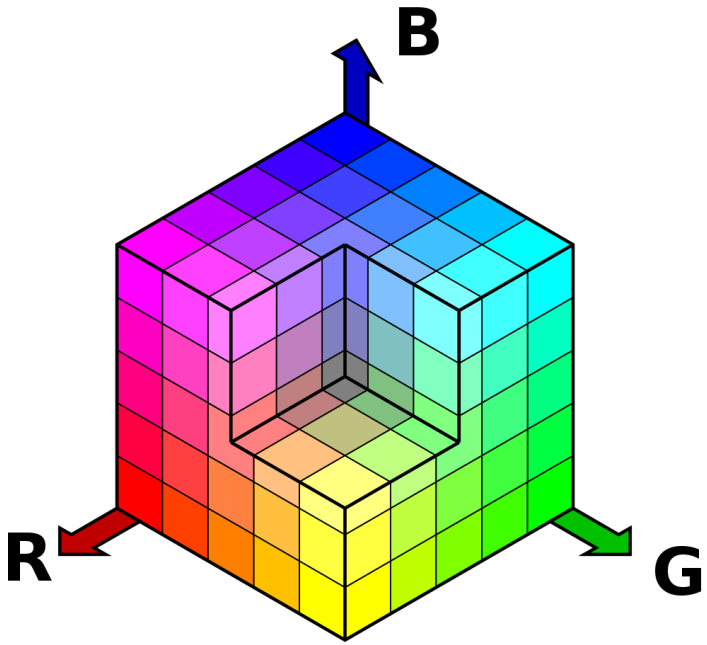
- Naming: certain color names do not occur in combination
  - ever heard of *reddish gree*n?
- Cross-cultural naming: Berlin and Kay [1969] showed that primary color terms are remarkably consistent across cultures
  - black and white in cultures with two color names, red if a third color is present, fourth and fifth are either yellow and green or green and yellow, sixth is blue
- Unique hues: if asked to adjust the spectral patch of light, there is evidence for a unique yellow hue, two green hues
- Categorical colors: certain colors are canonical (ideal in Plato's sense)
  - in an experiment to name 210 colors produced on a monitor, only eight colors were consistently named, plus white (1969)

