

# *SCIENTIFIC AND LARGE DATA VISUALIZATION*

*December 12, 2020*

*Applied Perception – Part II (Color)*

*Daniela Giorgi*

*Visual Computing Lab, CNR-ISTI*

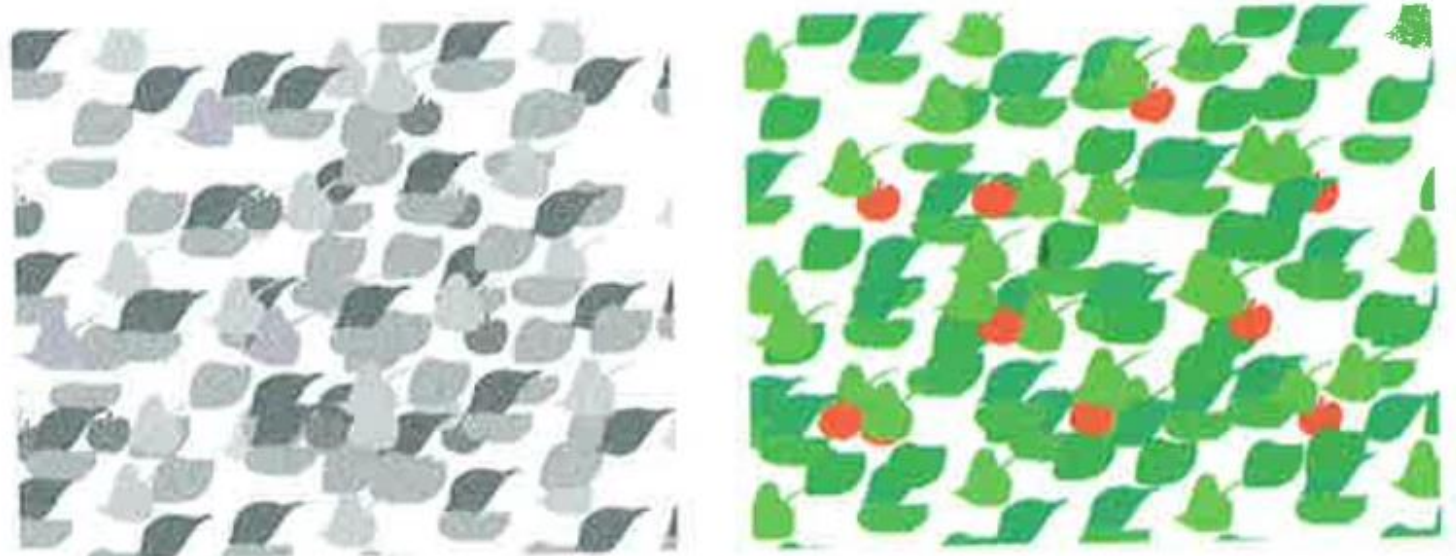
# *Why color*

# *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)

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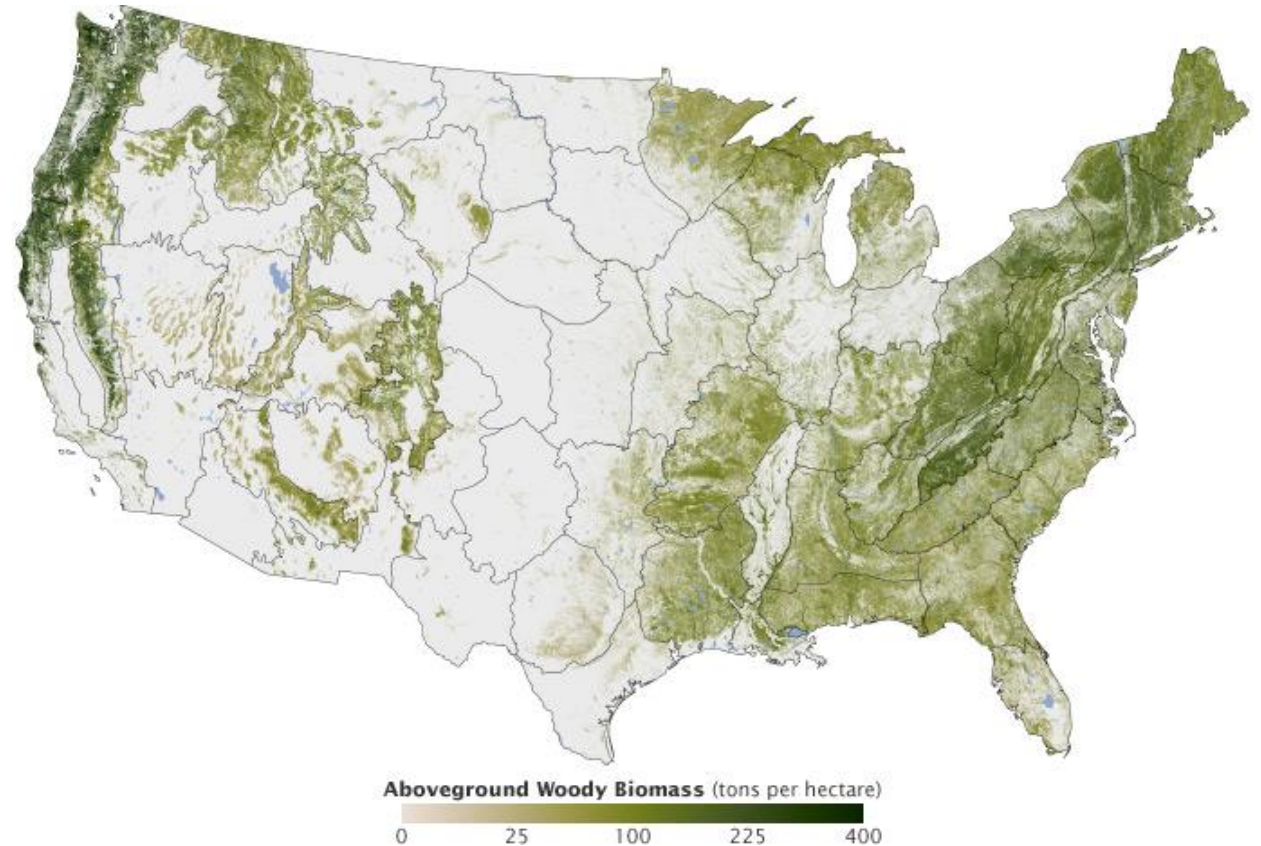


*[Breaking camouflage and finding the cherries, from Colin Ware's book Information Visualization – Perception for design]*

# *The function of color vision*

...yet color is extremely useful in data visualization:

- showing patterns
  - labeling
- highlighting

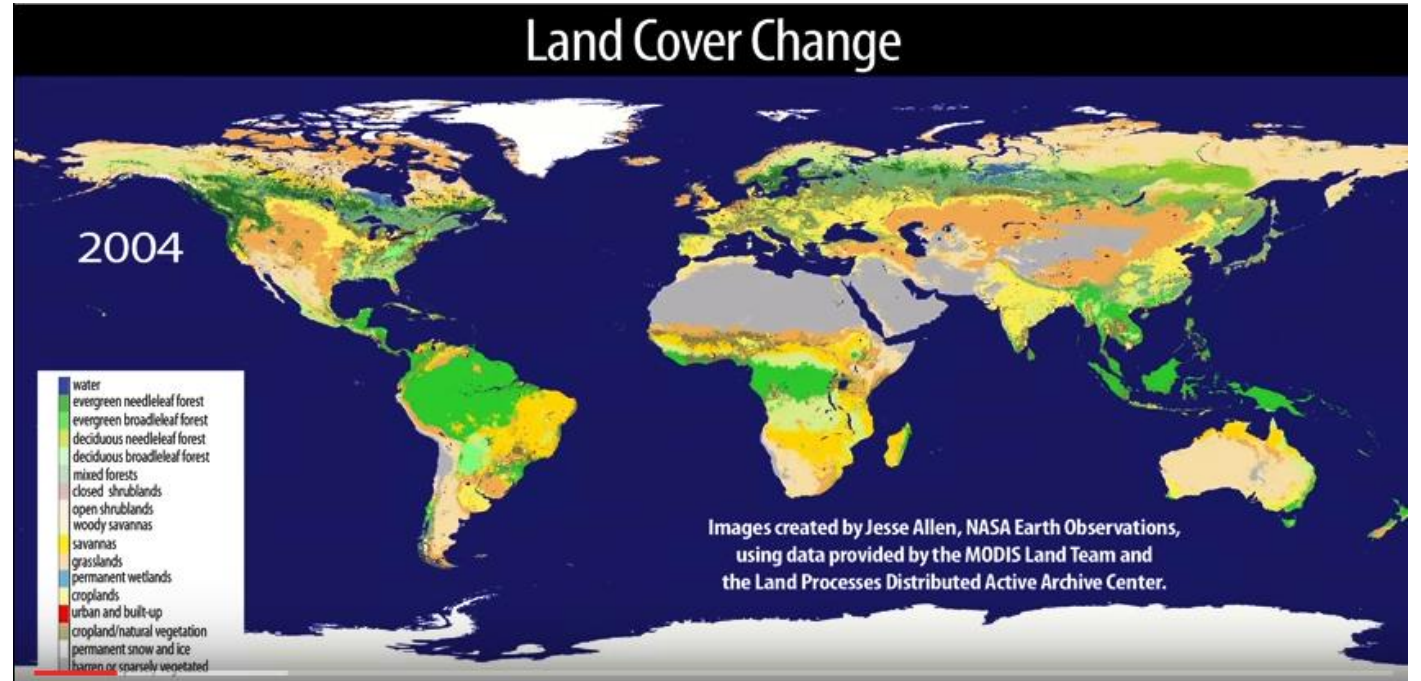


[<https://earthobservatory.nasa.gov/features/ForestCarbon/page4.php>]

