Color

Maneesh Agrawala

CS 448B: Visualization
Fall 2021

1

Reading Response Questions/Thoughts

How does change blindness apply to interactive charts and how should we design around it?

Is it feasible to make creating robust and highly customizable visual explainers easier for less technical users?

Why are these kind of "bad" visuals are justified in the talk by placing the context in a more specific community when the accessibility for those communities is not inherently better based on format?

When deciding which data should be encoded in which channels: should the most important data be noticed first, or noticed the most accurately?

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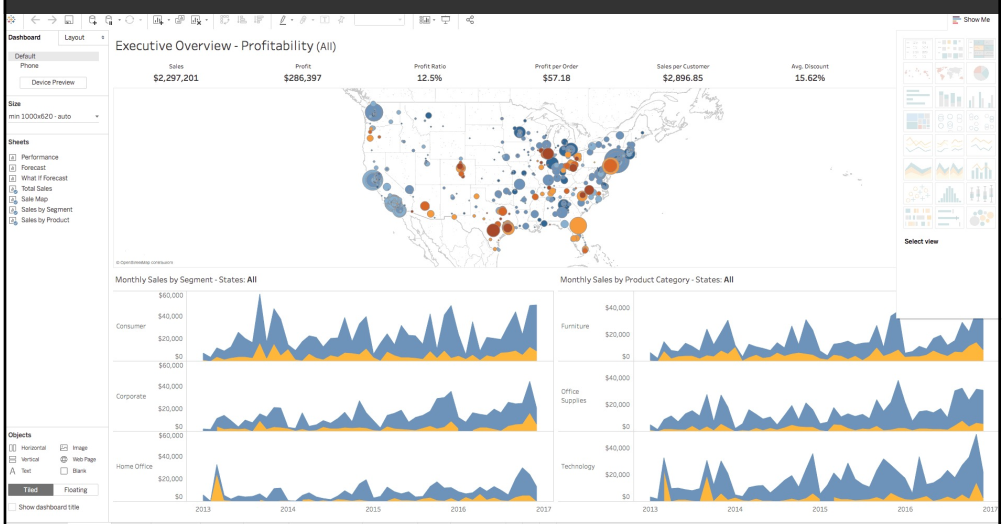
Last Time: Visual Explainers
Chart Sequences

3

Multiple Charts in Data Analysis



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Multiple Charts in Storytelling

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Chart Sequence Design [Hullman 2013]

Can we automatically identify sequences to recommend to a human designer?

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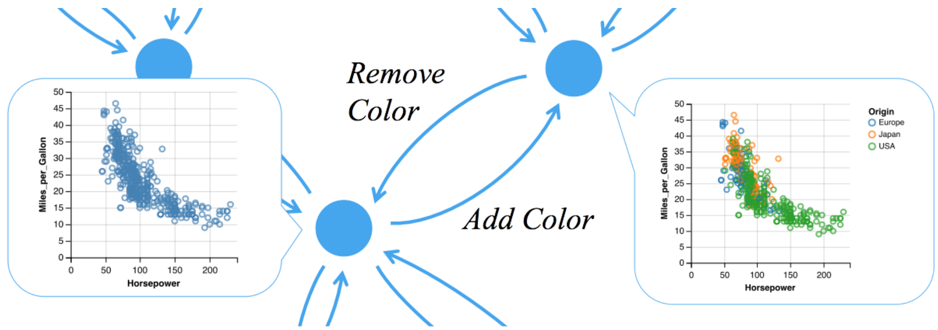
GraphScape: A Directed Graph Model



Nodes are **Vega-Lite specifications**. Edges represent **edit operations**, weighted by estimated **transition costs**.

[Kim, Wongsuphasawat, Hullman, Heer, 2017]

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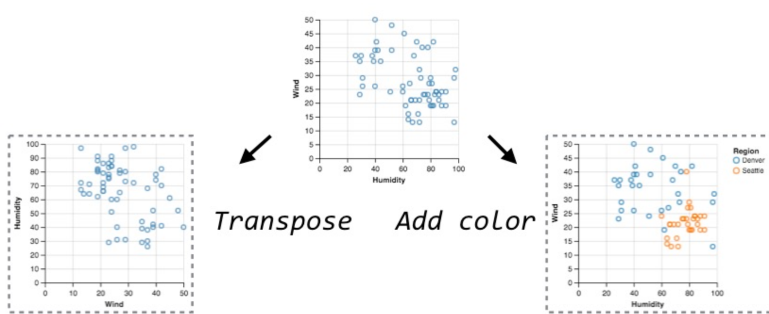
Constructing the Graph

After reading this chart,



which chart is easier to follow?

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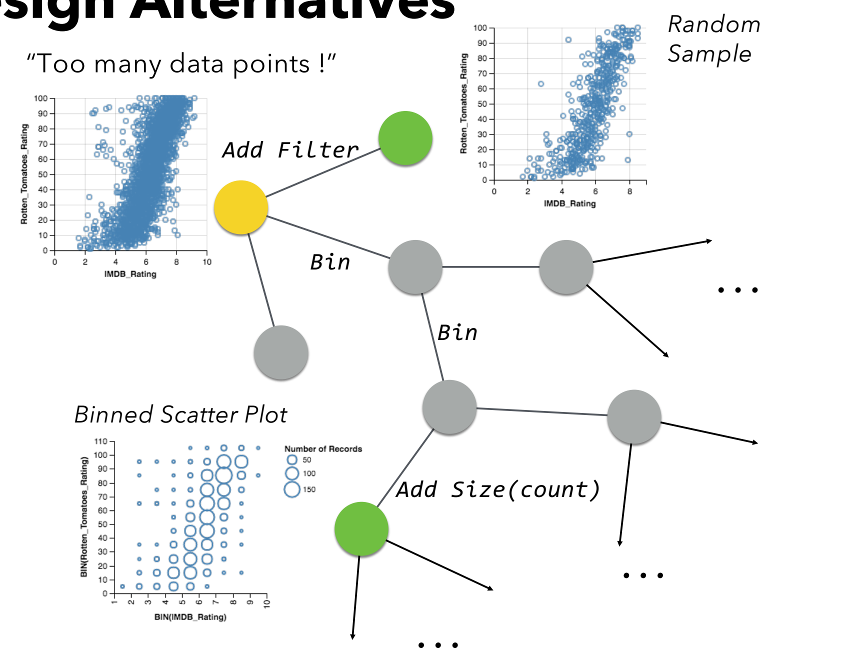
Design Alternatives