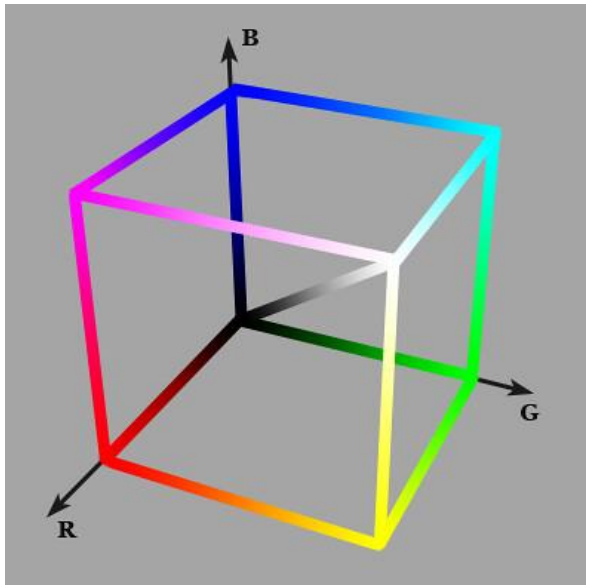
Opponent process theory



Color spaces

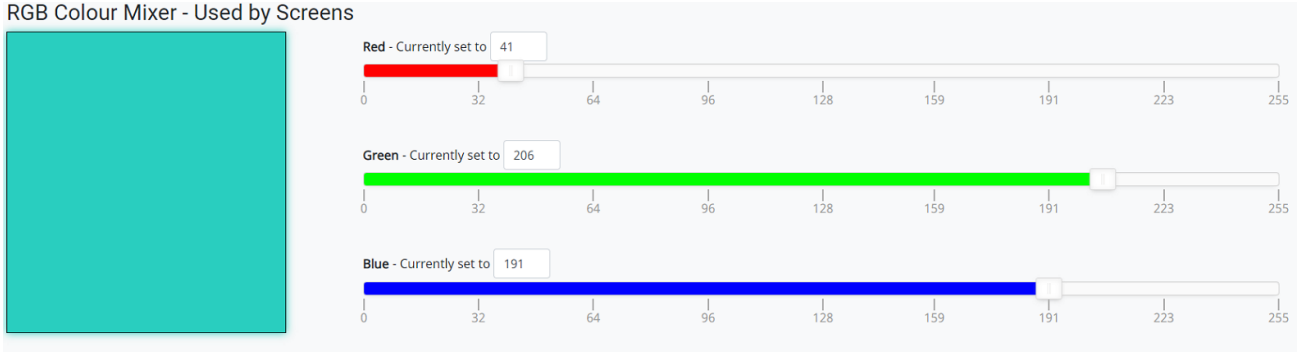
RGB color space



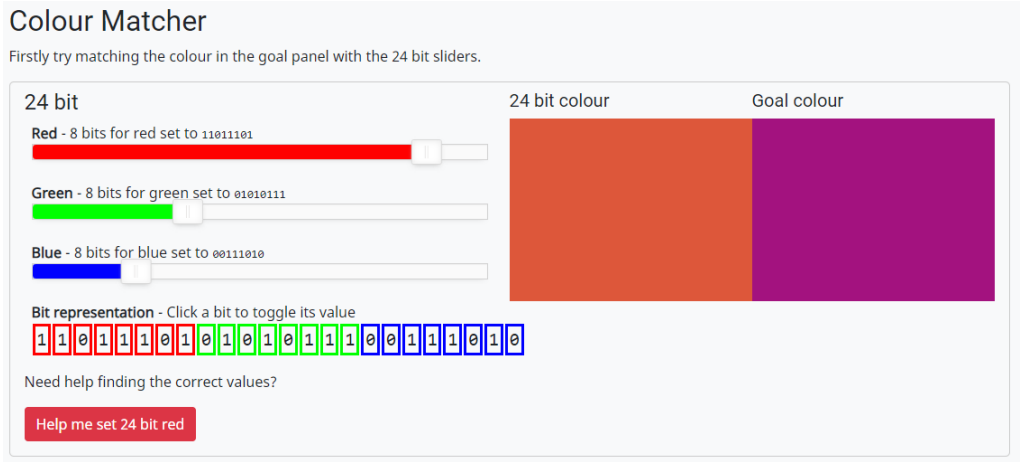


RGB color space

https://csfieldguide.org.nz/en/interactives/rgb-mixer/

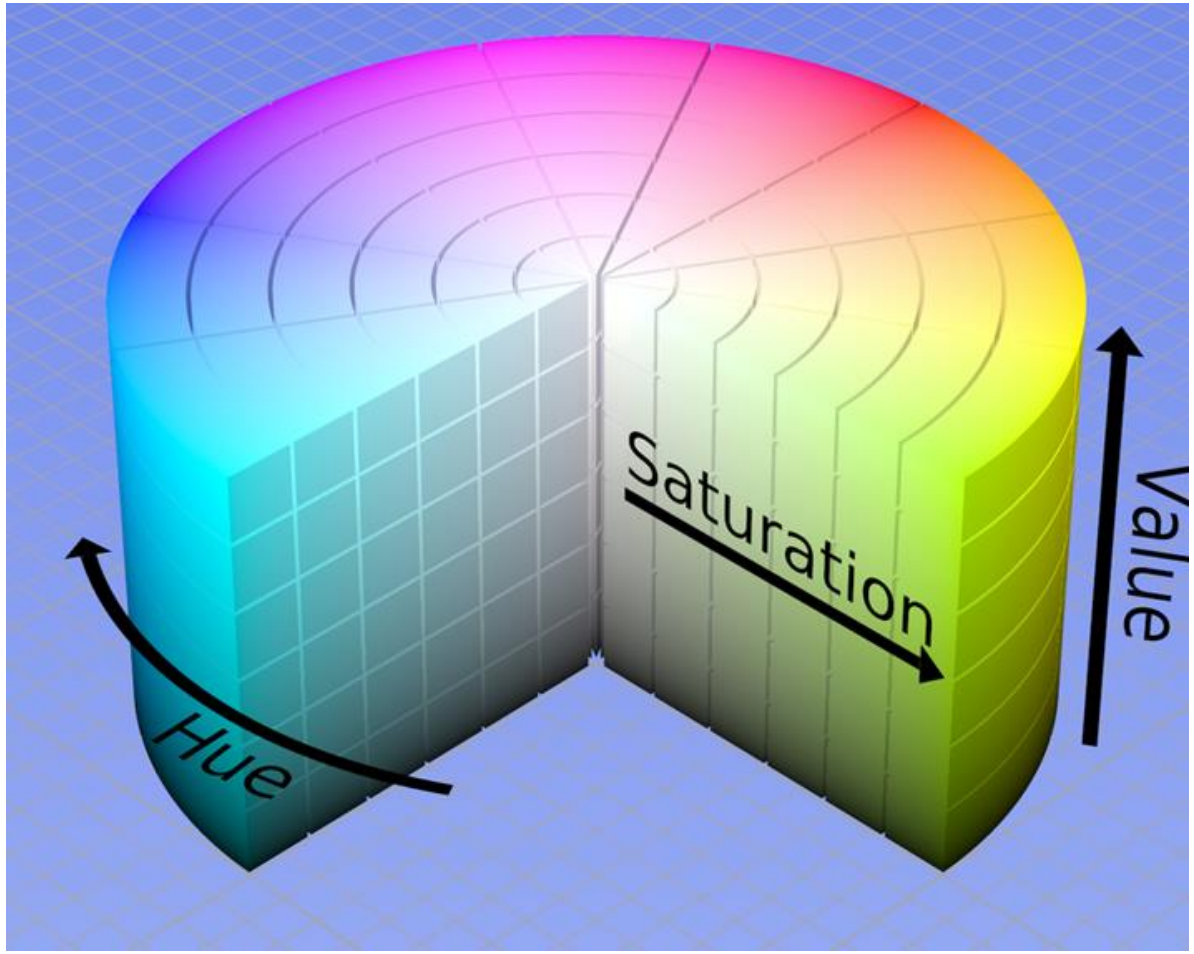


https://csfieldguide.org.nz/en/interactives/colour-matcher/



HSV/HSL color space