# *The function of color vision*

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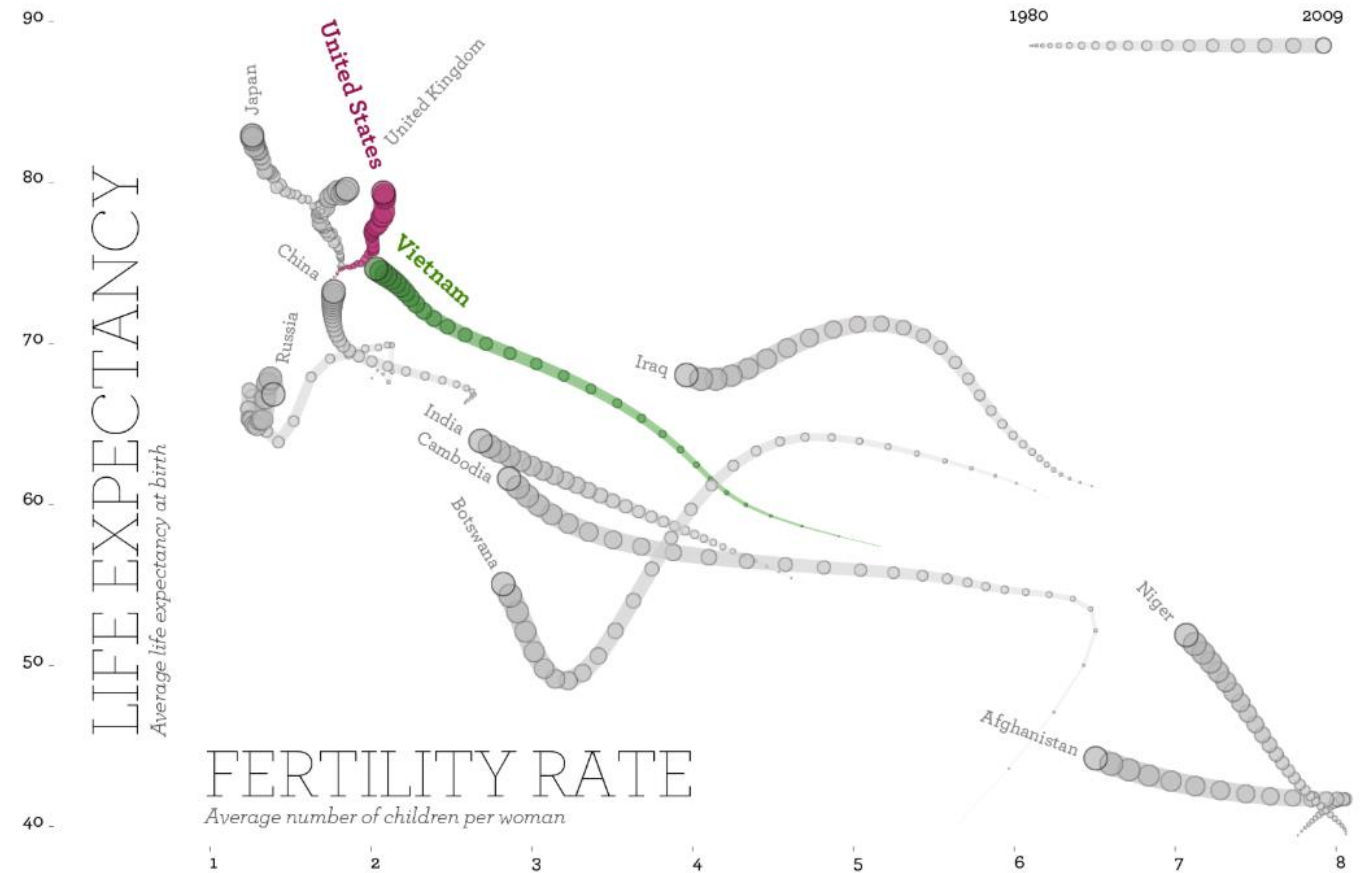
- showing patterns
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# The function of color vision

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

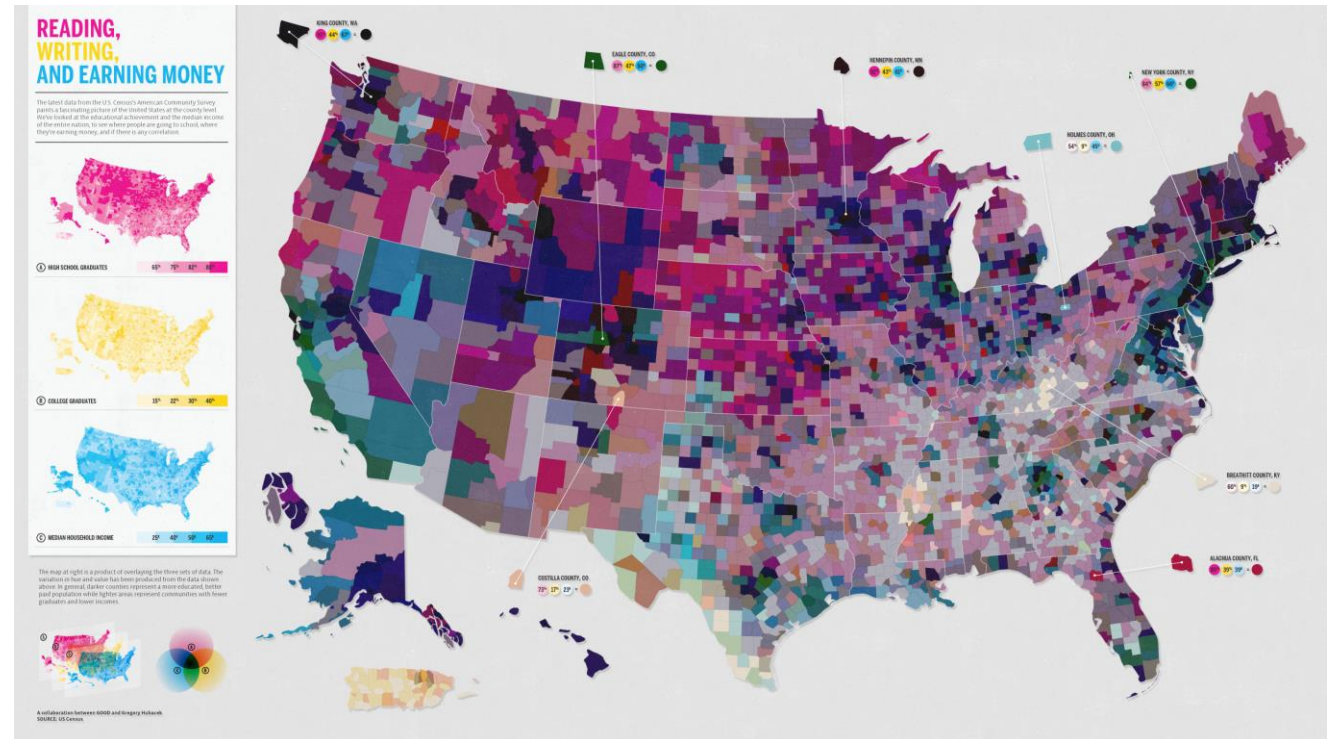
# The function of color vision

...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>]

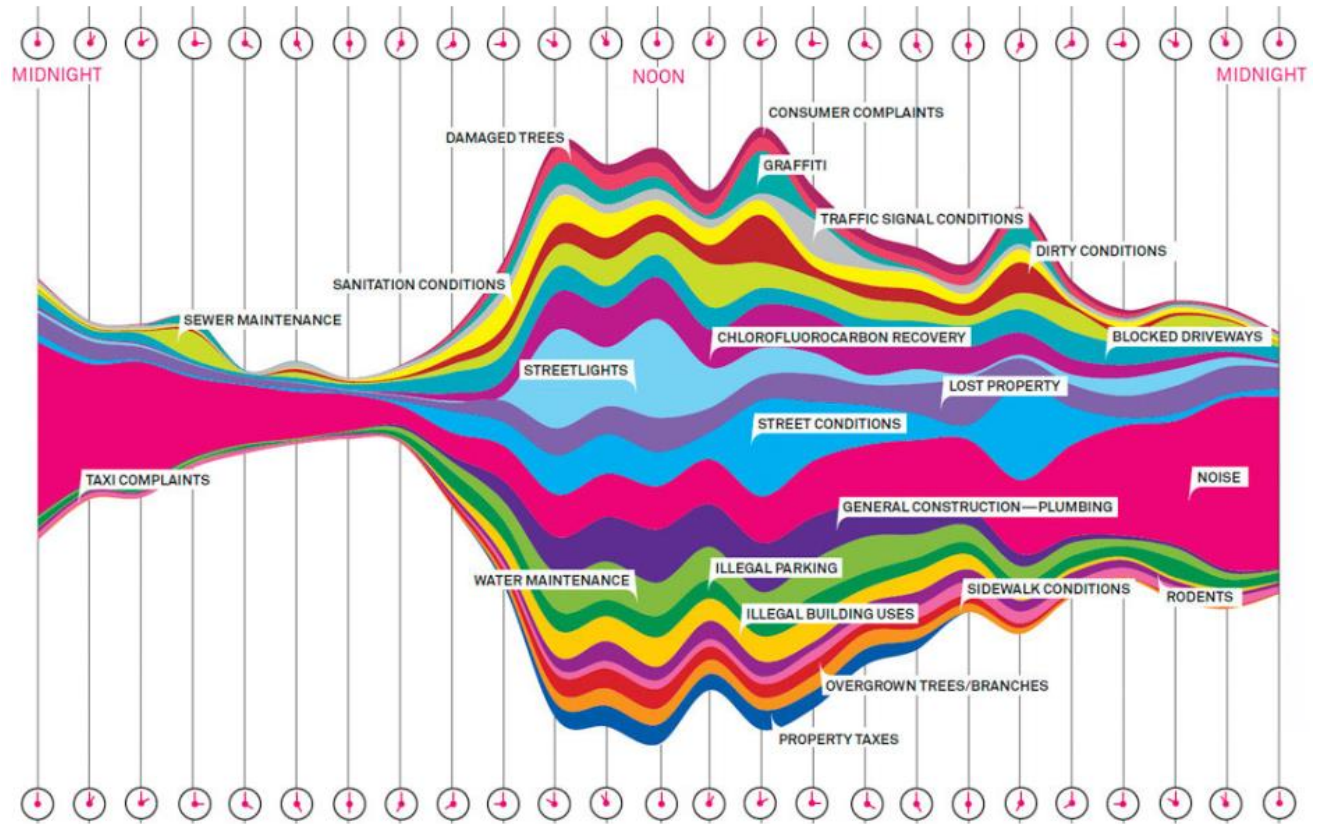
# The function of color vision

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[[https://www.wired.com/2010/11/ff\\_311\\_new\\_york/](https://www.wired.com/2010/11/ff_311_new_york/)]



