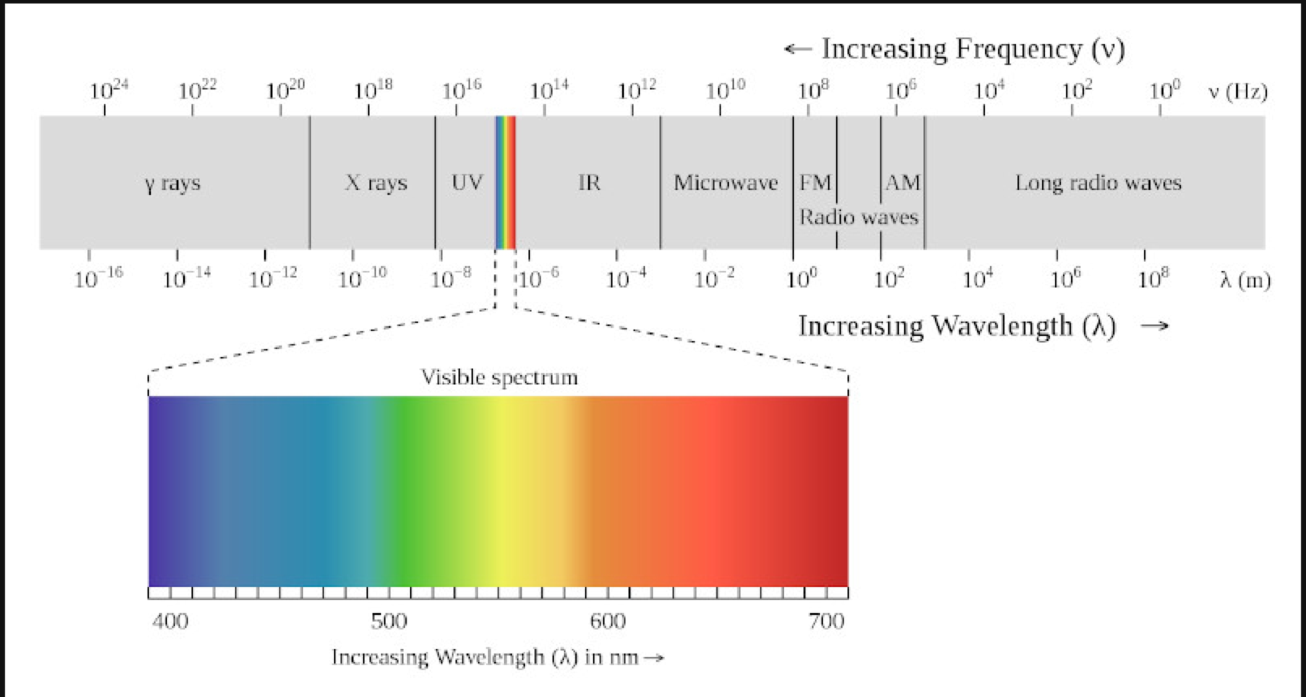
6a: Color

Color

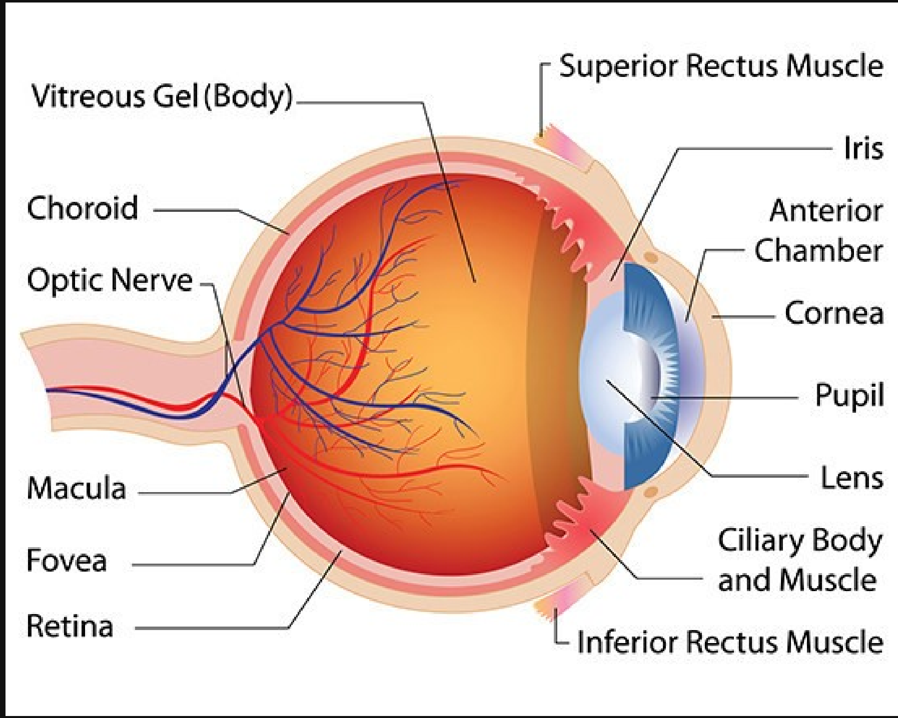
- **Perception**: How the eye perceives color
- **Specification**: How we specify color
