

What is Color?

Intro to Data Visualization

Gaston Sanchez

CC BY-SA 4.0

What is Color?

What is Color?

4 ways to talk about color

One of the difficulties in talking about color is that it seems to exist in several different forms:

- ▶ material color
- ▶ radiant color
- ▶ visual color
- ▶ conceptual color

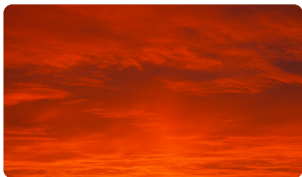
Material Color



Yellow Bus



Cadmium Orange



Red Sky



Lemon Green

Material Color

Material Color

Material color is the physical pigment, dye, filter, pigmented or dyed material, or light source that originates the experience of color. It is the sense in which we equate color with the physical world.

Bruce MacEvoy

Radiant Color



Radiant Color

Radiant Color

Radiant color is the mixture of light wavelengths emitted by a light source, or transmitted by a filter or other semitransparent medium, or reflected from an opaque material such as paint, ink, dye, or photographic emulsion. This defines color as a physical stimulus.

Bruce MacEvoy

Visual Color



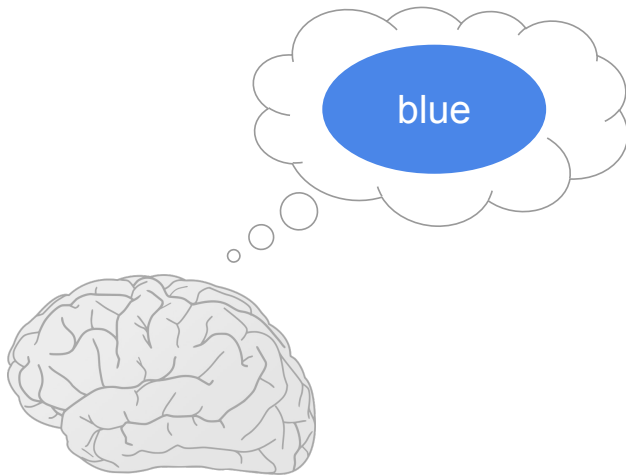
Visual Color

Visual Color

Visual color is the perception of radiant color in a specific viewing context. Visual color literally does not exist outside individual consciousness.

Bruce MacEvoy

Conceptual Color



Conceptual Color

Conceptual Color

Conceptual color is color as an abstract concept, a sensory memory, a color label that calls to mind a visual or material color that is not present as a physical exemplar or as a visual perception. It is color defined primarily through language, memory, custom and habit.

Bruce MacEvoy

Some words of caution

- ▶ Color experience is remarkably subjective and personal.
- ▶ It varies significantly across individuals (e.g. genetics, age, experience).
- ▶ The same radiant color can appear as very different visual colors.
- ▶ Color experience depends on the intensity of the light and the context in which it is viewed.

A little bit of history

Color Naming

- ▶ Every language has words to name colors
- ▶ The language color has evolved tremendously in the last 2 centuries
- ▶ Influenced by technological developments in:
 - painting, dyeing, weaving, ceramics
 - cosmetics, medical diagnosis
 - mineralogy, botany, horticulture, entomology
 - chemistry

Color Naming

- ▶ In many primitive cultures only a handful of words for colors are available
- ▶ Such words make very gross distinctions between:
 - light and dark
 - warm and cool colors
- ▶ e.g. the *Black Sea* is not black, but dark blue
(from when color ideas green, blue, dark and black were denoted by the same word)

Color Naming



Color Naming

Color Names

The naming of colors carries one out of the narrow realm of color perception, and into the larger realm of cultural and linguistic interpretation and classification of color, and thence into even larger philosophical, aesthetic, theological, and metaphysical considerations.

Elle Stone

Color Naming

- ▶ Earliest approach anchored color names on things:
- ▶ flowers, fruits, minerals or organic compounds (dye)
- ▶ colors: lemon, saffron, amber, gold, orange, vermillion,
- ▶ rose, ruby, carmine, violet, sapphire, turquoise, emerald,
- ▶ leaf green, ochre, sepia, indigo, ivory, ebony and so on.