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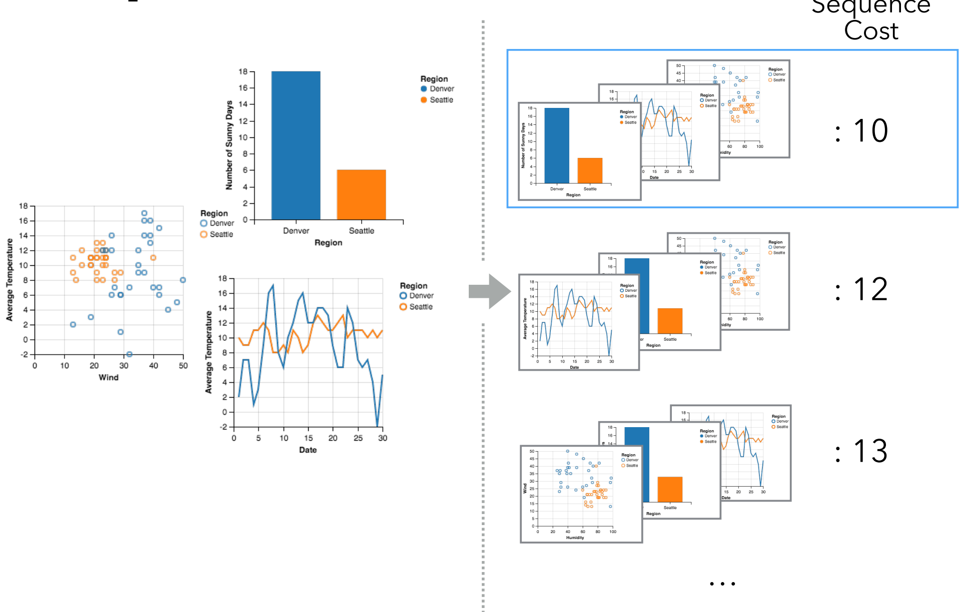
Sequence Recommendation



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GraphScape [Kim, Wongsuphasawat, Hullman, Heer 2017]

Previously we've discussed approaches for automatic design of a single visualization (e.g. Mackinlay's APT)

GraphScape supports automated design methods for collections of visualizations.

Plenty of future work to do here!

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Summary

Narrative visualizations blend communication via **imagery and text** with interaction techniques

Specific strategies can be identified by studying what expert designers make

Automating construction of effective explainers is an active area of Visualization research

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Announcements

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Assignment 3: Dynamic Queries

Create a **small** interactive dynamic query application similar to HomeFiner, but for restaurants data.

1. Implement interface
2. Submit the application and a short write-up on canvas

Can work alone or in pairs

Due before class on **Oct 25, 2021**

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Final project

Data analysis/explainer or conduct research

- **Data analysis**: Analyze dataset in depth & make a visual explainer
- **Research**: Pose problem, Implement creative solution

Deliverables

- **Data analysis/explainer**: Article with multiple different interactive visualizations
- **Research**: Implementation of solution and web-based demo if possible
- **Short video (2 min)** demoing and explaining the project

Schedule

- Project proposal: Wed 11/3
- Design Review and Feedback: 10th week of quarter
- Final code and video: Fri 12/10 11:59pm

Grading

- Groups of up to 3 people, graded individually
- Clearly report responsibilities of each member

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Color

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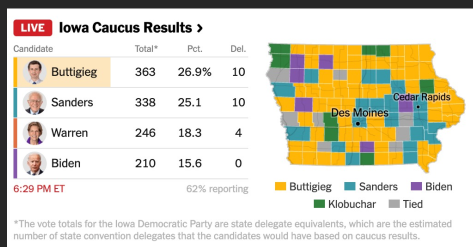

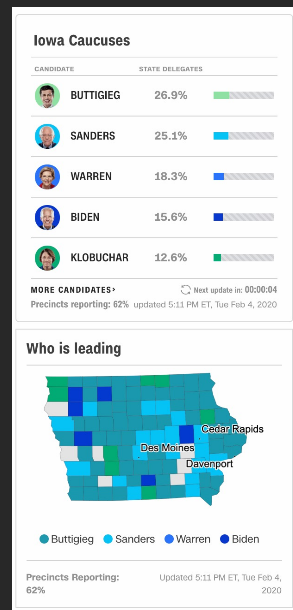

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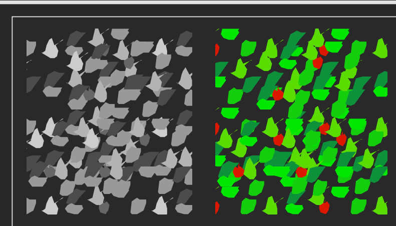
Purpose of Color

To label
To measure
To represent and imitate
To enliven and decorate



"Above all, do no harm."