- **Use**: Use of color in visualizations

Visible electromagenetic spectrum



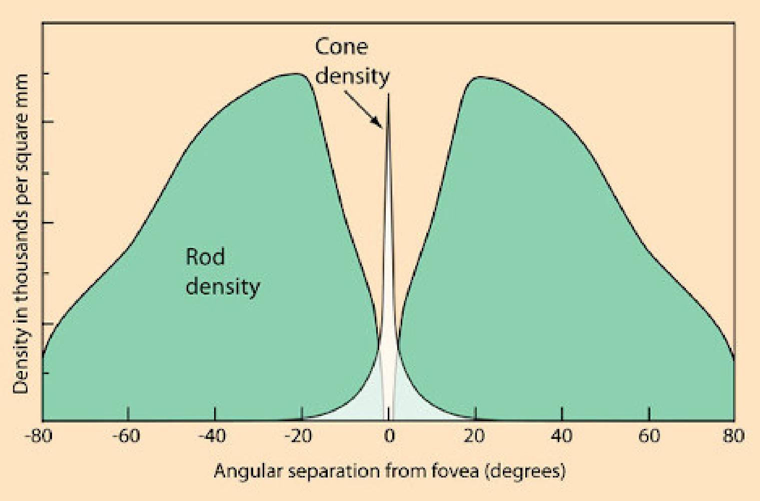
Visible light is roughly in the wavelengths of 400nm (4×10^{-7}m) to 700nm (7×10^{-7}m).