A cylindrical color space



HSV/HSL color space

Color specification is more natural with HSV/HSL than with RGB

http://hslpicker.com/

HSV/HSL color space

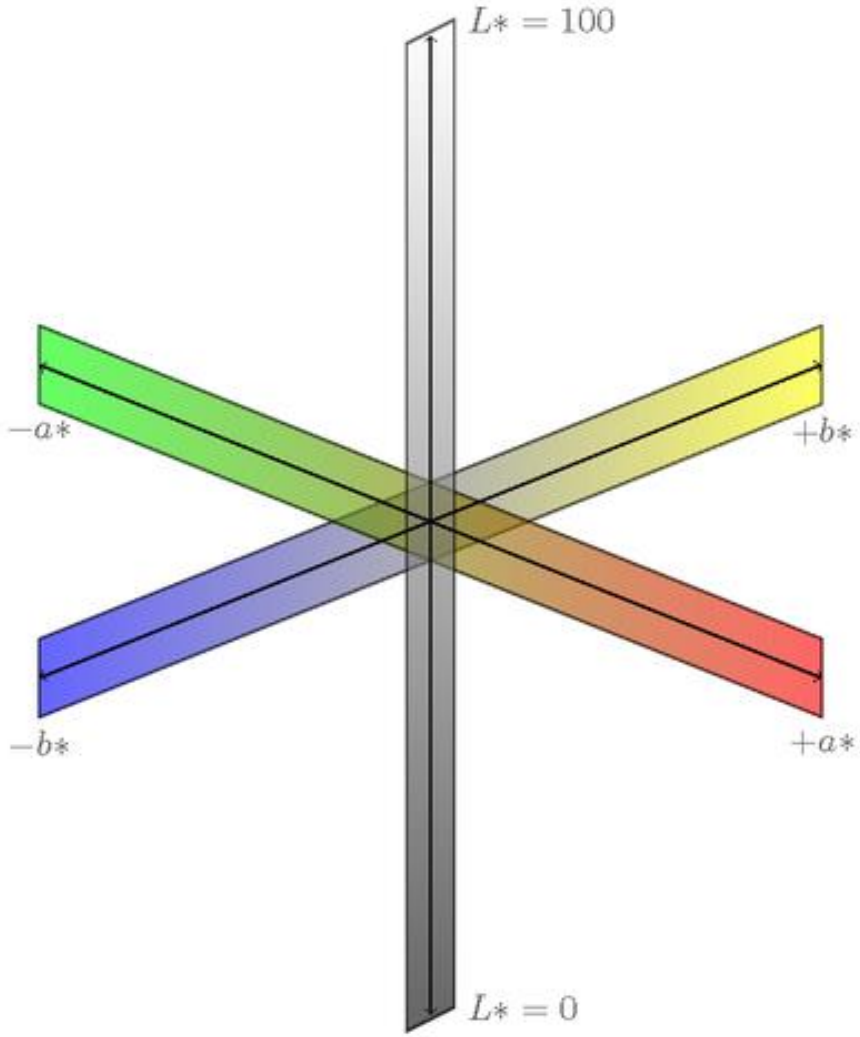
…but they are not perceptually uniform spaces (distances calculated in the color space do not correspond to perceptual distances)

[same V here]

[converted to grayscale]