MUSEI
WORMIANI
HISTORIA
LUGD· BATAVORUM
EX OFFICINA ELSEVIRIANA
Ad. 1700. 16. 55.

Naturalists of 16th and 17th centuries

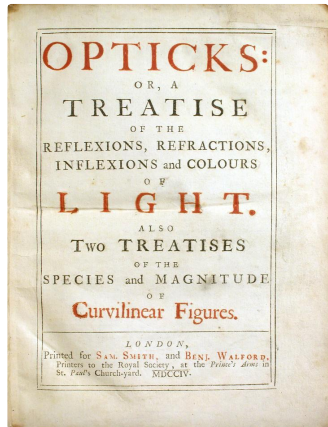
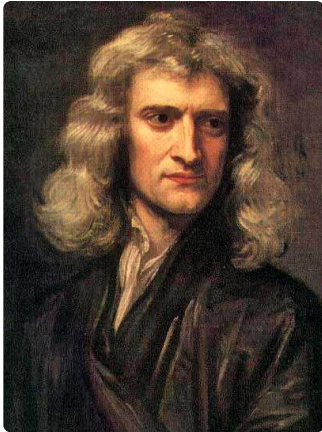
- ▶ rise of collections of curiosities (16th-17th centuries)
- ▶ assembled by naturalists, botanists, entomologists, etc
- ▶ flowers, animals, minerals, and objects around the world
- ▶ discovery of “new” colors never seen before
- ▶ a new insect, coral, flower or gem often revealed a new hue

Painter's Primaries

- ▶ Circa 1300 Cennino Cennini published a description of how a painter's work with seven natural colors namely black, red, yellow, green, lime white, blue ultramarine and azurite.
- ▶ Greek texts show awareness and use of subtractive primary mixtures based on red, yellow and blue colorants to ancient painters and dyers.
- ▶ By 1664 early chemists were studying dyes and pigments in order to improve them.
- ▶ Efforts motivated by the huge commercial importance of textile manufacture.

Isaac Newton's Opticks

Newton's Opticks



Isaac Newton's Opticks

- ▶ Physiological limits of color vision not understood before 18th c.
- ▶ Isaac Newton's **Opticks** published in 1704.
- ▶ First scientific analysis of color.
- ▶ Claimed identification of all fundamental colors and by extension all possible mixed colors.