# *Plan for today*

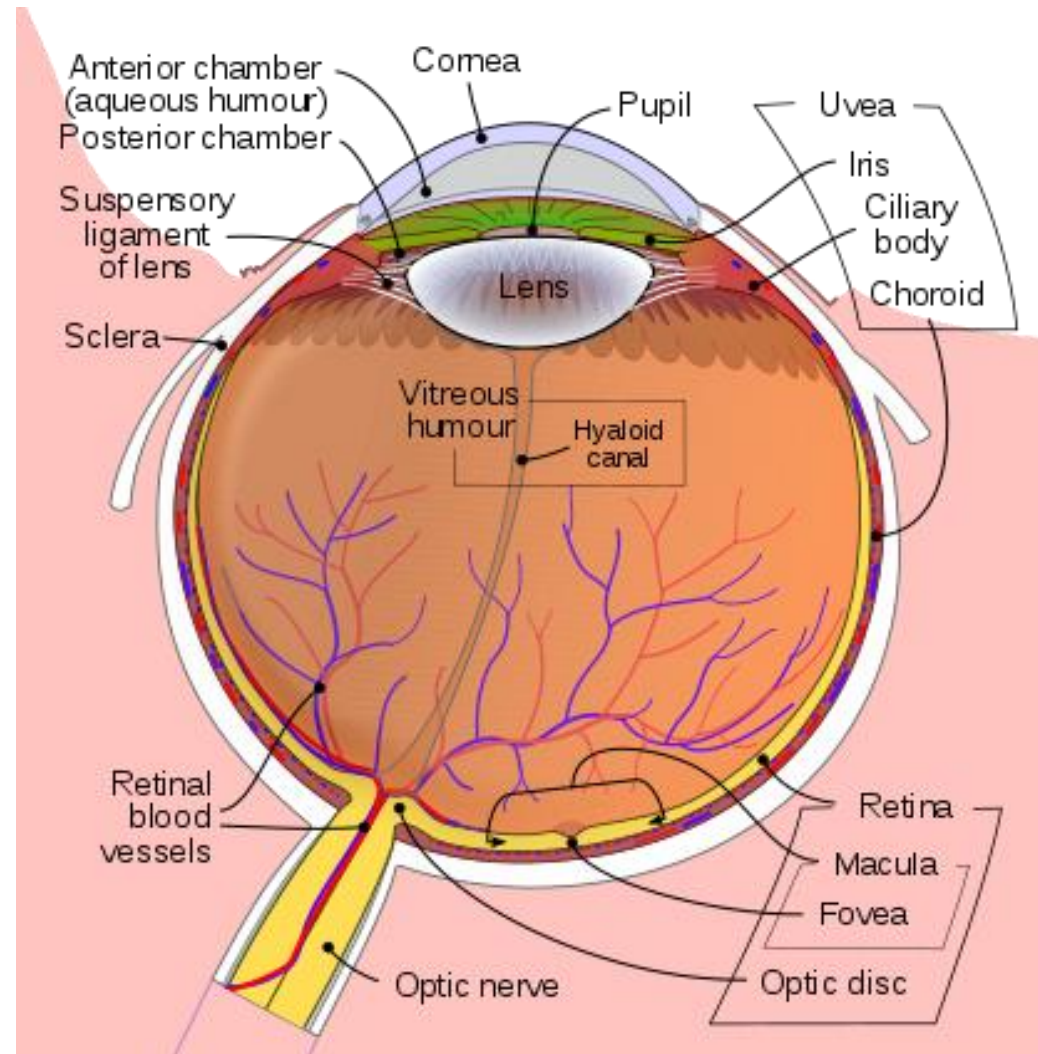
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- Basics on color perception
  - trichromacy theory
  - opponent process theory
- Color spaces
  - RGB, HSV/SL, CIE Lab/Luv, CIE LCh/HCL
  - perceptual uniformness, usability
- Color in visualization
  - lightness and saturation
  - categories
  -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

*Where we left off*

# *The Human Visual System*

The eye and the brain

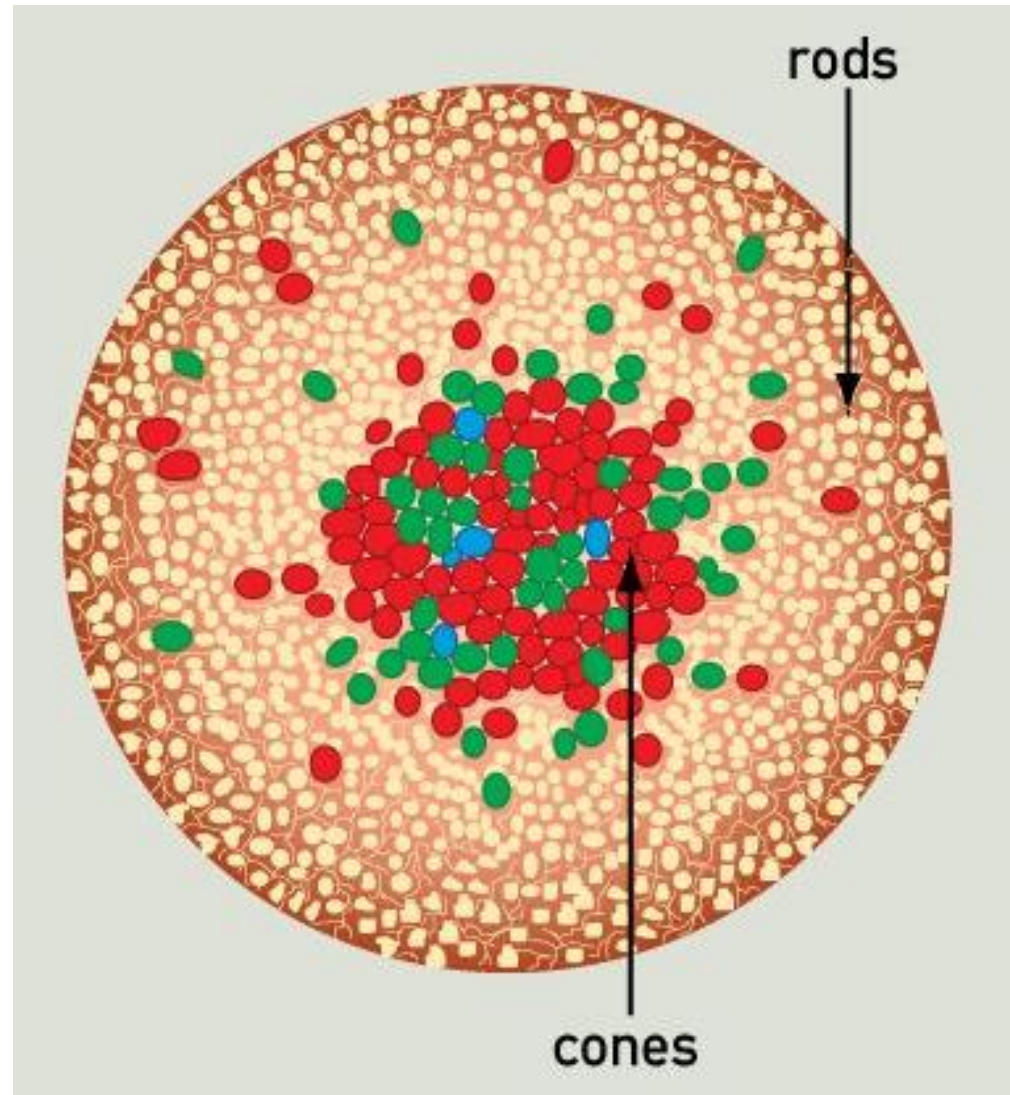




# *The Human Visual System*

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



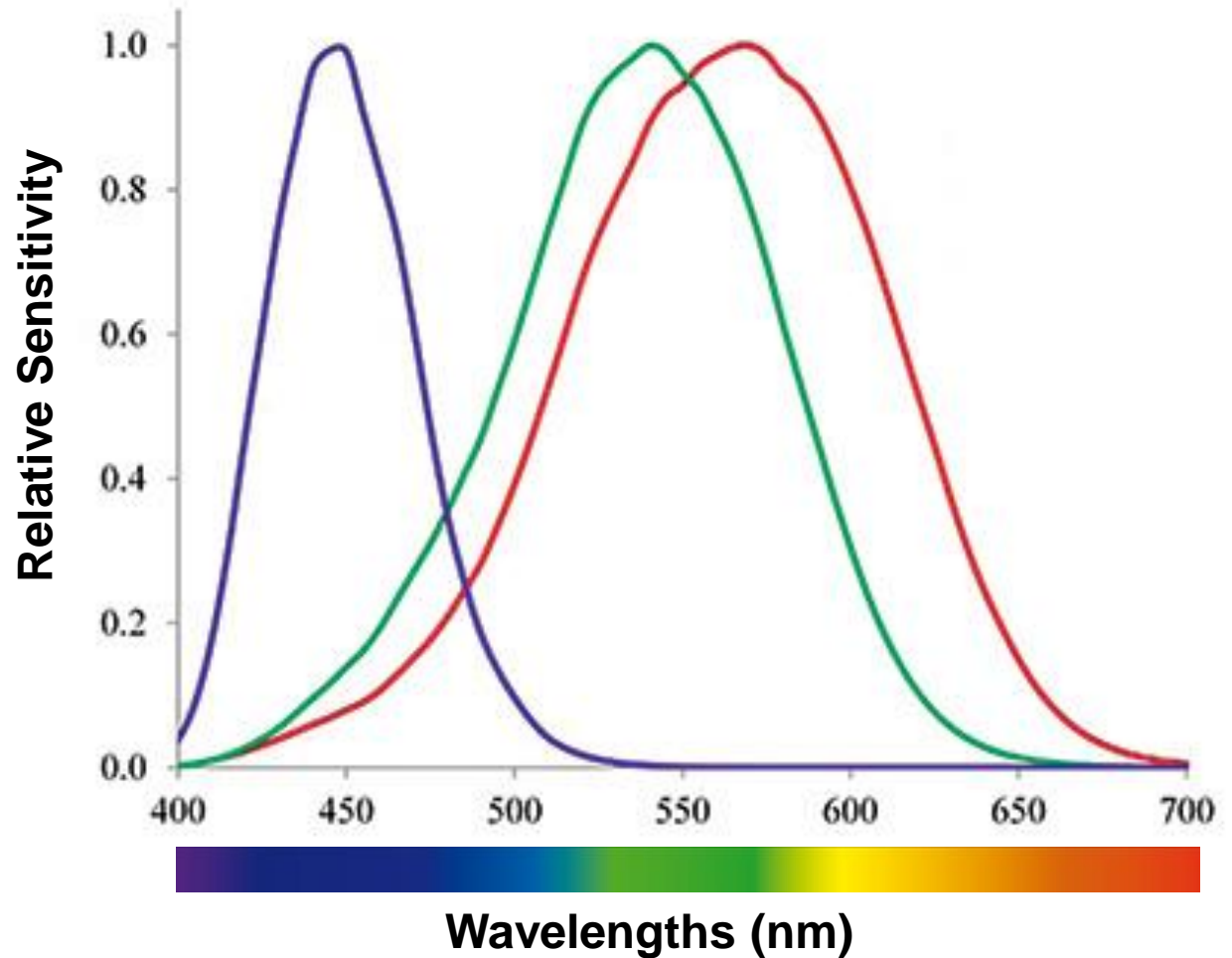
# *Trichromacy and Opponent process theories*