- Edward Tufte

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Color Perception

Physical World, Visual System, Mental Models

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What color is this?

22

What color is this?

"Yellow"

23

What color is this?

24

What color is this?

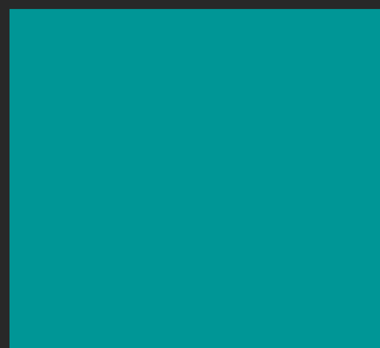
"Blue"

25

What color is this?

26

What color is this?



"Teal" ?

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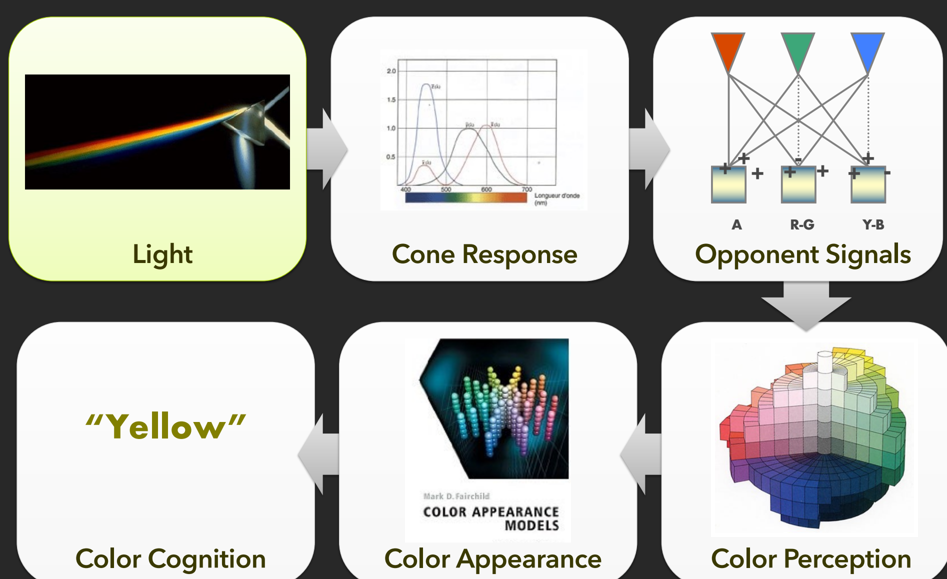
Perception of Color



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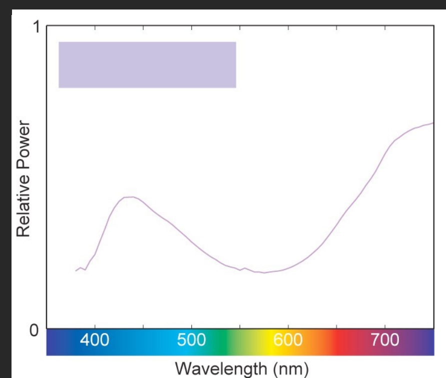
Physicist's view

- Light as electromagnetic wave
- Energy or "Relative power" across visible spectrum of wavelengths



A Field Guide to Digital Color, M. Stone

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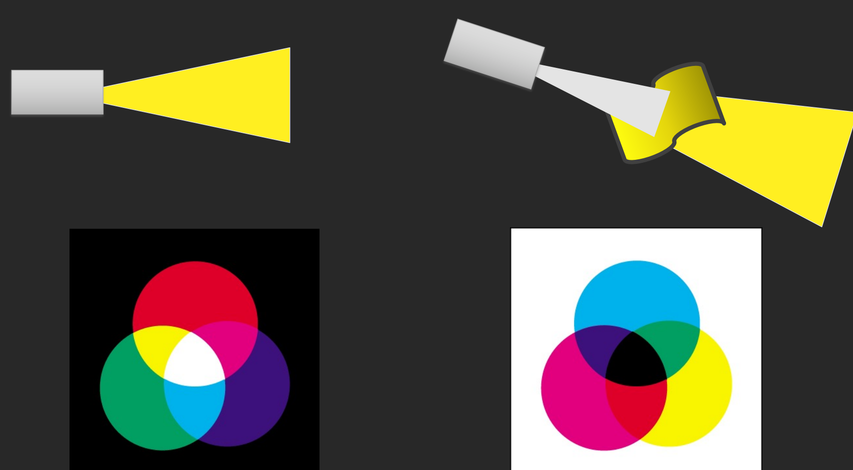
Emissive vs. reflective light



Additive
(digital displays)

Subtractive
(print, e-paper)