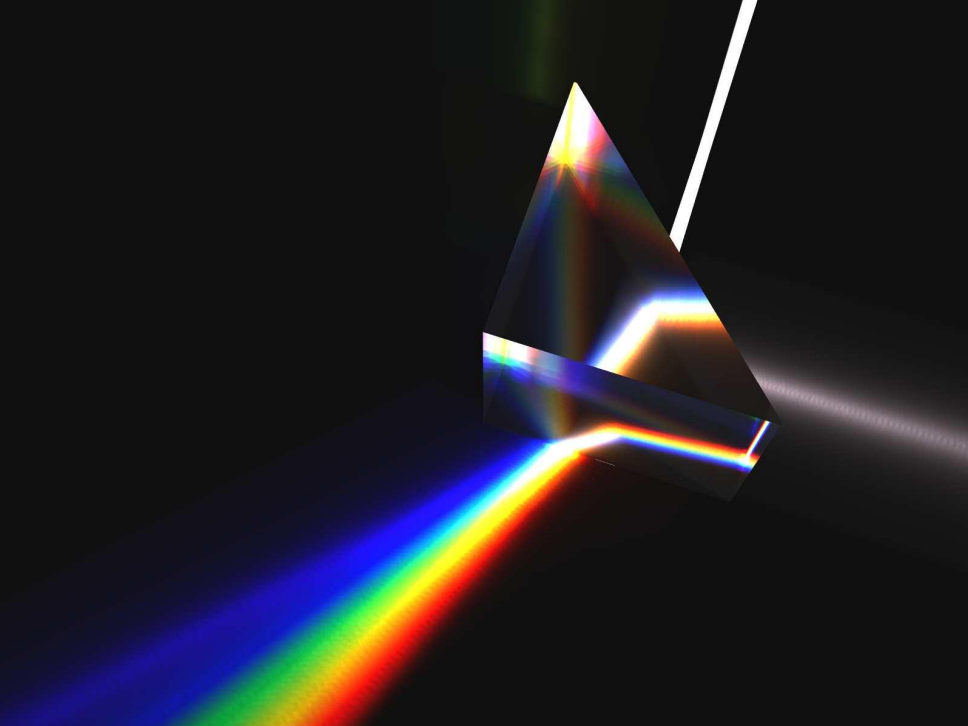
Newton's Experiments



Engraving of Sir Isaac Newton (1642-1727)

Newton's Experiments

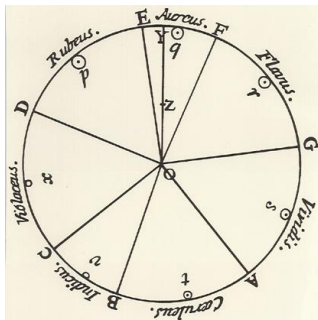
- ▶ Newton passed sunlight through a triangular prism.
- ▶ Decomposed light into a rainbow of colors.
- ▶ Showed that the colors of the rainbow could not be further decomposed.
- ▶ This experiment marked the beginning of the study of visible light.



Newton's Experiments

- ▶ Newton claimed to see the seven colors:
- ▶ red, orange, yellow, green, blue, indigo, and violet.
- ▶ It is beleived that Newton chose to have 7 colors to parallel the 7 notes of the standard musical scale.
- ▶ In practice, 4 or 6 are more natural numbers of colors.

Newton's Hue Circle



Newton's Conclusions

- ▶ Newton concluded that the color of paints arises from the selective absorption of some spectral hues and the reflection of others.
- ▶ He rejected the ancient Greek theory that colors arise from mixtures of light and dark.
- ▶ He rejected the painter's theory that there were just three primary colors—red, yellow and blue.

Color Light

- ▶ Physically, a given color can be related to wavelength.
- ▶ However, wavelengths do not entirely correspond to the way we perceive color.
- ▶ In terms of wavelength, red and violet are the two most different visible colors.
- ▶ However, we perceive red and violet as similar or somehow related.
- ▶ Newton noticed this and arranged the visible colors into a color wheel.

Color Atlas

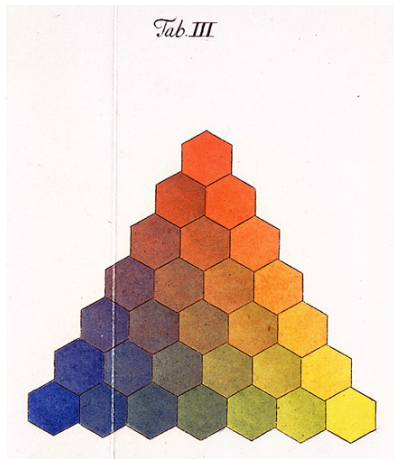
Color Systems

- ▶ 18th century color enthusiasts focused on a specific practical problem:
- ▶ how to define and represent all possible colors as a single color order system.
- ▶ These early color models were motivated by a scientific interest in summarizing color perception
- ▶ by the need for a standardized system of color identification for use in science and industry.
- ▶ and by an artist's mystical enthusiasm for color.

Color Models Requirements

- ▶ a color specification that defines all possible colors as a mixture of fundamental attributes, such as “primary” colors;
- ▶ a geometrical framework that locates all colors in relation to each other and to the fundamental attributes;
- ▶ a standardized system of unique color labels;
- ▶ pigment mixture recipes or physical color exemplars

Tobias Mayer's Trichromatic Mixing Triangle











First comprehensive color order system proposed by the Gottingen mathematician and astronomer Tobias Mayer (1723-1762).