Eye Structure

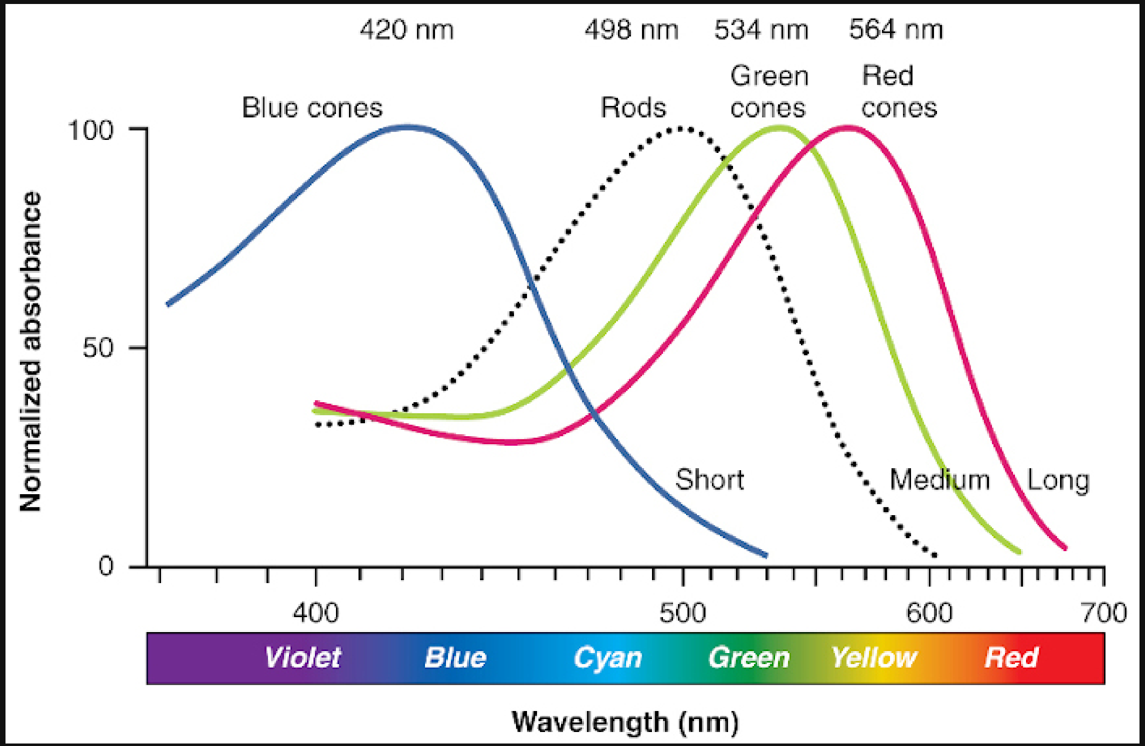


Eye: Rods and Cones

Rods	Cones
Used for scotopic vision (vision under low light conditions)	Used for photopic vision (vision under high light conditions)
Very light sensitive; sensitive to scattered light	Not very light sensitive; sensitive only to direct light
Loss causes night blindness	Loss causes legal blindness
Low visual acuity	High visual acuity; better spatial resolution
Not present in fovea	Concentrated in fovea
Slow response to light, stimuli added over time	Fast response to light, can perceive more rapid changes in stimuli
Have more pigment than cones, so can detect lower light levels	Have less pigment than rods, require more light to detect images
Stacks of membrane-enclosed disks are unattached to cell membrane directly	Disks are attached to outer membrane
About 120 million rods distributed around the retina[13]	About 6 million cones distributed in each retina[13]
One type of photosensitive pigment	Three types of photosensitive pigment in humans
Confer achromatic vision	Confer color vision



Cones: photoreceptor wavelength

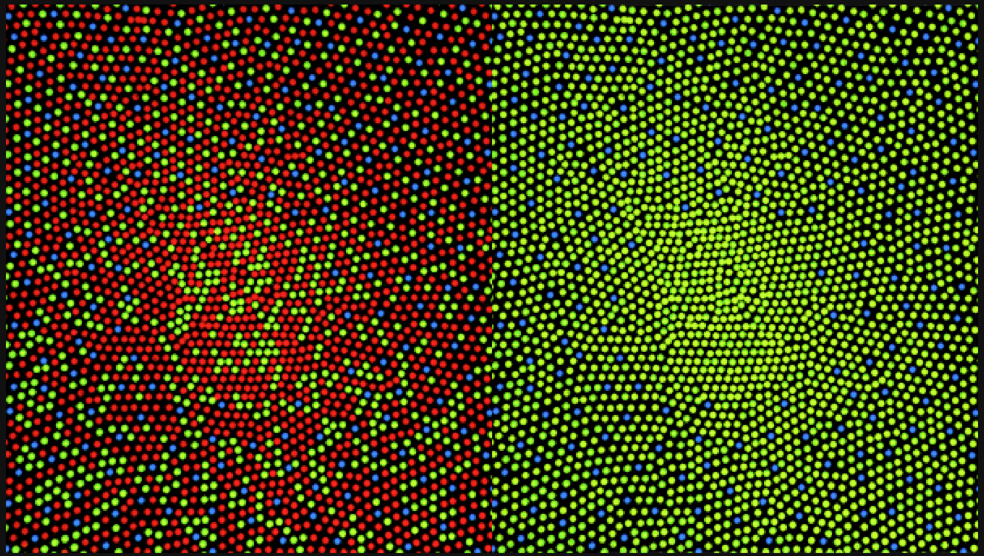


Red cones, or L-cones. 64% of total cones, maximally sensitive to long-wave light

Green cones, or M-cones. 32% of total cones, maximally sensitive to medium-wave light

Blue cones, or S-cones. 2 – 7% of total cones, maximally sensitive to short-wave light

Cones: distribution



Left: Illustration of distribution of cones in fovea of human with normal color vision.