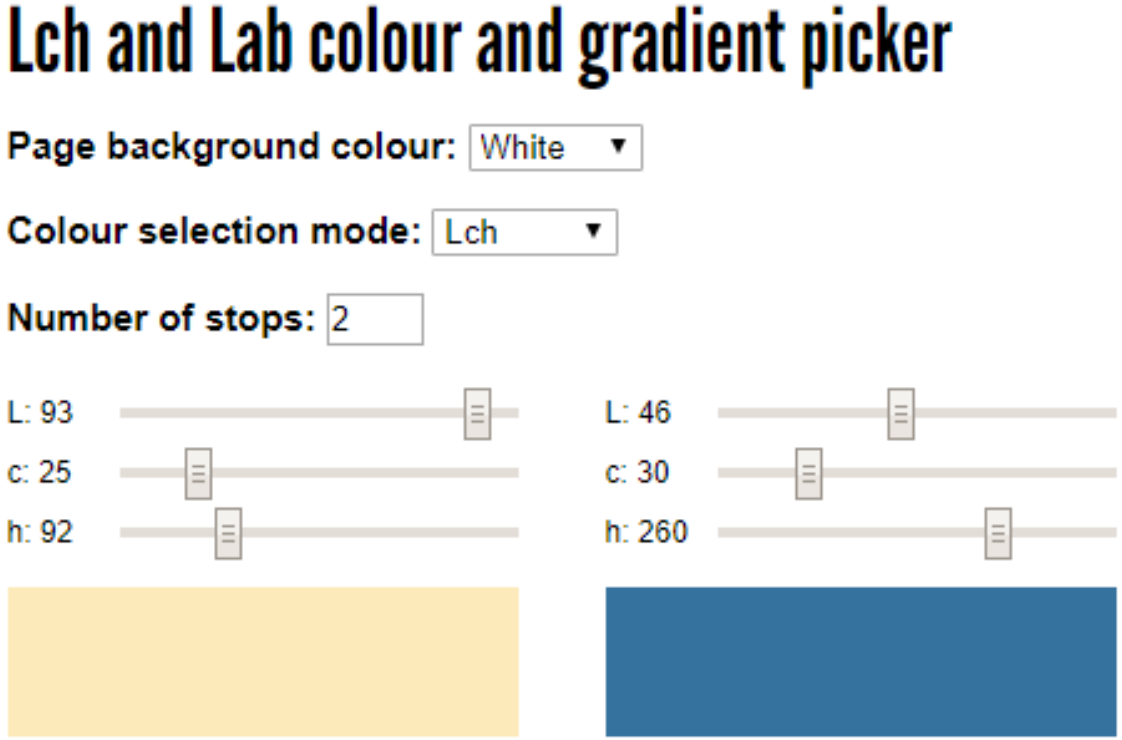
CIE Lab color space

Perceptually uniform color spaces (remember opponent process theory?)



CIE Lab / Lch color space

http://davidjohnstone.net/pages/lch-lab-colour-gradient-picker



Color differences

Having a color space in which equal perceptual distances are equal distances is useful to specify color tolerances, color codes, *pseudocoloring* (using sequences of colors to represent data values, possibly with perceptually-equal steps)

- The Euclidean distance is meaningful from a perceptual point of view for CIE Lab color space.
- *Delta E (1976)* is defined as:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

- ΔE < 1 : not perceptible, 1 < ΔE < 2 close observation needed to perceive the difference, 2 < ΔE < 10 different but similar color
- Not perceptually uniform as originally intended, hence superseded by 1994 and 2000 specifications

Color differences

Though, uniform color spaces only provide a rough first approximation of how color differences will be perceived

An important influencing factor is size (we are much more sensitive to differences between large patches)

Tip: Use saturated colors when coding small symbols o thin lines, and less saturated colors for large areas

[Redrawn from C. Ware, Information for Visualization

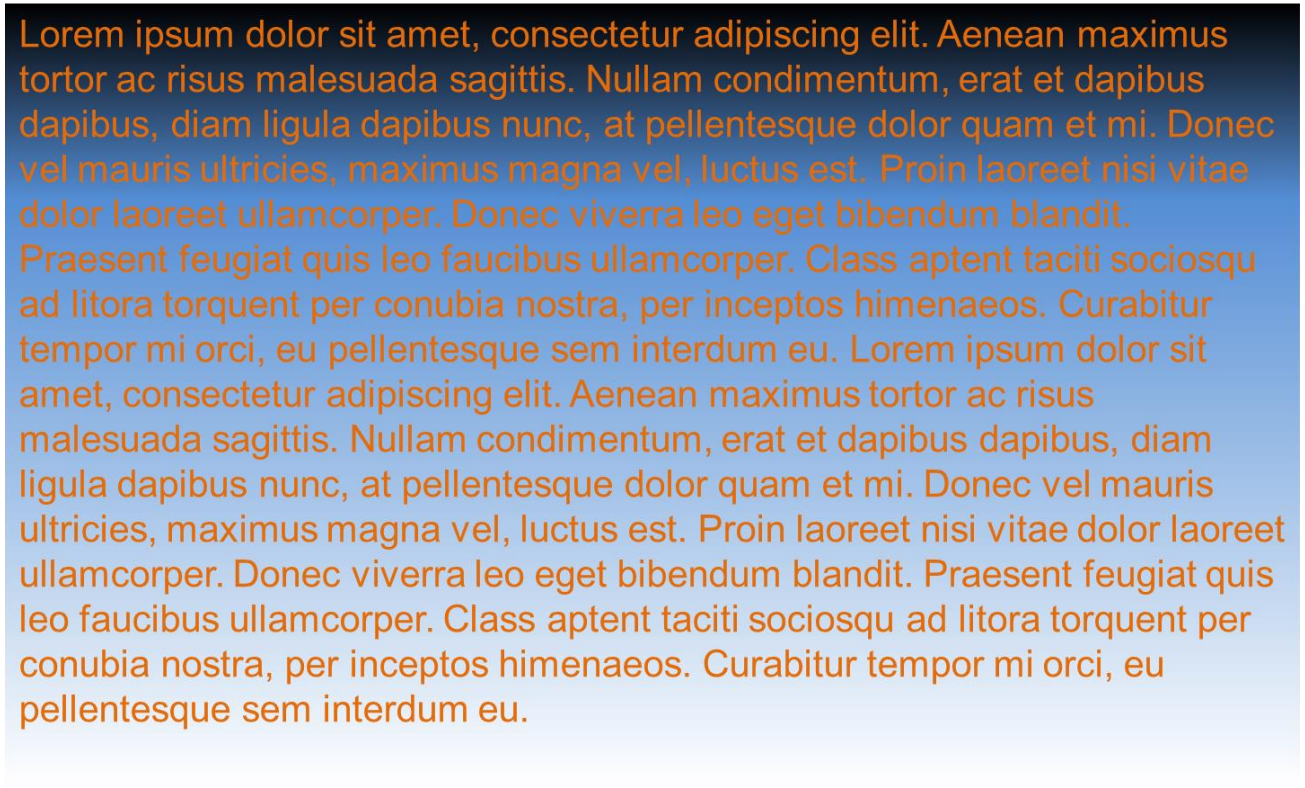
Color and visualization

Luminance and visualization

The red-green and yellow-blue chromatic channels are each capable of carrying only about 1/3 of the amoint of detail carried by the black and white channel (Mullen, 1985)