# *Trichromacy theory*

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

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

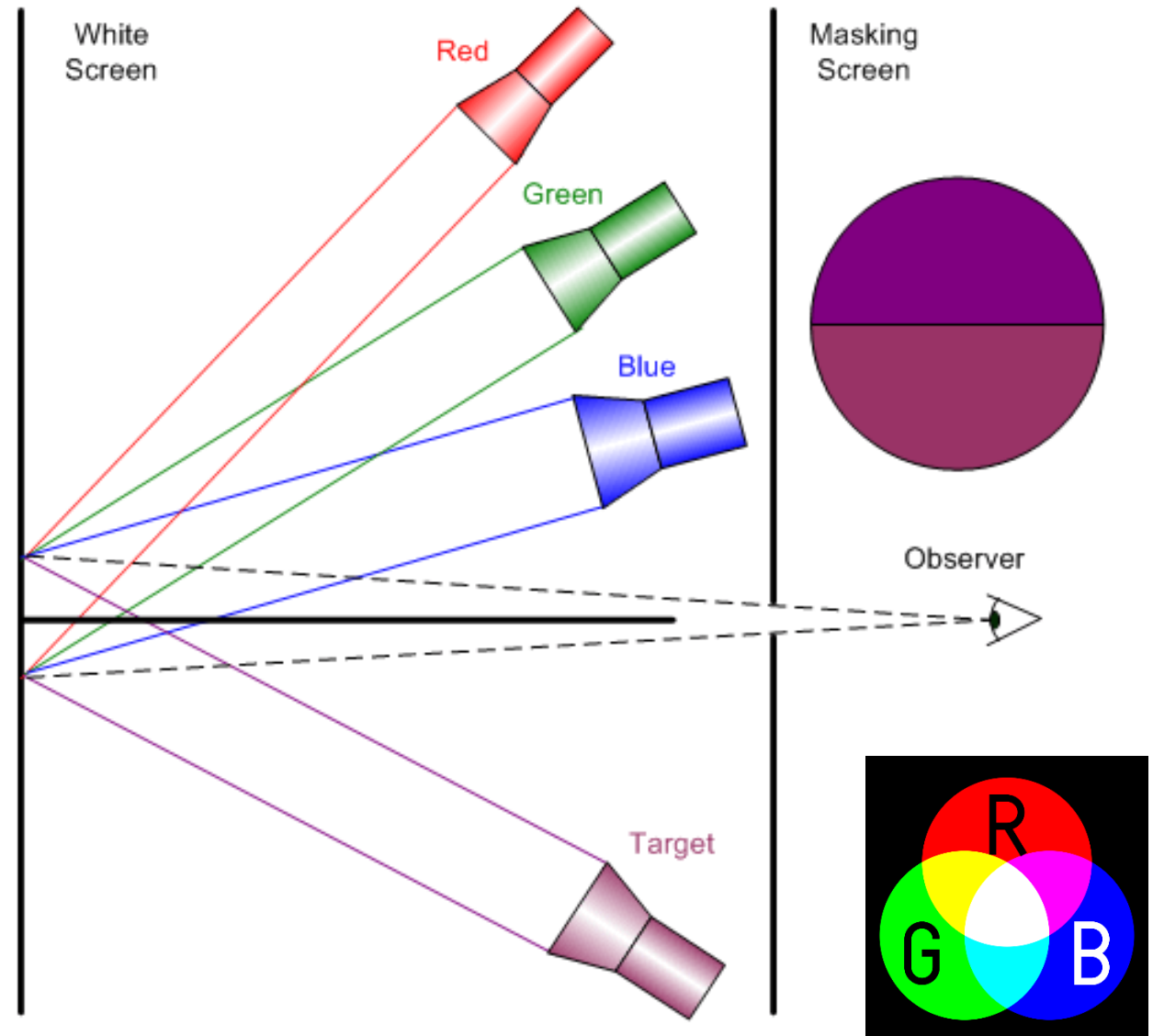
The theory says that we perceive color as a three-channel system. All color spaces, even if designed to different purposes, are three-dimensional



# 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*

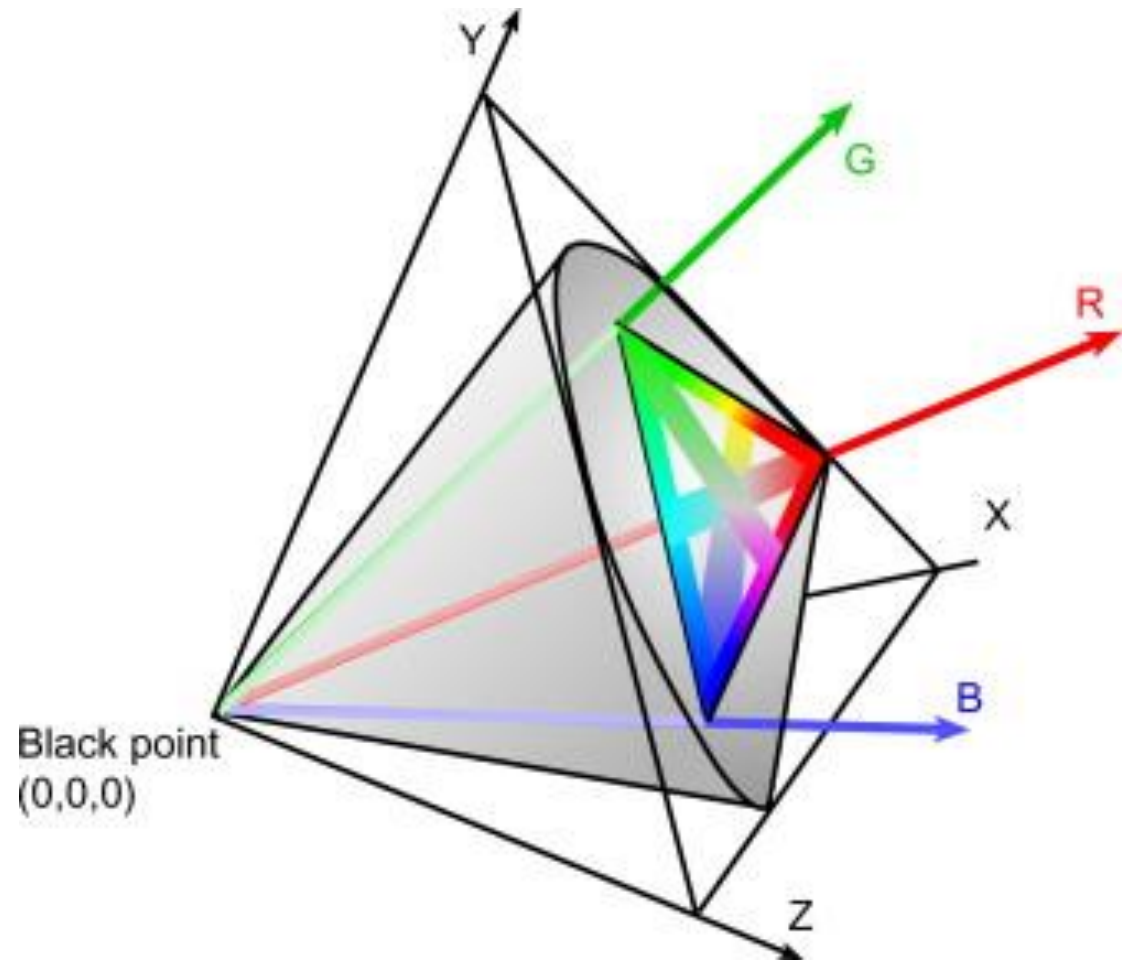
Given a standard set of primaries, one can use a transformation to create the same color on different output devices