Color Atlas

- ▶ Precise spectral mixtures hard to achieve before 19th c.
- ▶ Naturalists derived color identifications using a color atlas.
- ▶ A.G. Werner's *Nomenclature of Colors* (1774).
- ▶ Hand painted colored patches as a visual standard for each color.

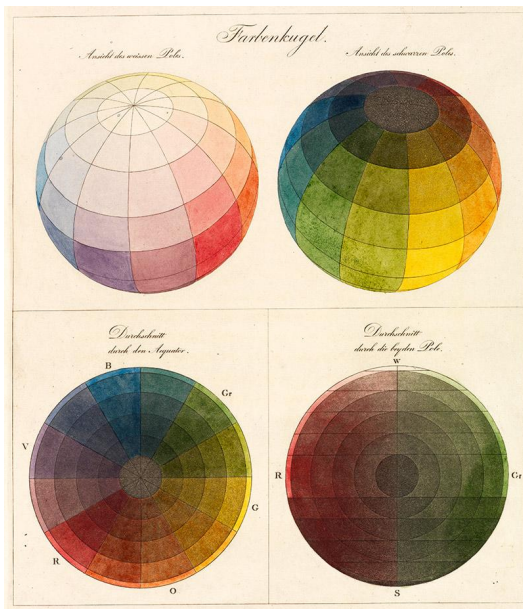
Nomenclature of Colors

GREENS.					
N ^o .	Names	Colours	ANIMAL	VEGETABLE	MIXERAL
46	<i>Calandine Green.</i>		<i>Phalena Margaritaria.</i>	<i>Back of Tussock Leaves.</i>	<i>Beryl.</i>
47	<i>Mossy Green.</i>		<i>Phalena Tenebraria.</i>	<i>Thick leaved Coleroid, Silver leaved Almond.</i>	<i>Actinolite Beryl.</i>
48	<i>Leek Green.</i>			<i>Sea Kale. Leaves of Leeks in Winter.</i>	<i>Actinolite Prase.</i>
49	<i>Blackish Green.</i>		<i>Elytra of Meloe Violaceus.</i>	<i>Dark Streaks on Leaves of Cayenne Pepper.</i>	<i>Serpentine.</i>
50	<i>Verdigris Green.</i>		<i>Tail of small Long tailed Green Parrot.</i>		<i>Copper Green.</i>
51	<i>Bluish Green.</i>		<i>Egg of Thrush.</i>	<i>Under Disk of Wild Rose leaves.</i>	<i>Beryl.</i>
52	<i>Apple Green.</i>		<i>Under Side of Wings of Green Brown Moth.</i>		<i>Crysoprase.</i>
53	<i>Emerald Green.</i>		<i>Beauzy Spot on Wing of Tral Drake.</i>		<i>Emerald.</i>

Color Mixture

- ▶ Recipe of proportional mixture of a few standard colorants.
- ▶ Industrial color printing by Jakob Christoffel Le Blon.
- ▶ Multicolor printing system started in 17th century.
- ▶ Color images created from three primary or "primitive" colored inks.
- ▶ Modern color mixing systems include the four ink process (CMYK).

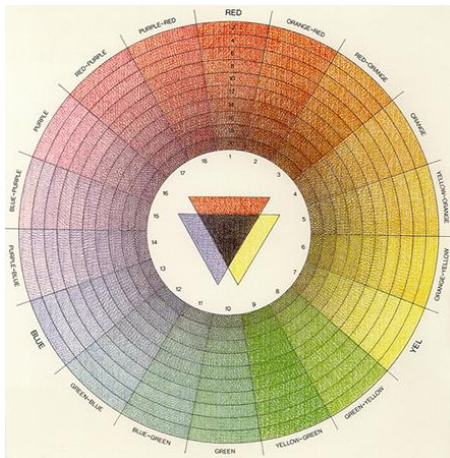
Runge's Color Sphere



Color Order Systems

- ▶ Need for a geometrical framework or map of color.
- ▶ Main idea: colors as combinations of fundamental attributes.
- ▶ 1st color order system proposed by German astronomer Tobias Mayer in 1758.
- ▶ **Color Sphere:** 1st color model to adopt the 3-dimensional framework proposed by German painter Philipp Otto Runge (1810).
- ▶ Modern color mixing systems include the four ink process (CMYK).