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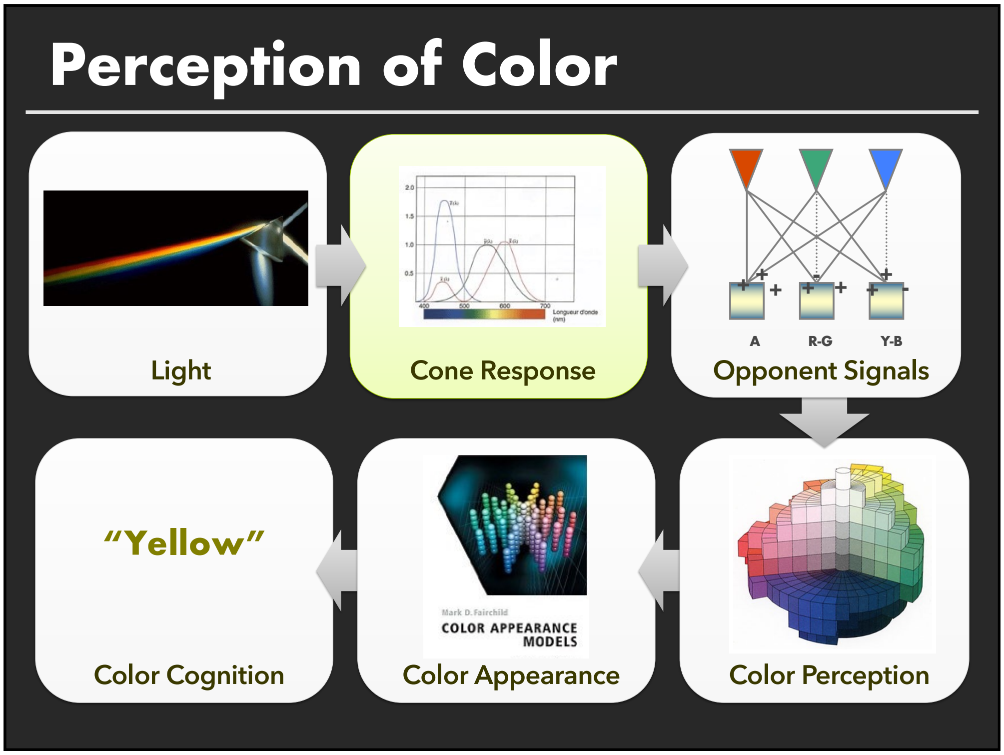
Perception of Color
Light
Cone Response
A
R-G
Y-B
Opponent Signals
"Yellow"
Color Cognition
Mark D. Fairchild
COLOR APPEARANCE MODELS
Color Appearance
Color Perception

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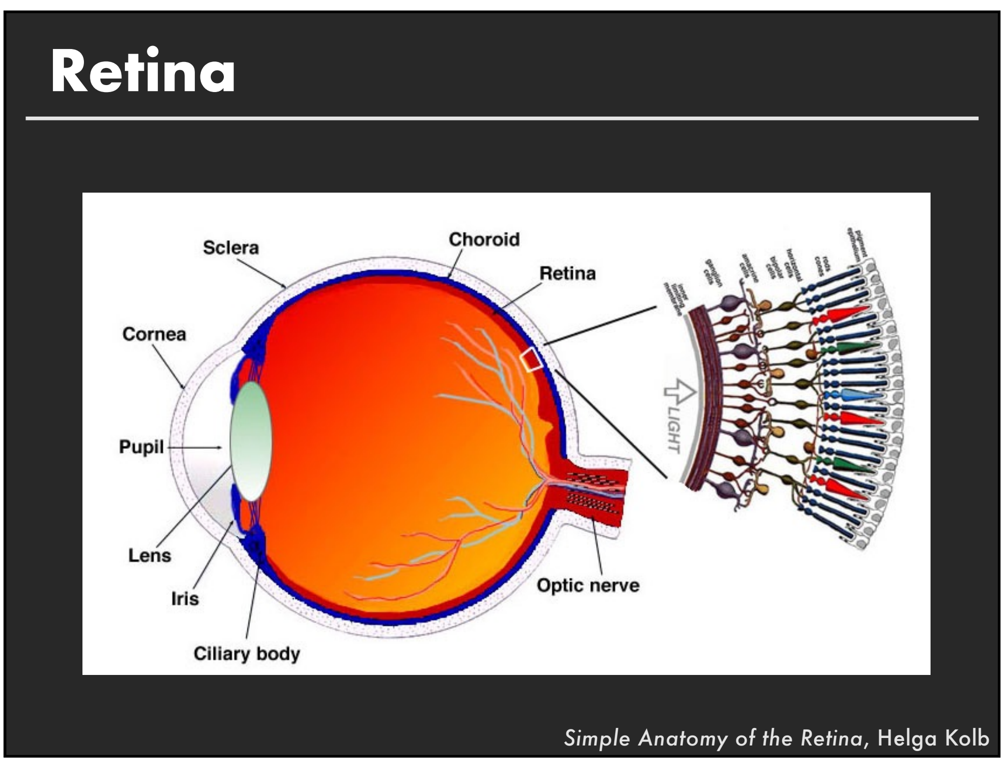
Retina
Sclera
Choroid
Retina
Cornea
Pupil
Lens
Iris
Ciliary body
Optic nerve
LIGHT
Simple Anatomy of the Retina, Helga Kolb

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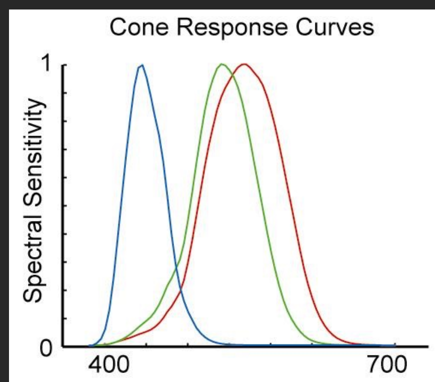
As light enters our retina…