Purely chromatic differences are not enough to display fine details

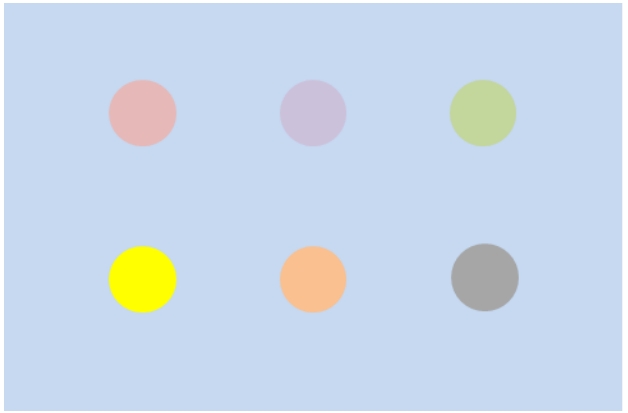
Ensure adequate luminance contrast with the background (also if colors with different chromaticity are used)

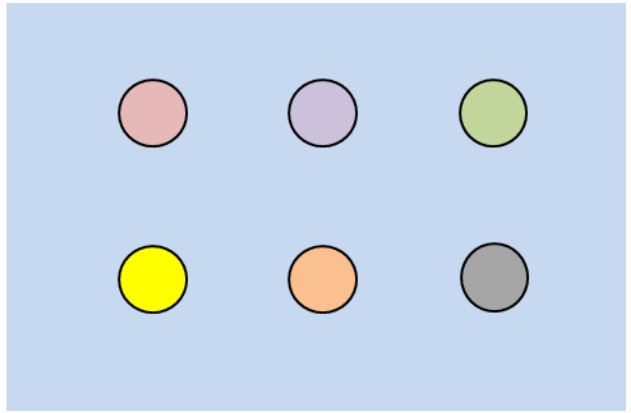


[Brown text on a blue gradient. From C. Ware, Information for Visualization]

Luminance and visualization

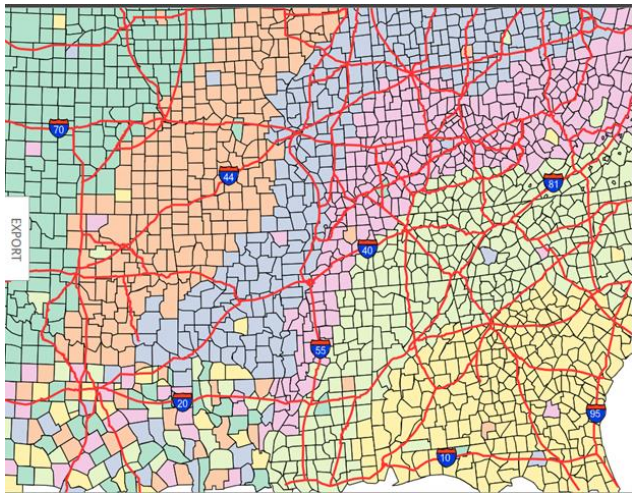
A contrast boundary can improve the readability of colored symbols

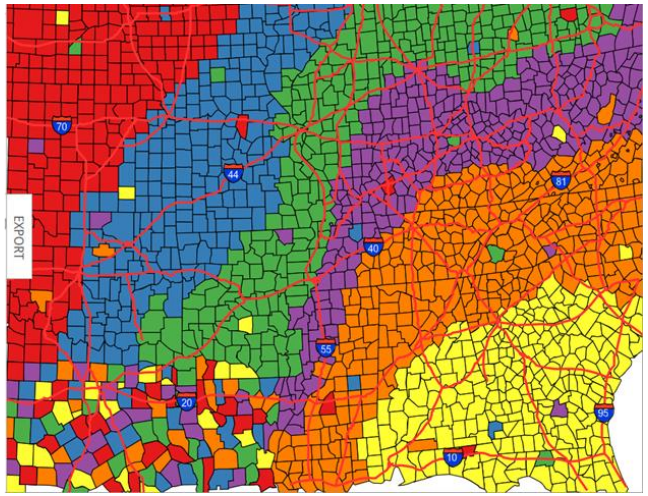




Saturation and visualization

Use saturated colors for coding small symbols/fine details, and less saturated colors for coding large areas