Right: Illustration of distribution of cones in fovea of human with protanopic vision, i.e. no L-cones (red cones)

Color blindness

	Cone system	Red		Green		Blue		N=normal		
		N	A	N	A	N	A	A=anomalous		
1	Normal vision							Trichromat	Normal	
2	Protanomaly							Anomalous trichromat	Partially color blind	Red–green
3	Protanopia							Dichromat		
4	Deuteranomaly							Anomalous trichromat		
5	Deuteranopia							Dichromat		
6	Tritanomaly							Anomalous trichromat		Blue–yellow
7	Tritanopia							Dichromat		
8	Achromatopsia							Monochromat	Totally color blind	
9	Tetrachromat							Tetrachromat		
10										

Color blindness is genetically inherited. About 8% men, 0.5% women around the world

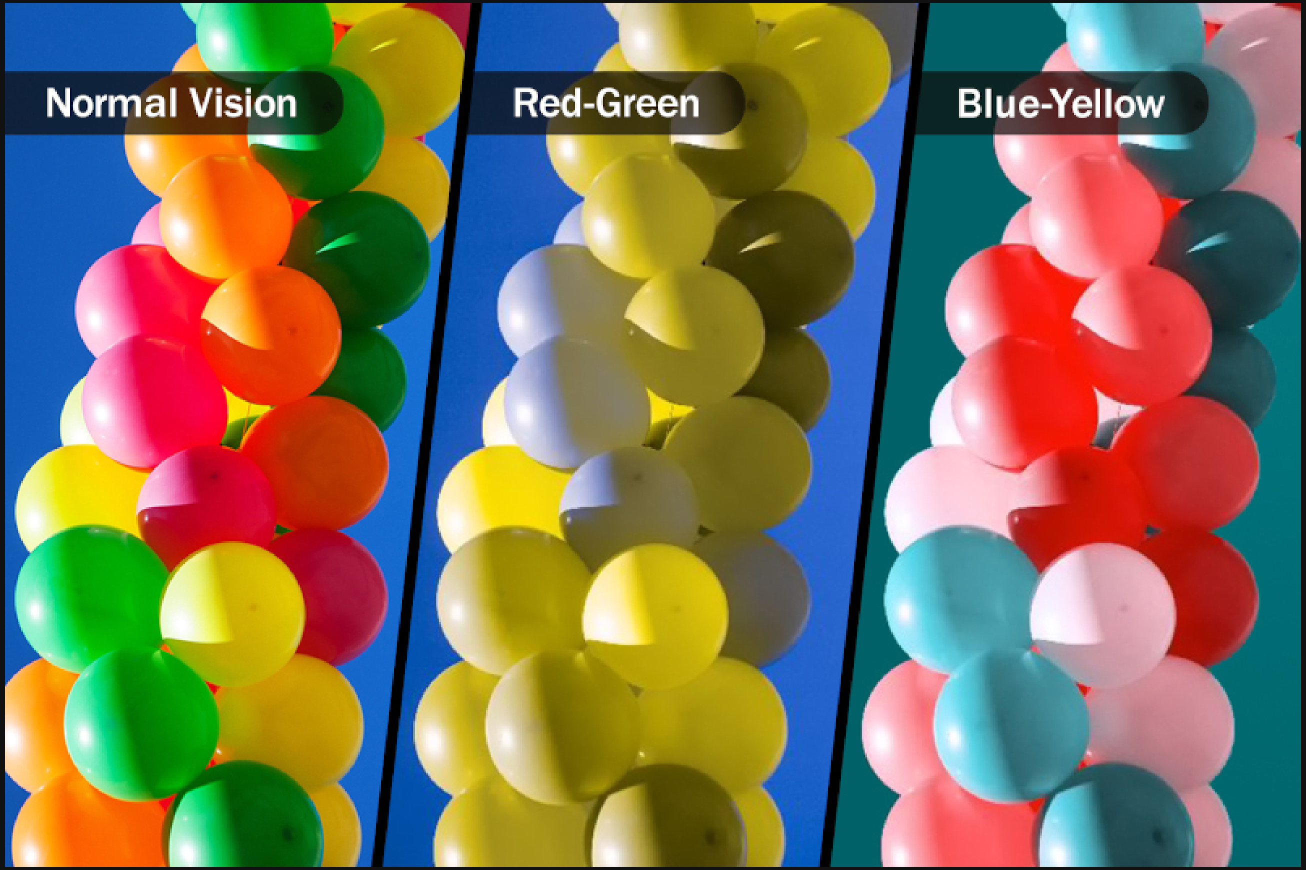
Red-green color blindness is passed down on the X chromosome, of which men have only 1 X chromosome (women have 2).