LMS (Long, Middle, Short) Cones

- Sensitive to different wavelength



A Field Guide to Digital Color, Maureen Stone

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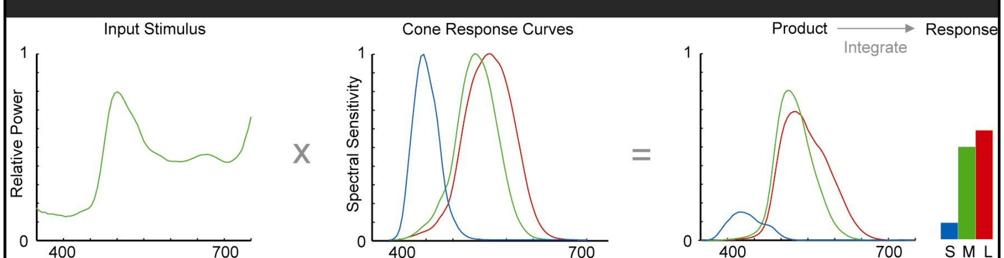
As light enters our retina…

LMS (Long, Middle, Short) Cones

- Sensitive to different wavelength
- Integration with input stimulus



$$L = \int \Phi(\lambda)L(\lambda)\mathrm{d}\lambda$$
$$M = \int \Phi(\lambda)M(\lambda)\mathrm{d}\lambda$$
$$S = \int \Phi(\lambda)S(\lambda)\mathrm{d}\lambda$$

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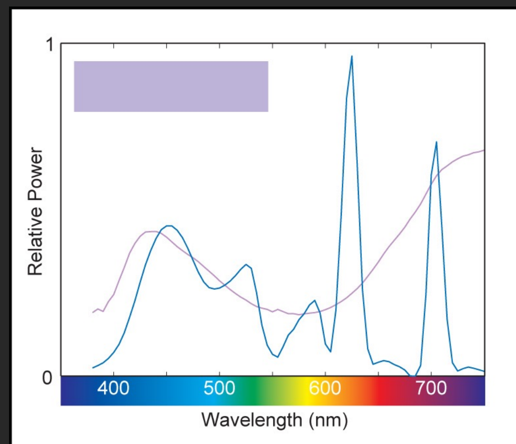
Effects of Retina Encoding

Spectra that stimulate the same LMS response are indistinguishable (a.k.a. "metamers")

Tri-stimulus response
- **Computer displays**
- **Digital scanners**
- **Digital cameras**



A Field Guide to Digital Color, M. Stone

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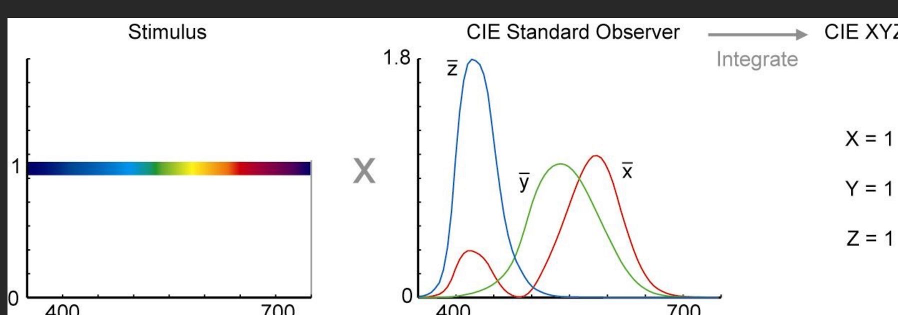
CIE XYZ Color Space

Standardized in 1931 to mathematically represent tri-stimulus response

"Standard observer" response curves



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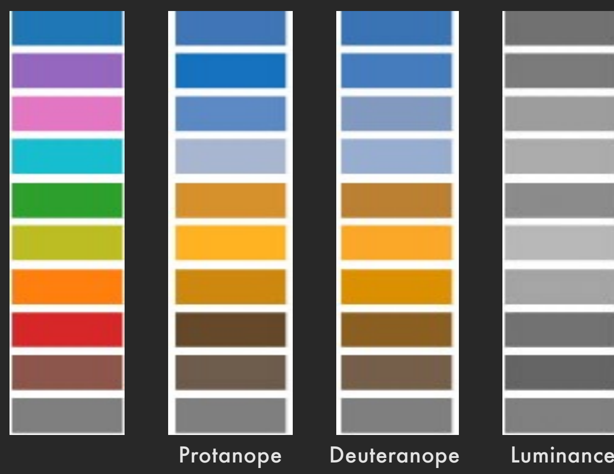
Color Blindness

Missing one or more retina cones or rods



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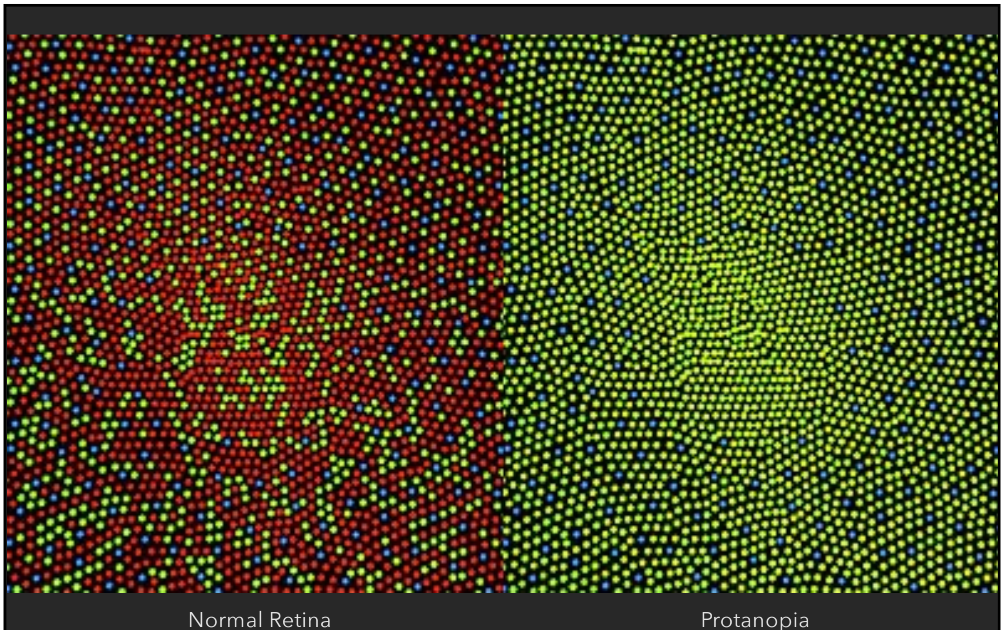