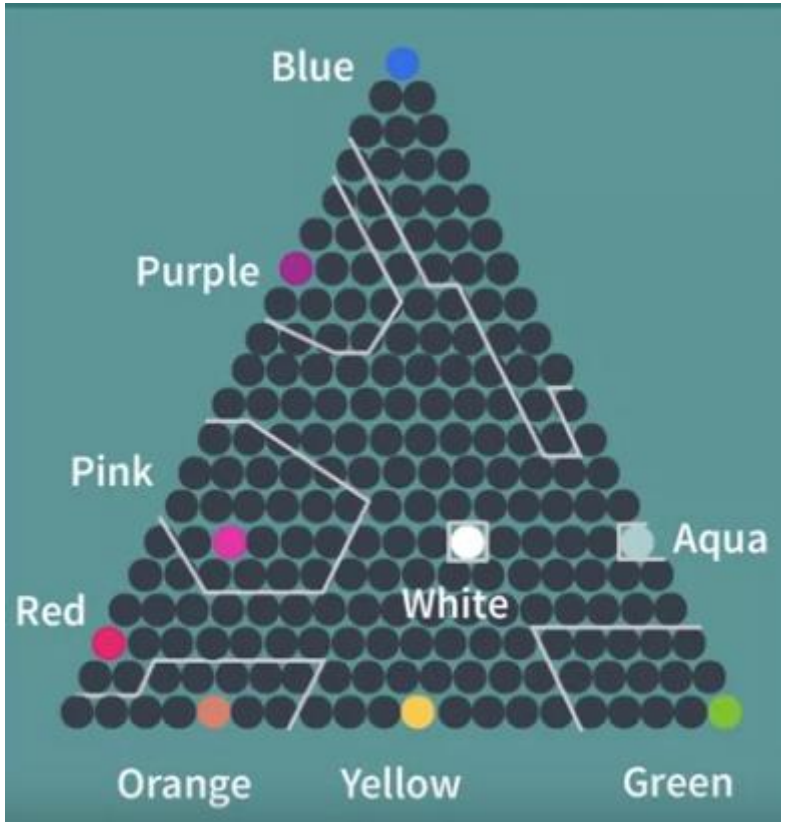


Color for labeling

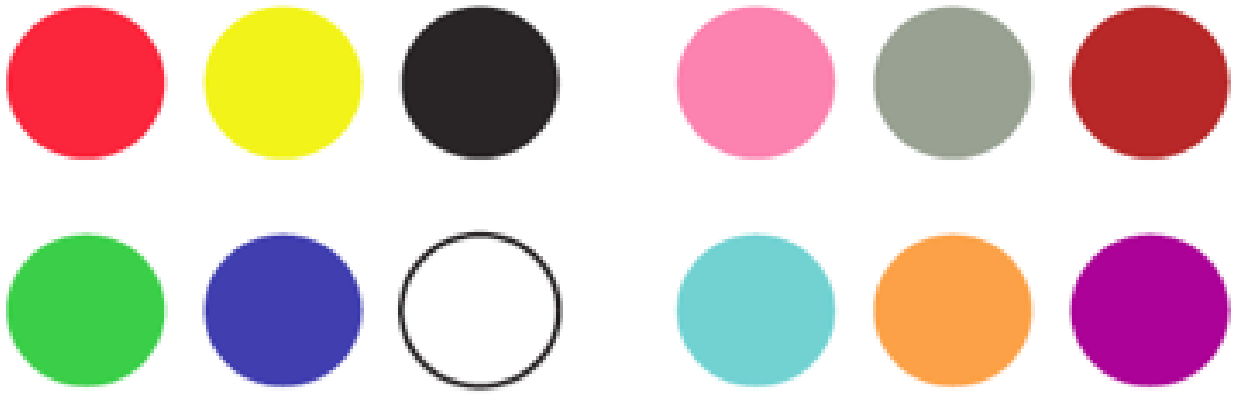
Post and Greene (1986) carried out an experiment on the naming of colors (210 different colors were shown on a black background in a darkened room)

Only eight colors plus white are consistently named

Though not generally applicable, this suggests that only few colors can be used as category labels



Color for labeling



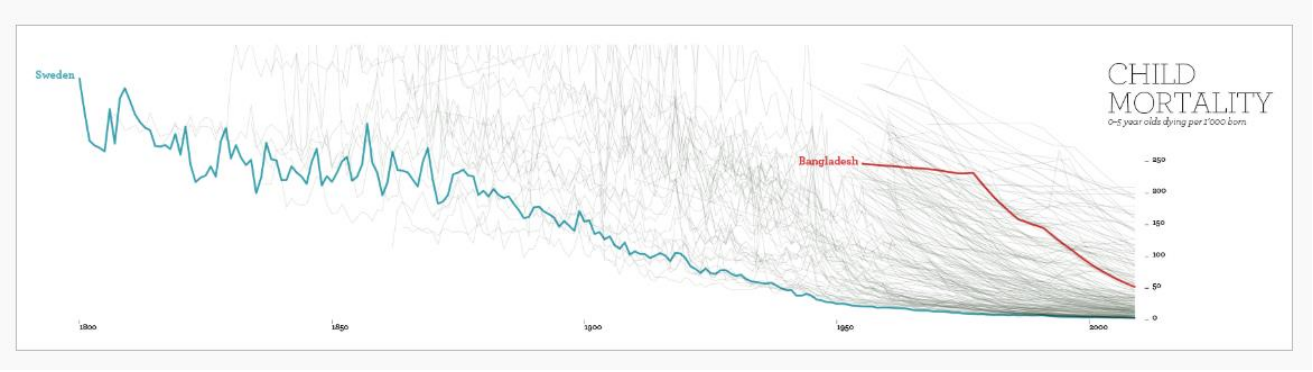
12 colors recommended by Colin Ware: red, green, yellow, blue, black, white, pink, cyan, gray, orange, brown, purple