Common: red-green deficiency, deuteronomaly. Uncommon: protonomaly.

Rare: blue-yellow deficiency, tritanomaly.

More info on color blindness

Color blindness 2



Vischeck: color blindness simulation and correction

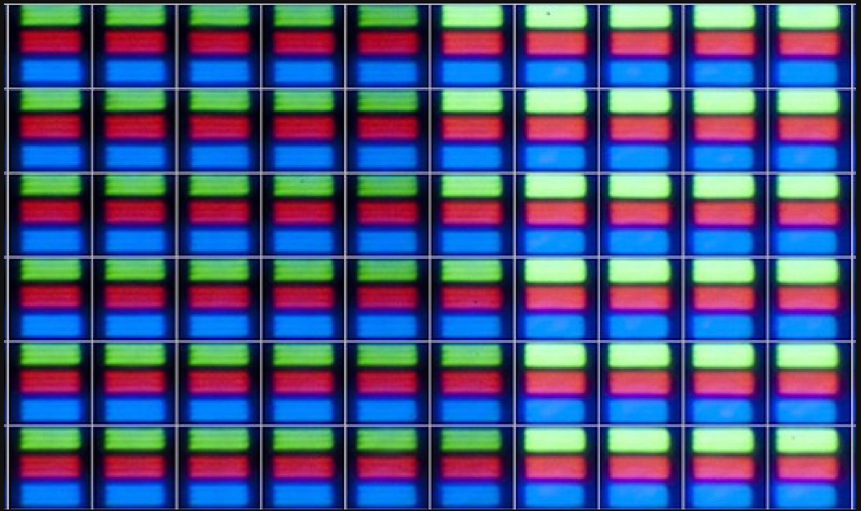
Colorspace

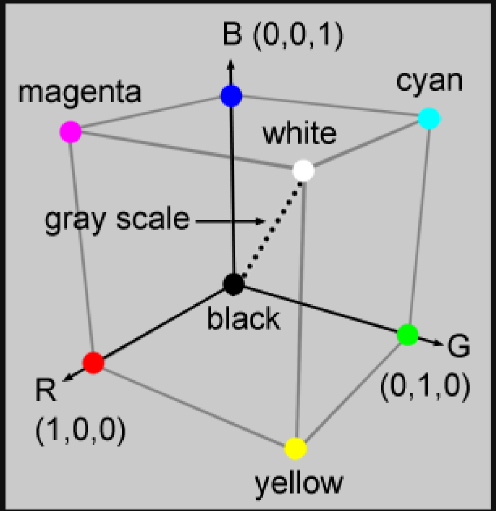
A colorspace is a system for describing color numerically.

- RGB
- CMYK
- HSV/HSL
- CIE Lab
- CIE HCL

There are many more: XYZ, Munsell, CMS, etc.