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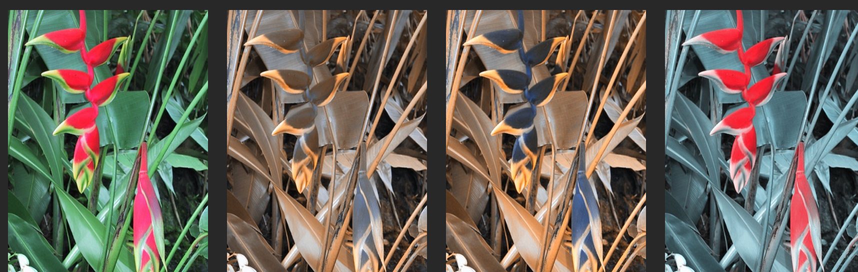
Color Blindness Simulators

Simulates color vision deficiencies
- Web service (NoCoffee, SEE, …)
- Photoshop plugins available



Deuteranope Protanope Tritanope

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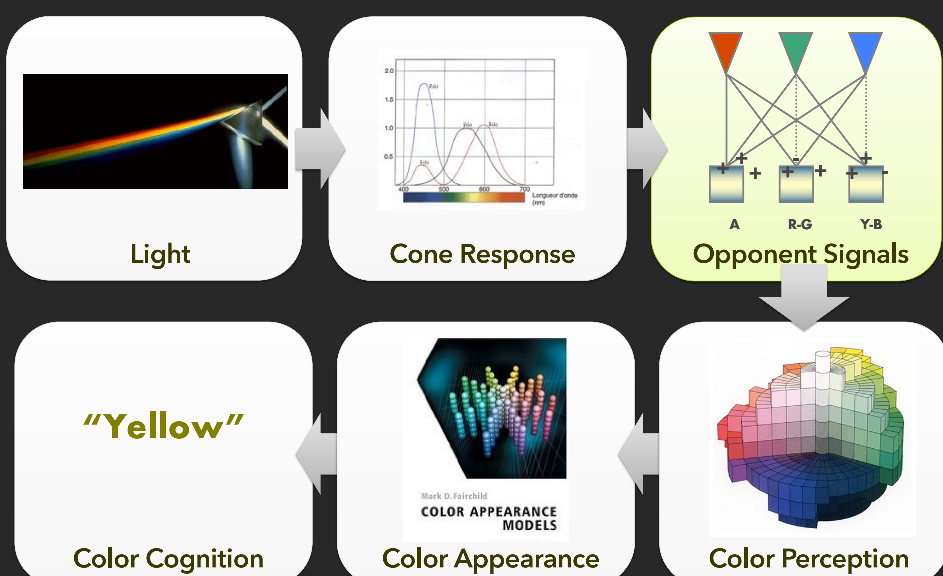
Perception of Color



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Primary Colors

To paint "all colors":

Leonardo da Vinci, circa 1500 described in his notebooks a list of simple colors...

Yellow
Blue
Green
Red

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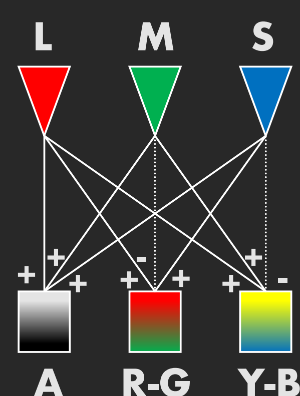
Opponent processing

LMS are linearly combined to create:

- Lightness
- Red-green contrast
- Yellow-blue contrast



Fairchild

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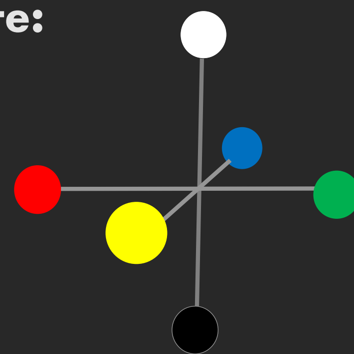
Opponent processing

LMS are combined to create:

- Lightness
- Red-green contrast
- Yellow-blue contrast



Experiments:

- No reddish green, no bluish yellow
- Color after images

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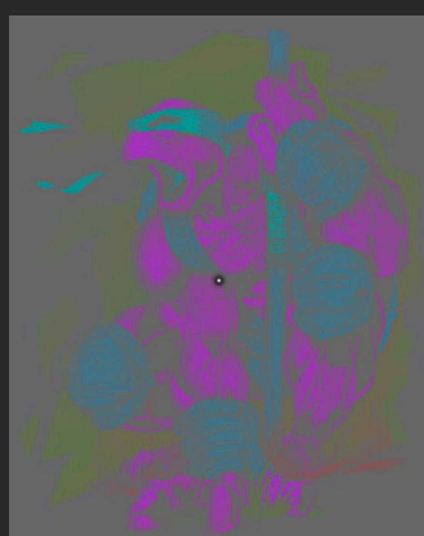