Widely agreed-upon category names, and reasonably far apart in color space

Semantics

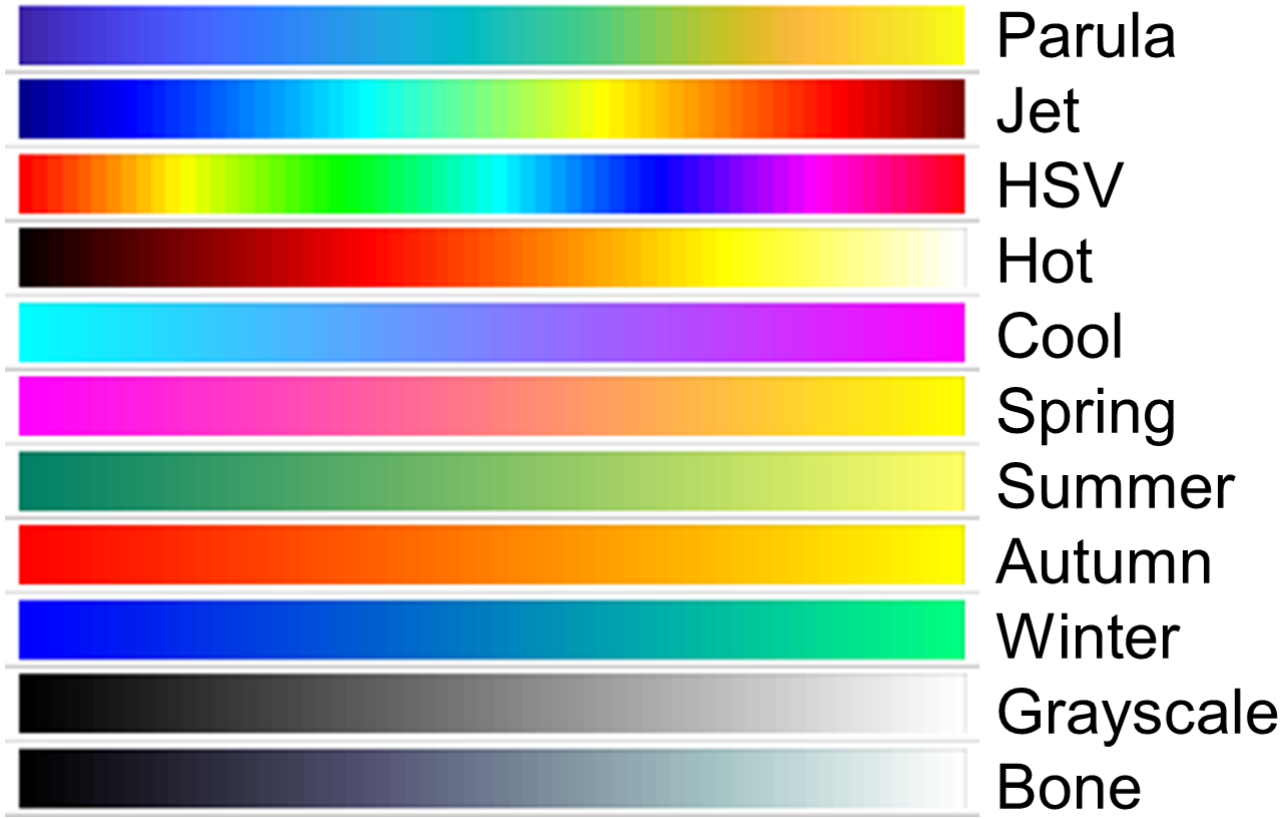
Pay attention to color convention and semantic associations (red for hot/bad/danger, blue for cold, green for life/go, etc.) as conventions are not universal

The semantic association with gray is that of belonging to an unspecified category (useful for highlighting)