Colorspace: RGB





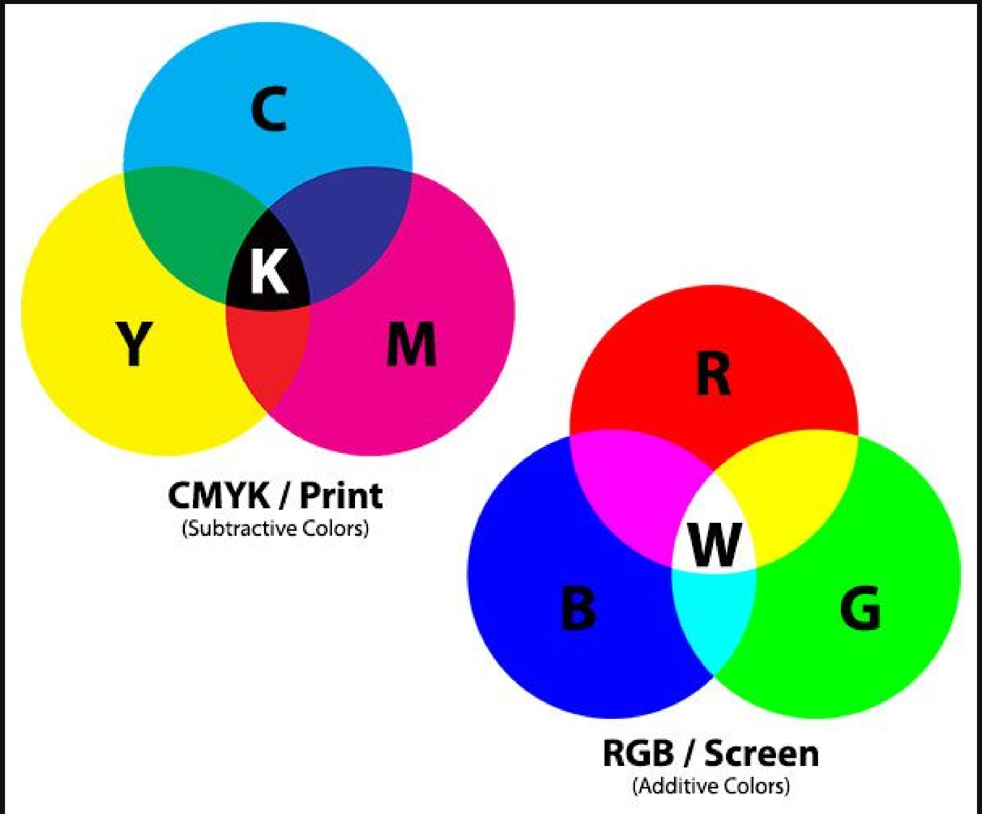
Left: Magnification of pixels on a screen. Right: RGB color cube.

RGB colorspace is additive.

Problems: Not intuitive, not perceptually uniform.