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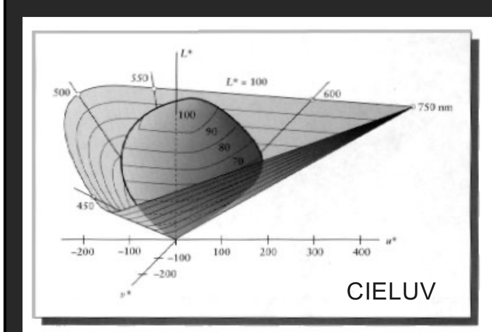
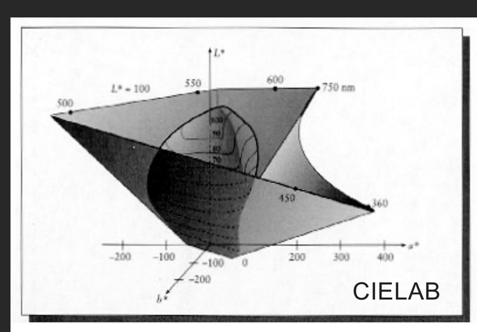
CIE LUV and LAB color spaces

Standardized in 1976 to mathematically represent opponent processing theory





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Axes of CIE LAB

Correspond to opponent signals
- L* = Luminance
- a* = Red-green contrast
- b* = Yellow-blue contrast

Scaling of axes to represent "color distance"
- JND = Just noticeable difference (~2.3 units)

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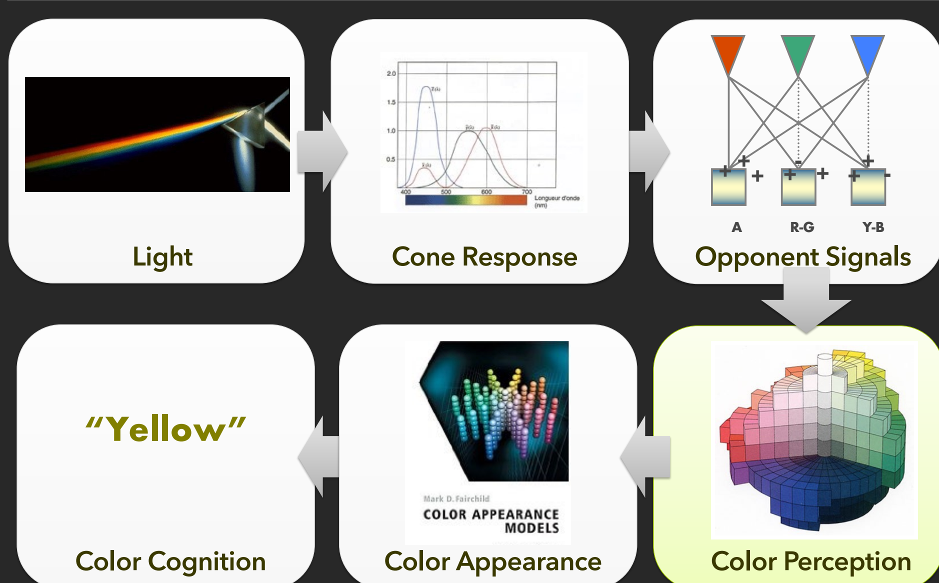
Perception of Color



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Munsell Atlas

Developed the first perceptual color system based on his experience as an artist (1905)

Courtesy Gretag-Macbeth

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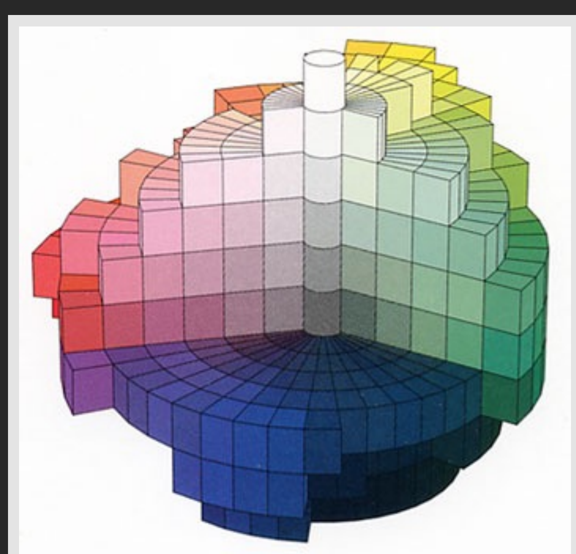
Hue, Value, Chroma



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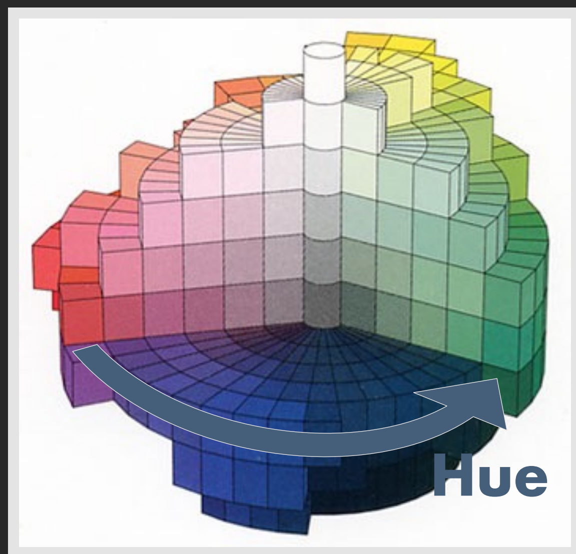
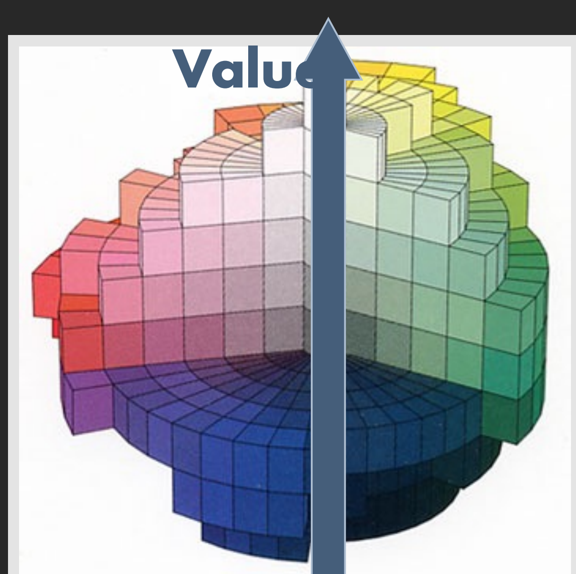
Hue, Value, Chroma