# *Colour measurement and specification*

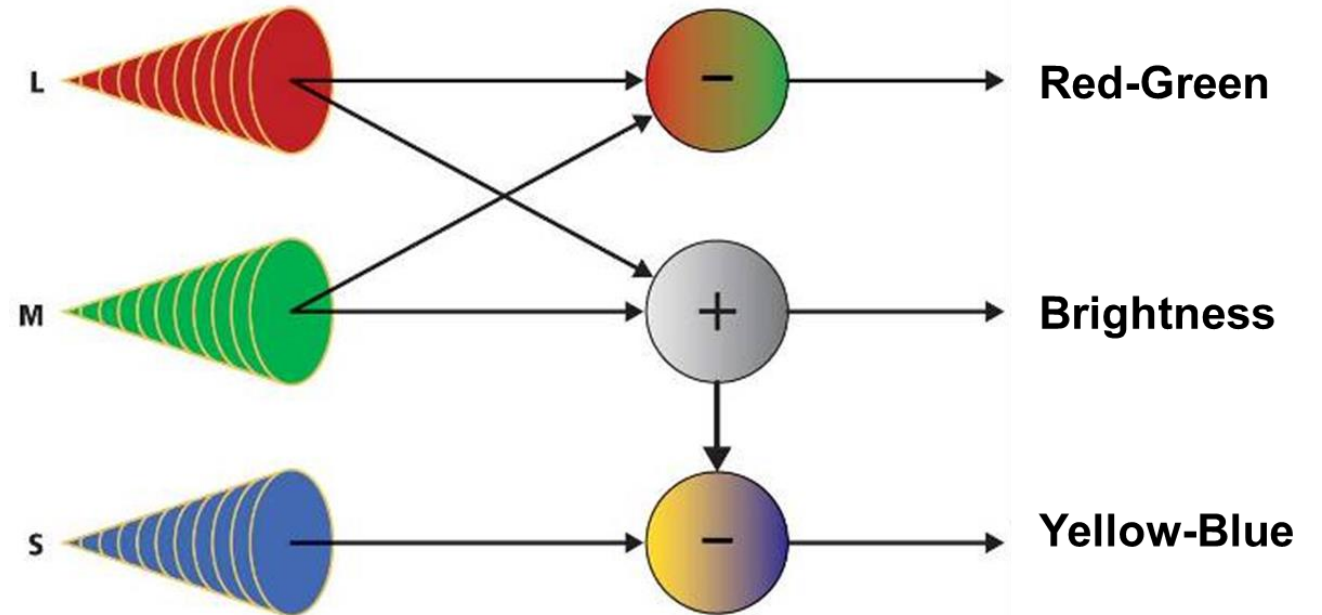
CIE (*Commission Internationale de l'Eclairage*) performed measurements (prior to 1931) to collect color matching functions from observers, and transformed them to have a set of abstract primaries called the XYZ tristimulus values



[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 19<sup>th</sup> 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

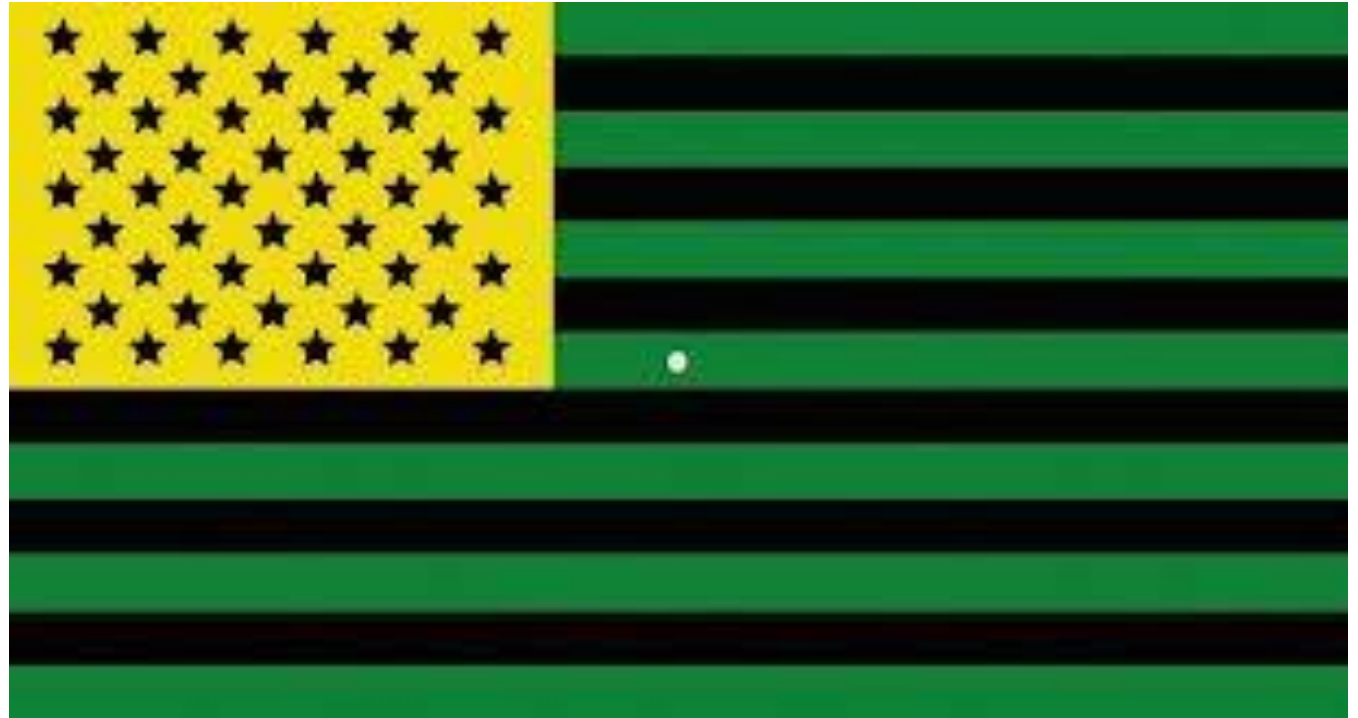


# *Opponent process theory*

## Scientific evidence

- Naming: certain color names do not occur in combination
  - ever heard of *reddish green*?
- 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)

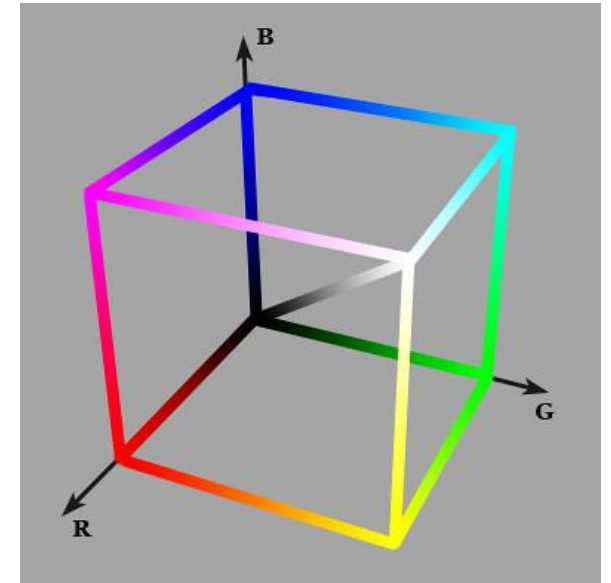
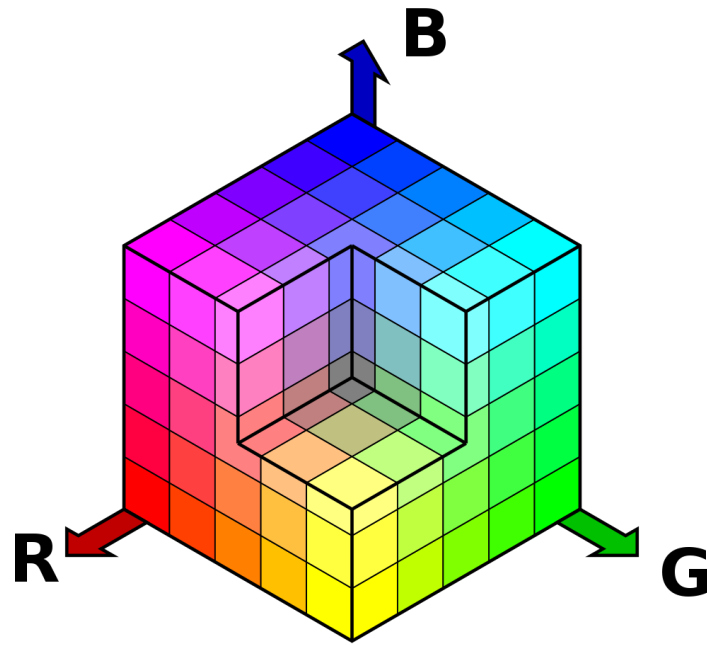
# *Opponent process theory*





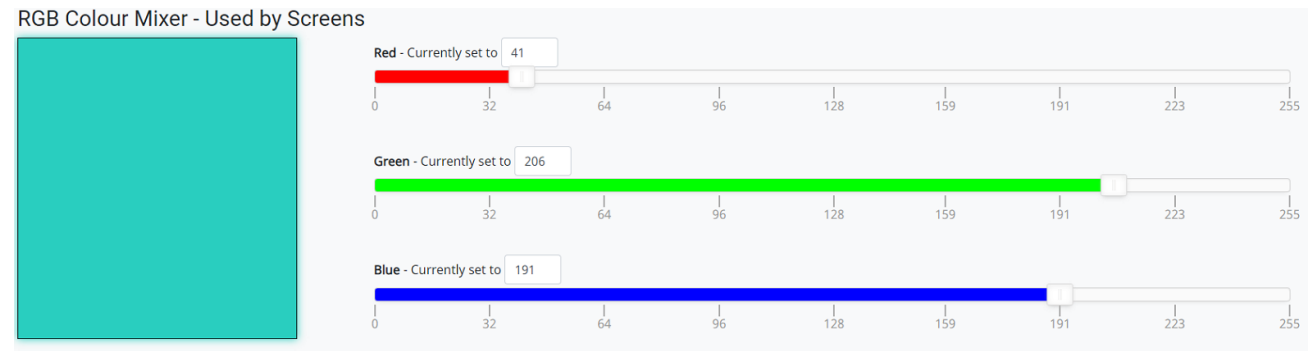
# *Color spaces*

# *RGB color space*



# RGB color space

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



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

Colour Matcher

Firstly try matching the colour in the goal panel with the 24 bit sliders.