Reading: Perceptually Smooth Multi-Color Linear Gradients

Colorspace: CMYK

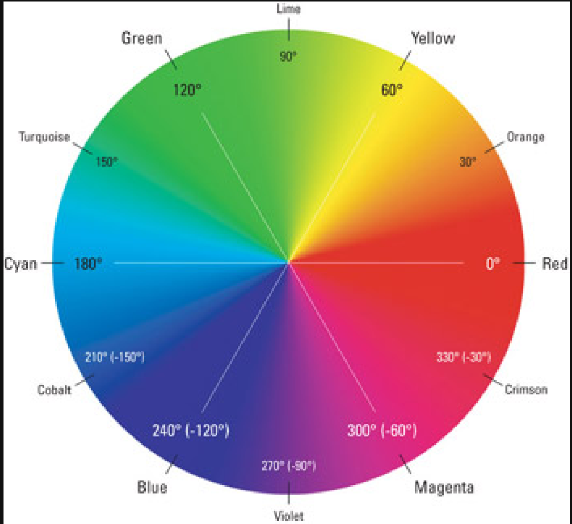


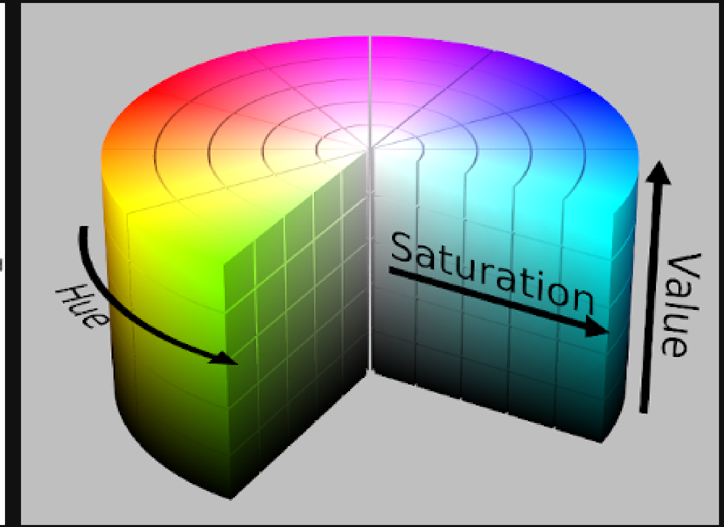
CMYK colorspace is subtractive. For print only.

Reading: Why printing uses CMYK

Colorspace: HSV/HSL

H = Hue, S = Saturation (vividness of color), V/L = Value / Lightness



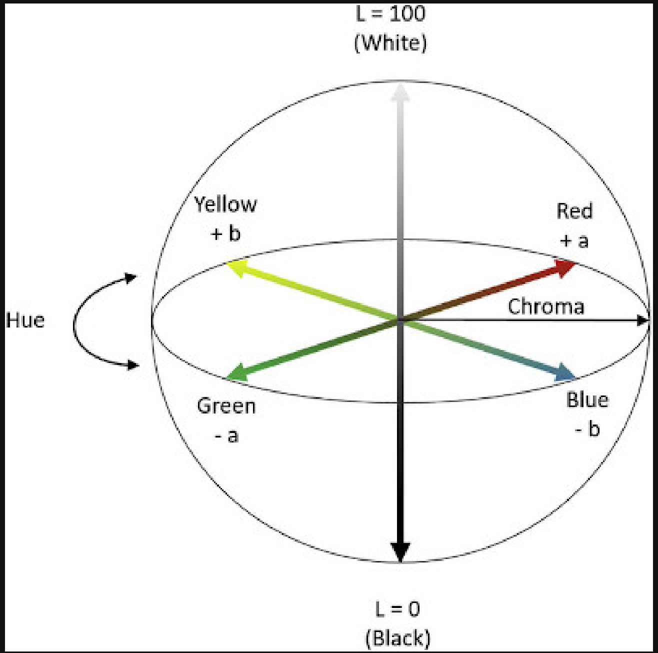


Left: Hue described radially. Right: HSV color cylinder

Problems: More intuitive, but also not perceptually uniform.

Colorspace: CIE Lab (or Lab)

L = Lightness, a = red-green scale, b = yellow-blue scale



CIE (Commission internationale de l'éclairage, or International Commission on Illumination) - international authority on light, illumination, colour, and colour spaces.

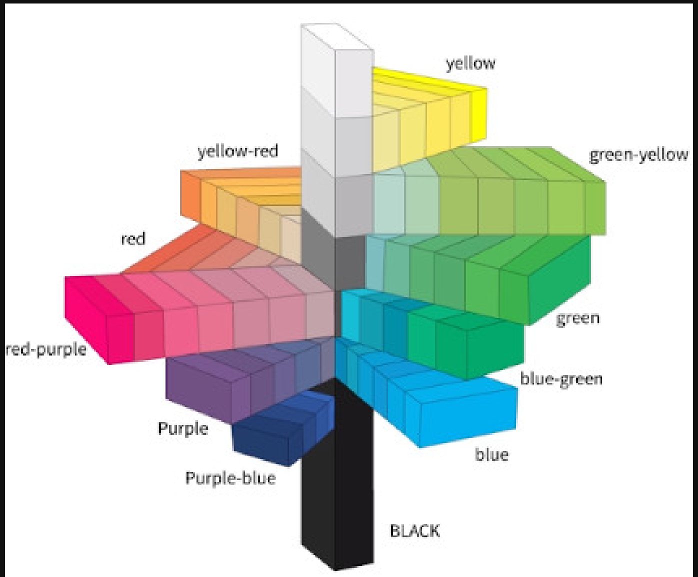
Designed to better approximate human perception of color.