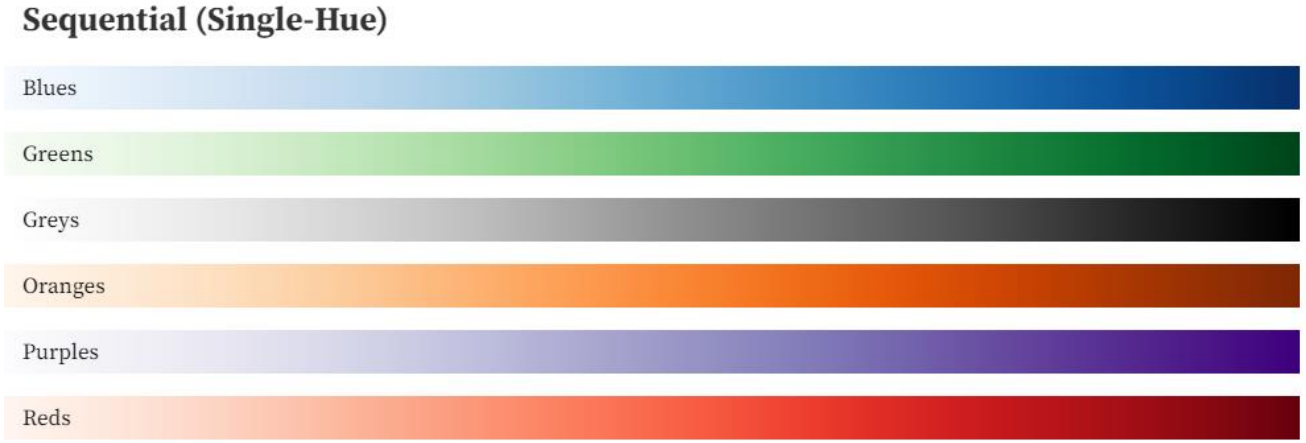
[http://truth-and-beauty.net/projects/remixing-rosling]

Color scales



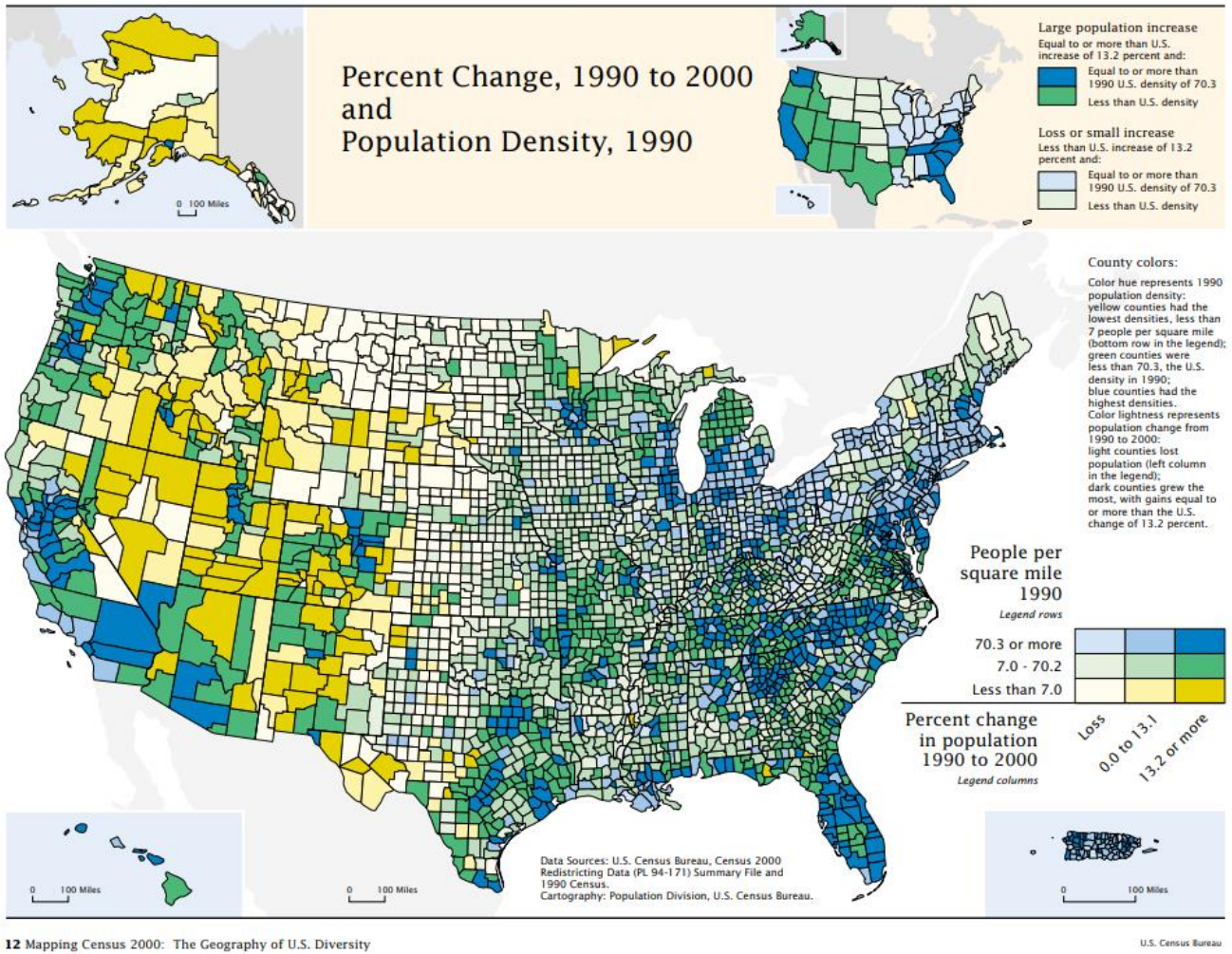
[Matlab pre-defined color ramps]

Single-Hue sequential scales



[https://observablehq.com/@d3/color-schemes]

Multi-Hue sequential scales



[by Cynthia Brewer]

https://blog.xkcd.com/2010/05/03/color-survey-results/

The end