24 bit

Red - 8 bits for red set to 11011101

Green - 8 bits for green set to 01010111

Blue - 8 bits for blue set to 00111010

24 bit colour

Goal colour

Bit representation - Click a bit to toggle its value

1 1 0 1 1 1 0 1 0 1 0 1 0 1 1 1 0 0 1 1 1 0 1 0

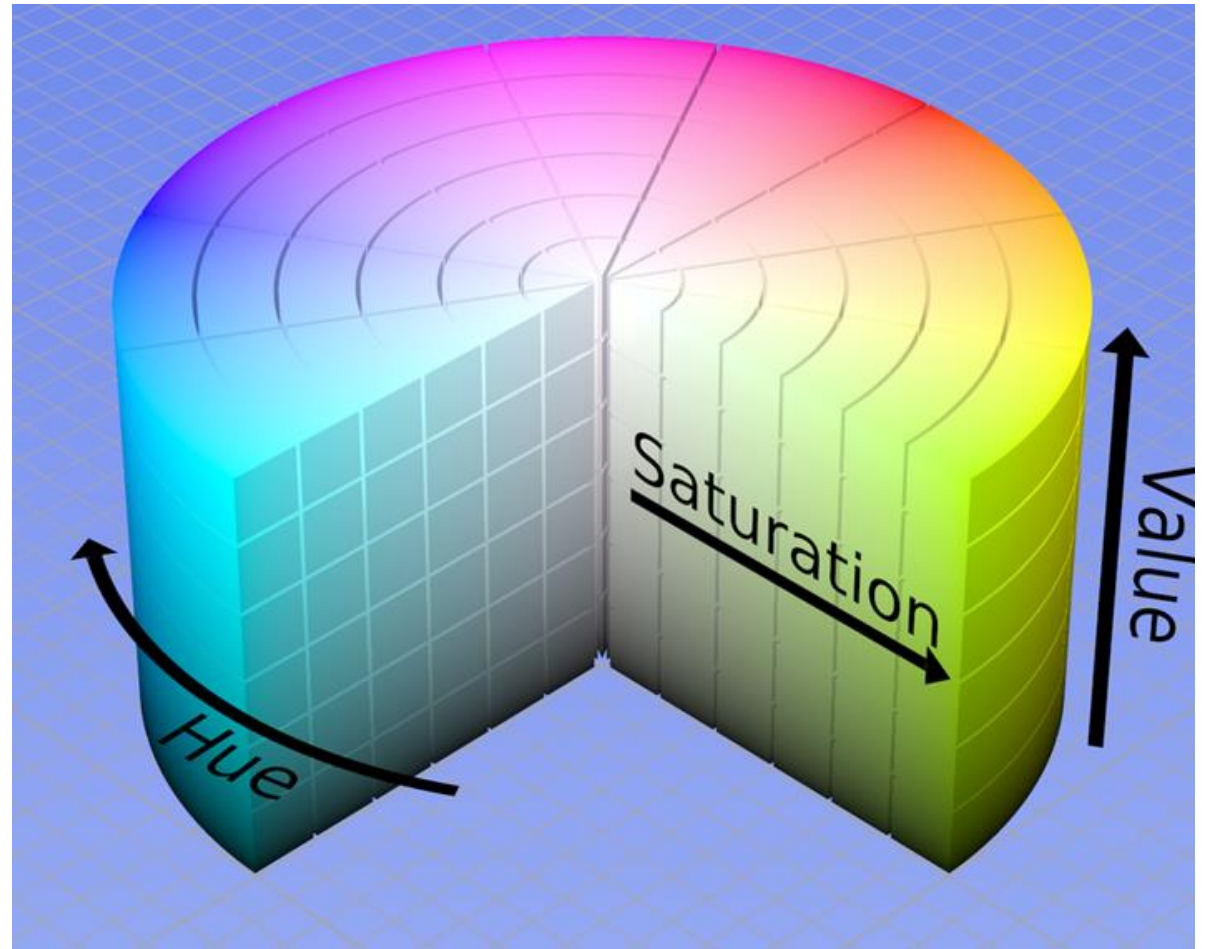
Need help finding the correct values?

Help me set 24 bit red



# *HSV/HSL color space*

A cylindrical color space



# *HSV/HSL color space*

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

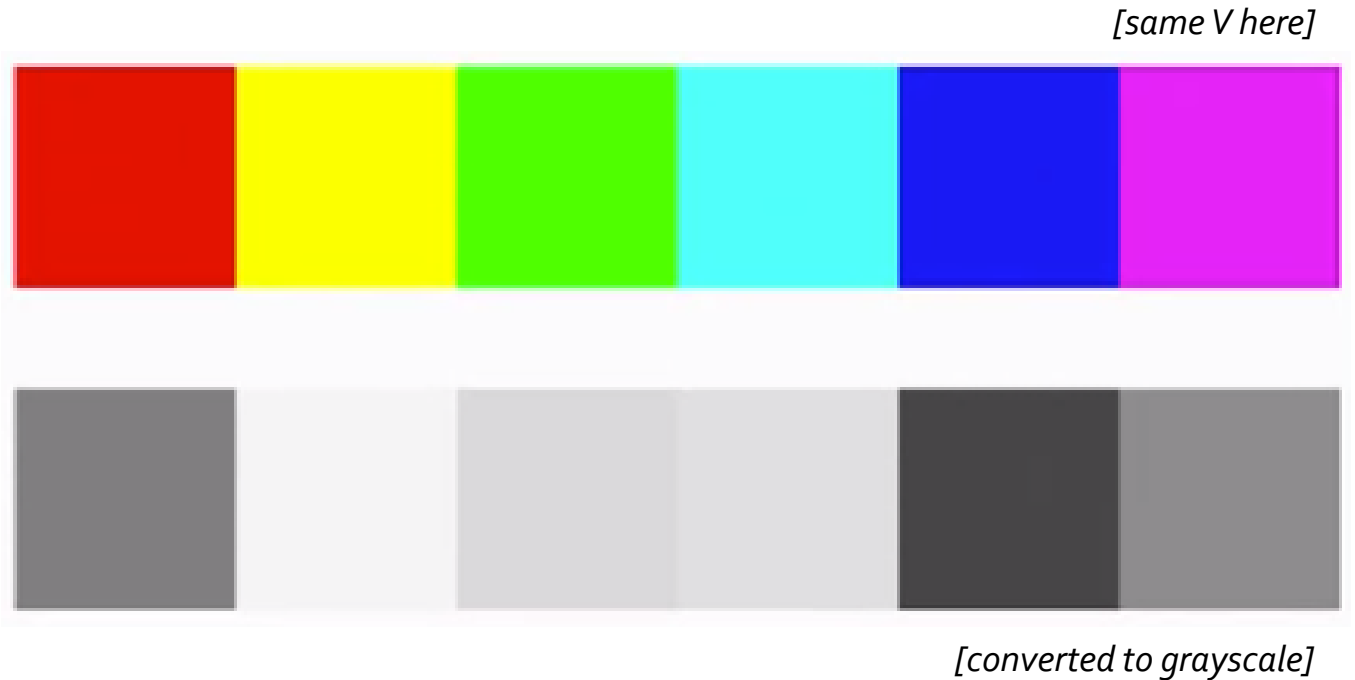
<http://hslpicker.com/>

A MOST EXCELLENT  
**HSL COLOR PICKER**  
CREATED FOR YOUR ENJOYMENT, BY BRANDON MATHIS

The interface features a central color selection area with a color wheel and a vertical gradient bar. To the right, there are four sliders for H, S, L, and Alpha, with numerical values displayed next to them: 69, 100, 50, and 1. Below the sliders, three boxes display the color codes: #d9ff00, rgba(217, 255, 0, 1), and hsla(69, 100%, 50%, 1). At the bottom, there is a footer with the text: HSL Color Picker adores modern browsers. ©2012 Brandon Mathis | What's HSL? | Source

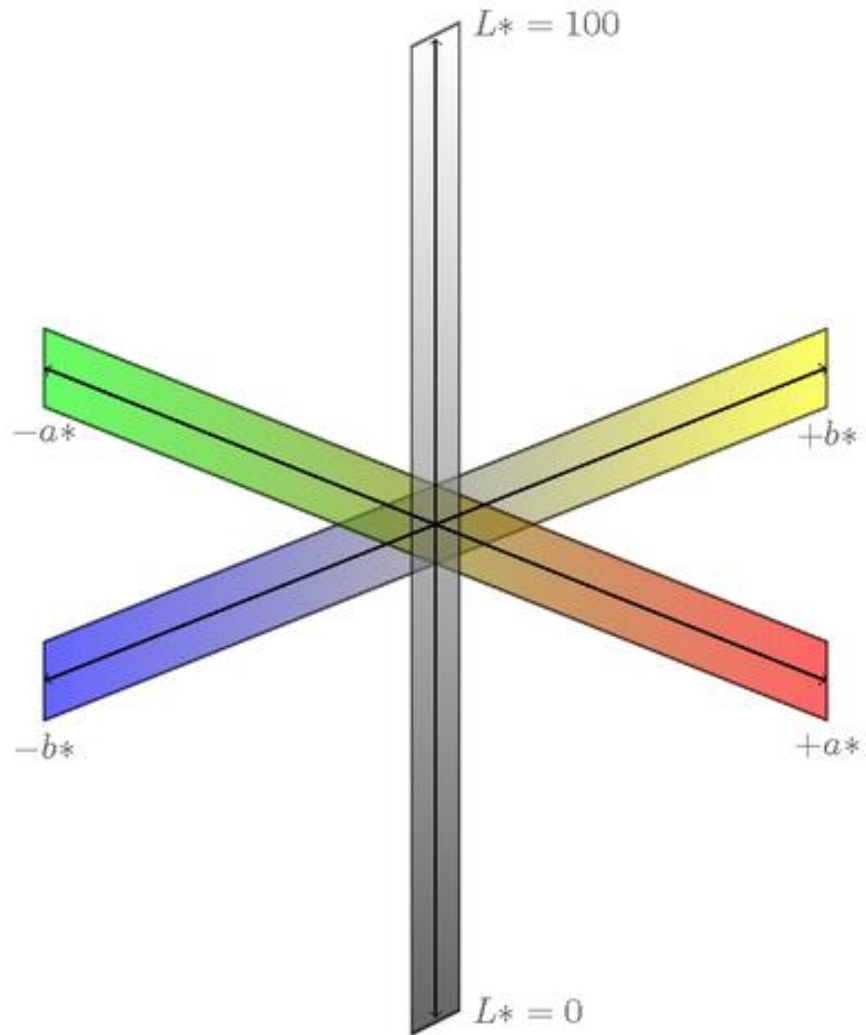
# *HSV/HSL color space*

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



# *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>

## Lch and Lab colour and gradient picker

Page background colour:

Colour selection mode:

Number of stops:

L: 93  
c: 25  
h: 92



L: 46  
c: 30  
h: 260



# 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:

$$\Delta E_{ab}^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

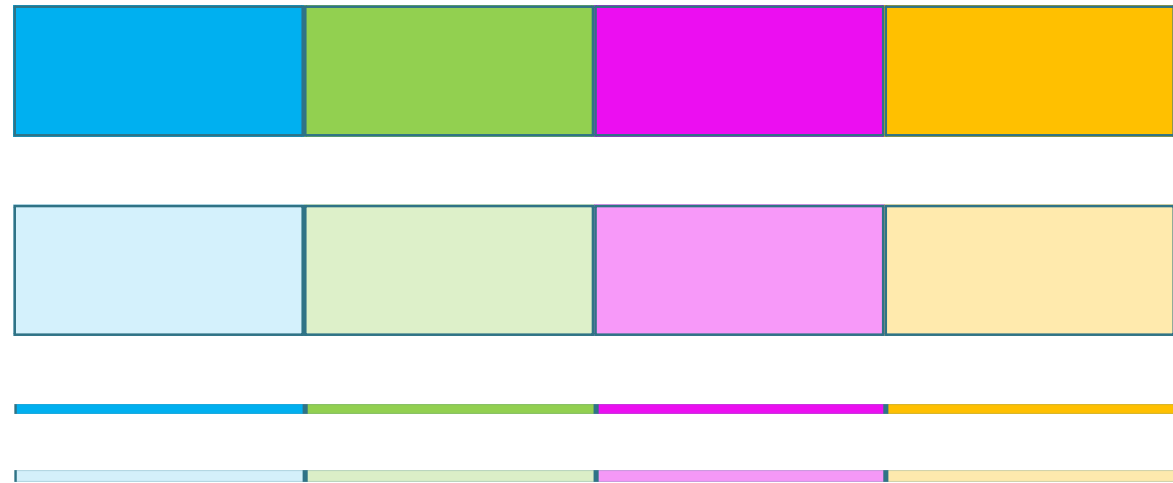
- $\Delta E < 1$  : not perceptible,  $1 < \Delta E < 2$  close observation needed to perceive the difference,  $2 < \Delta E < 10$  different but similar color
- Not perceptually uniform as originally intended, hence superseded by 1994 and 2000 specifications

# 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 or 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 amount of detail carried by the black and white channel (Mullen, 1985)

Purely chromatic differences are not enough to display fine details

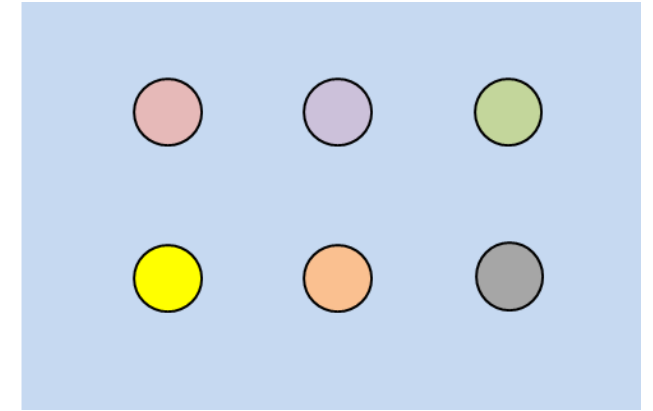
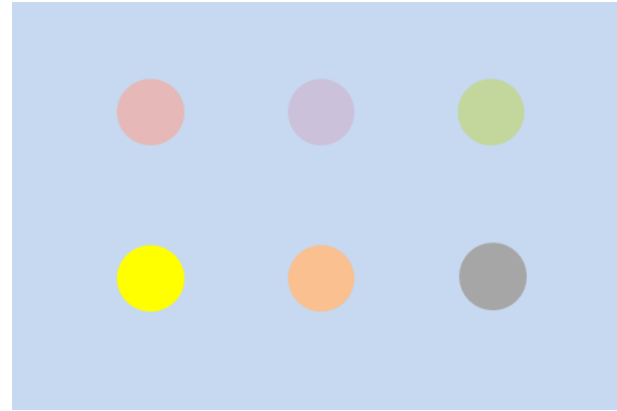
Ensure adequate luminance contrast with the background (also if colors with different chromaticity are used)

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aenean maximus tortor ac risus malesuada sagittis. Nullam condimentum, erat et dapibus dapibus, diam ligula dapibus nunc, at pellentesque dolor quam et mi. Donec vel mauris ultricies, maximus magna vel, luctus est. Proin laoreet nisi vitae dolor laoreet ullamcorper. Donec viverra leo eget bibendum blandit. Praesent feugiat quis leo faucibus ullamcorper. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Curabitur tempor mi orci, eu pellentesque sem interdum eu. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Aenean maximus tortor ac risus malesuada sagittis. Nullam condimentum, erat et dapibus dapibus, diam ligula dapibus nunc, at pellentesque dolor quam et mi. Donec vel mauris ultricies, maximus magna vel, luctus est. Proin laoreet nisi vitae dolor laoreet ullamcorper. Donec viverra leo eget bibendum blandit. Praesent feugiat quis leo faucibus ullamcorper. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Curabitur tempor mi orci, eu pellentesque sem interdum eu.

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

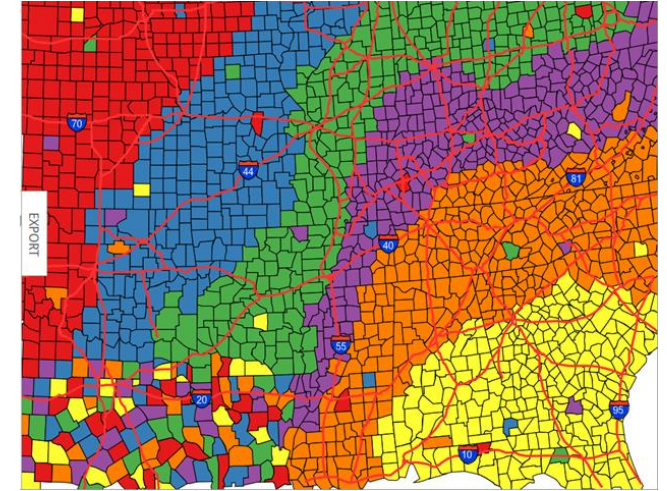
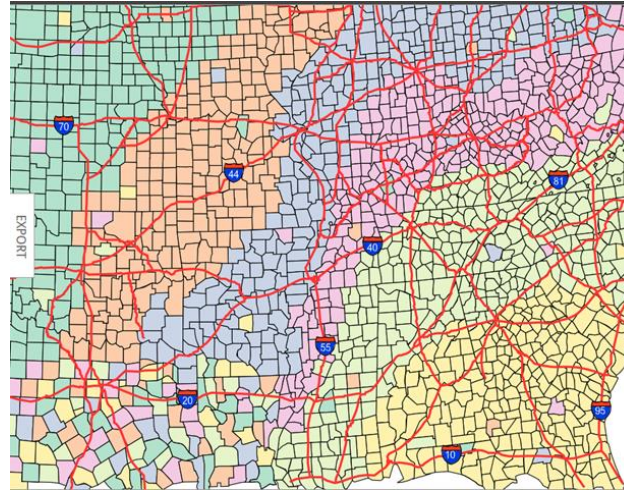
# *Luminance and visualization*

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

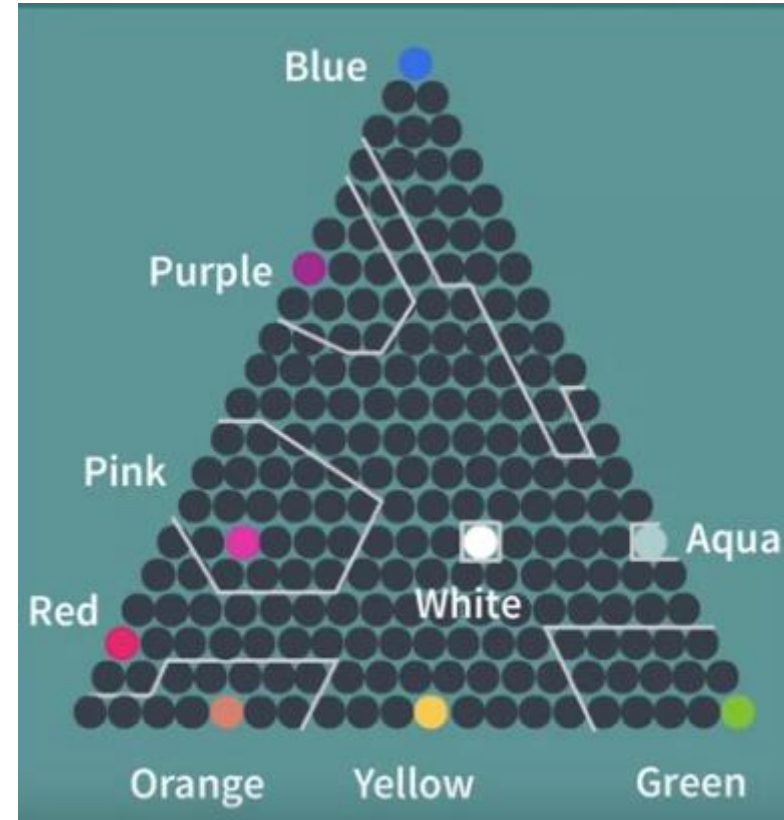


# *Color for labeling*

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

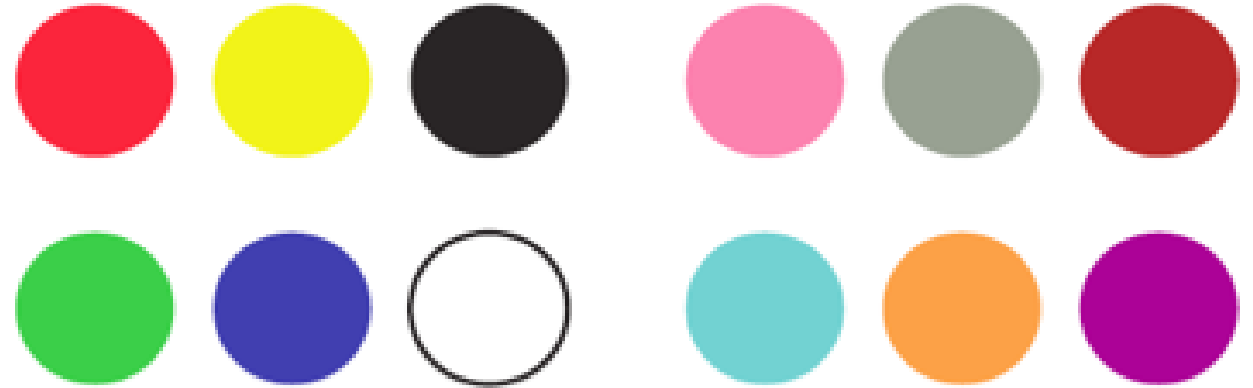
Though not generally applicable, this suggests that only few colors can be used as category labels