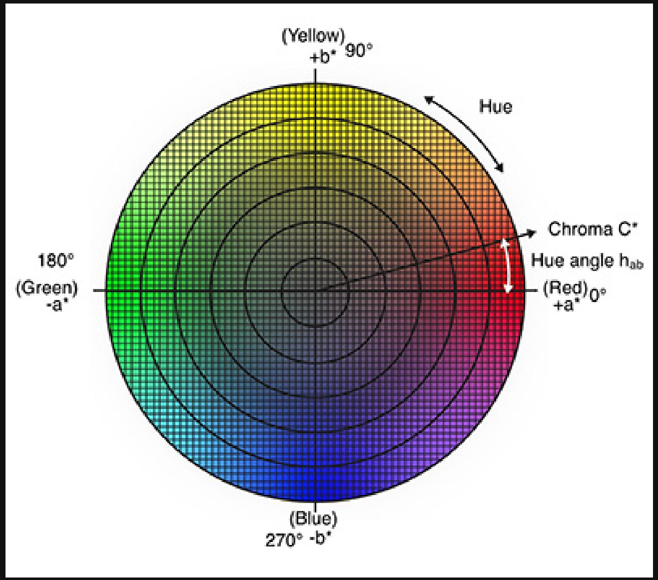
Perceptually linear (or close).

Colorspace: CIE HCL (or HCL)

H = Hue, C = Chroma, L = Luminance

H and C are transformations of a and b in the Lab model.

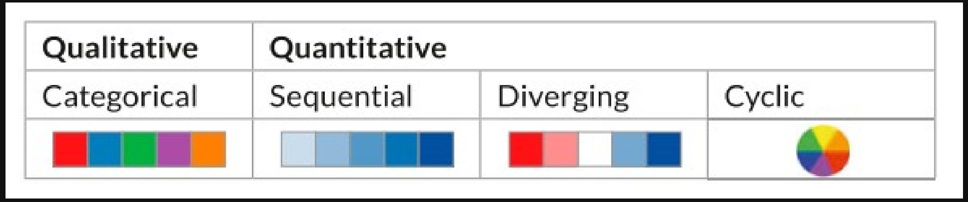


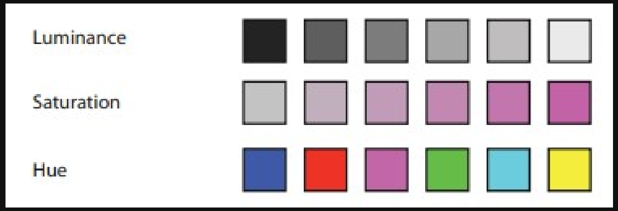


Perceptually linear, and more intuitive.

Recap: Color channels

Magnitude channel (quantitative) or identity (qualitative)?





4th channel: Transparency (used as layer for interaction)

D3: Color scales (aka as a channel)

D3: Colorspace

Viridis color palette

Recap: color blindness

- Colorful (spans wide palette)
- Perceptually uniform
- Robust to color blindness
- Pretty!

Viridis color palette

Reading: 5 tips on designing colorblind-friendly visualizations

Redundantly encode channels - shape, tooltip, etc.

Color Tools

Recap: Channel effectiveness: Discriminability.

Not too many color bins. Perceptually distinct colors.

I want hue

Color Brewer 2.0

Color: Channel Implications

Channel: separability - luminance and saturation are not the most separable. Also not separable from transparency. For separability, pick hue vs saturation / luminance.

Channel: salience (popout) - small number of bins.

Rainbow color maps: Pros and cons

Reading: Choosing colors for your visualization

Reading: Using color in Information Display Graphics

Color: Contrast

Color is perceived differently depending on how it is contrasted with other colors. It is relative and not absolute.

Bezold Effect and White's Illusion

Reading: Luminance contrast

Reading: Simultaneous and successive contrast

Color Theory

Color theory is the collection of rules and guidelines which designers use to communicate with users through appealing color schemes in visual interfaces.

Color theory and the color wheel

Role of color in UX

Questions?

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