Moses Harris's Color Wheel



English entomologist Moses Harris (1731-1785) published a color wheel in his *Natural System of Colours* (1766)

Light and Color

Newton's Experiments

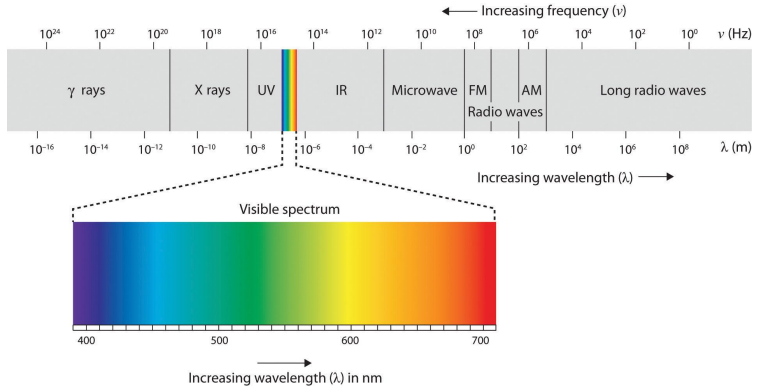


Engraving of Sir Isaac Newton (1642-1727)

Light Recap

- ▶ Light is a form of electromagnetic radiation.
- ▶ Electromagnetic radiations are characterized by their wavelength.
- ▶ Visible light has wavelengths in a narrow band centered on 600 nanometers.

Electromagnetic Spectrum



<http://open.lib.umn.edu/intropsyc/chapter/4-2-seeing/>

Visible Light

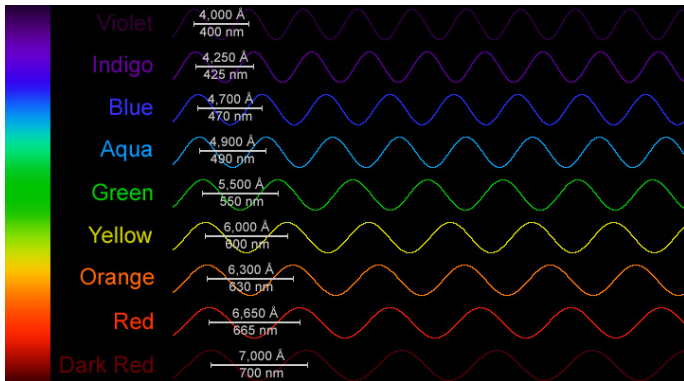
Visible Spectrum

If the electromagnetic spectrum spanned the distance from Los Angeles to New York City, the part visible to the human eye would span the width of a dime.

Visible Light

- ▶ Our eyes detect wavelengths in a tiny portion of the electromagnetic spectrum.
- ▶ We call this the *visible light spectrum*.
- ▶ We perceive short wavelengths as blue.
- ▶ We perceive longer wavelengths as red.
- ▶ We cannot perceive wavelength beyond the limits of the visible spectrum.
- ▶ Shorter wavelengths of ultraviolet light.
- ▶ Longer wavelengths of infrared radiation.

Electromagnetic Spectrum



www.astronomersgroup.org/EMspectrum.html

Visible Spectrum



If the visible spectrum is divided into thirds, the predominant colors are blue, green, and red.

Some considerations

- ▶ Color is part of how we sense the world around us.
- ▶ Light enters the eyes.
- ▶ It is processed by light receptors (cones and rods).
- ▶ And sent via the optic nerves to the brain for further processing and interpretation.
- ▶ Light varies in wavelengths, which our eyes and brain interpret as varying colors.