# *Color for labeling*

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

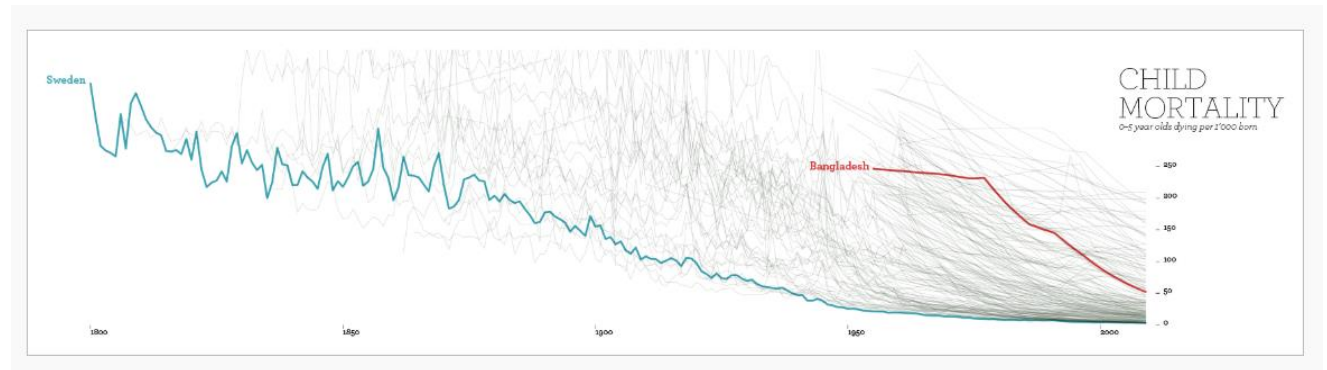
Widely agreed-upon category names, and reasonably far apart in color space



# Semantics

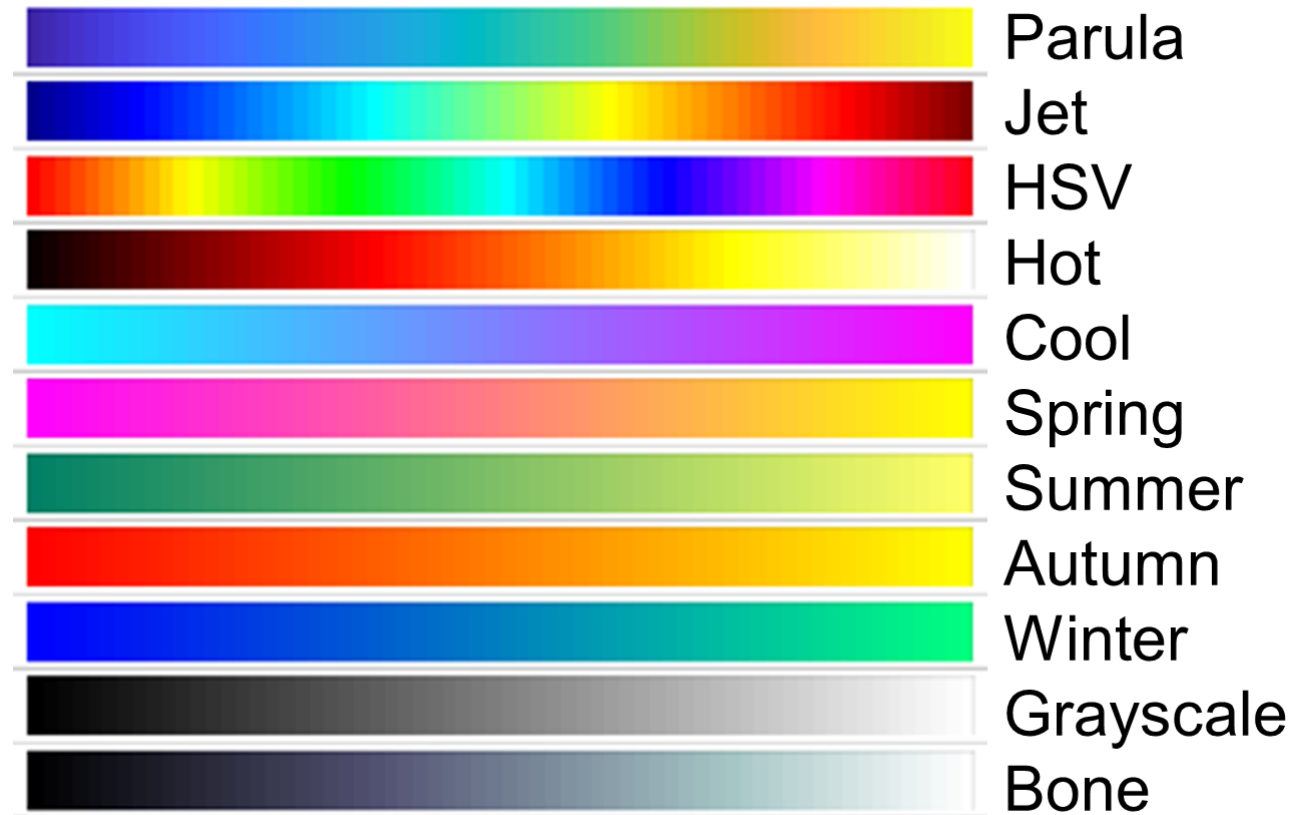
Pay attention to color convention and semantic associations (red for hot/bad/danger, blue for cold, green for life/go, etc.) as conventions are not universal

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*

## Sequential (Single-Hue)

Blues

Greens

Greys

Oranges

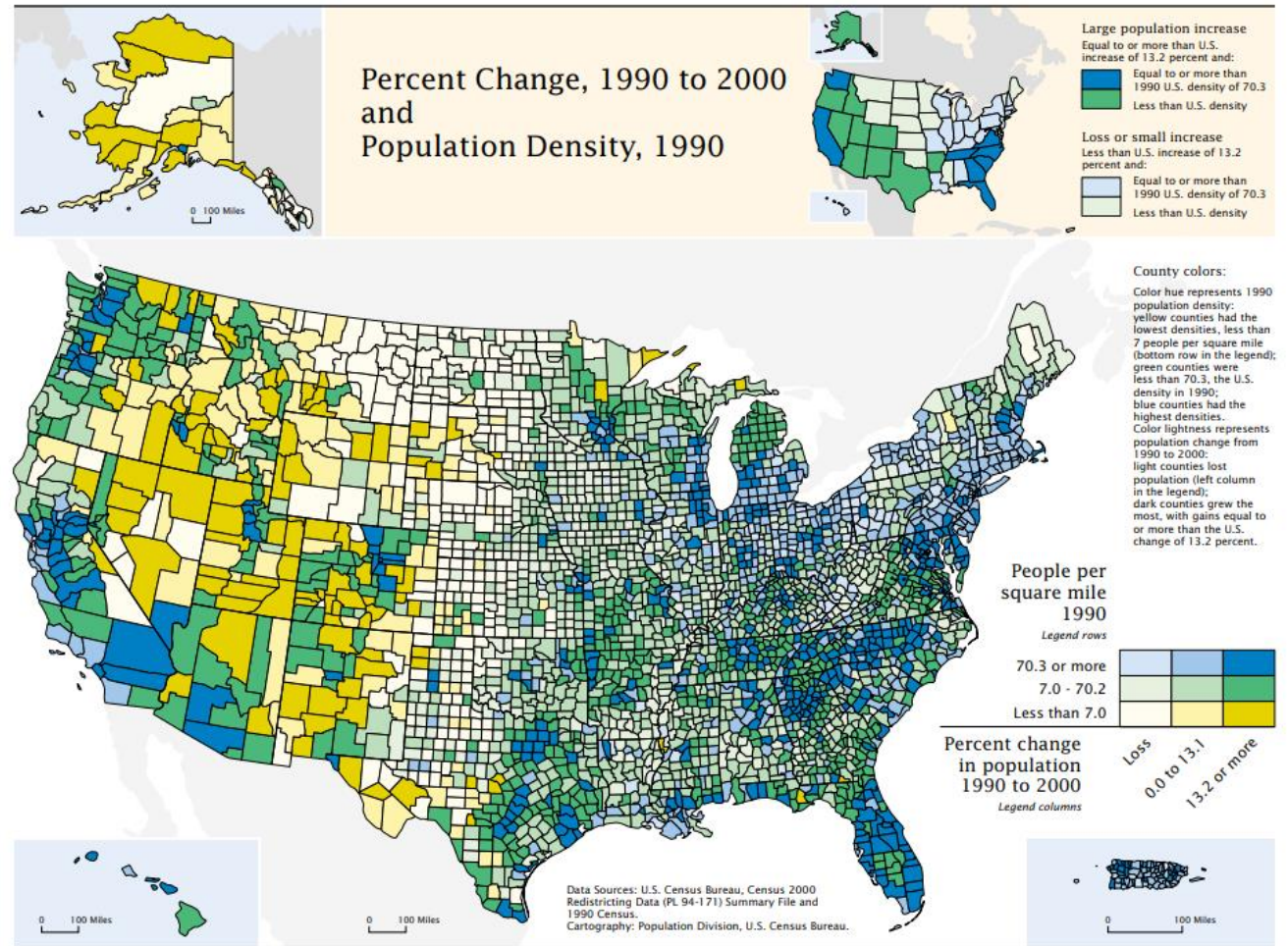
Purples

Reds

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



# Multi-Hue sequential scales



12 Mapping Census 2000: The Geography of U.S. Diversity

U.S. Census Bureau

[by Cynthia Brewer]

Color names if  
you're a girl...

Color names if  
you're a guy...



Doghouse Diaries  
"We take no as an answer."

*The end*