66

Hue, Value, Chroma



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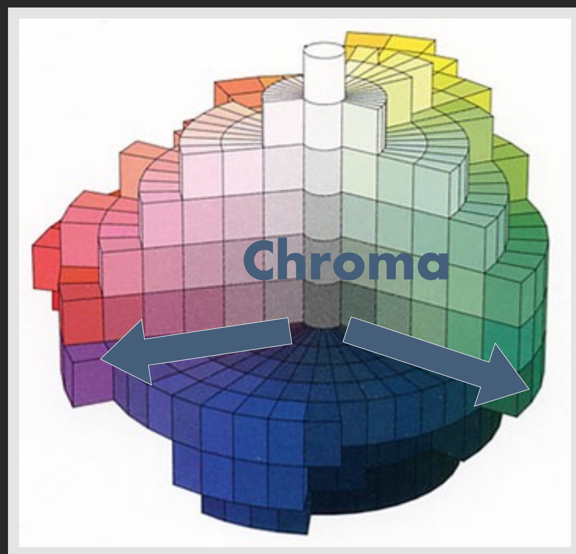
Hue, Value, Chroma



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Perceptual brightness

Color palette

Luminance Y

(CIE XYZ)

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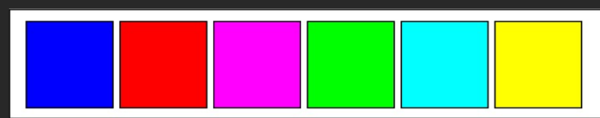
Perceptual brightness

Color palette



Munsell Value

L* (CIE LAB)

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Psuedo-Perceptual Models

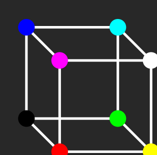
HLS, HSV, HSB

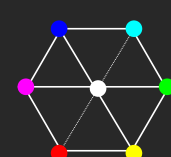
NOT perceptual models

Simple re-notation of RGB

- View along gray axis
- See a hue hexagon
- L or V is grayscale pixel value

Cannot predict perceived lightness





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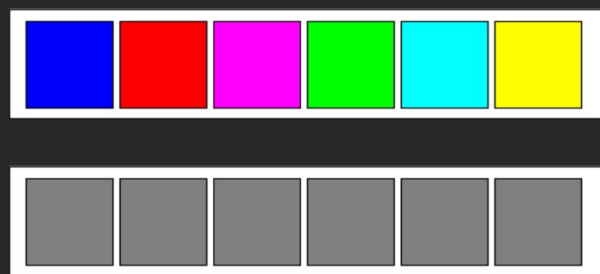
Perceptual brightness

Color palette

HSL Lightness *(Photoshop)*



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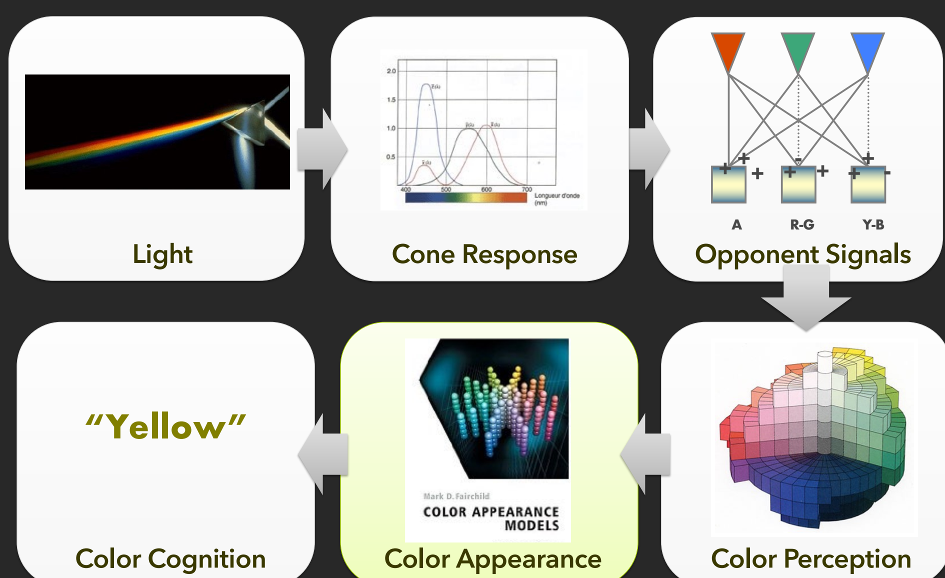
Perception of Color



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If we have a perceptually-uniform color space, can we predict how we perceive colors?

"In order to use color effectively it is necessary to recognize that it deceives continually."

- Josef Albers, *Interaction of Color*

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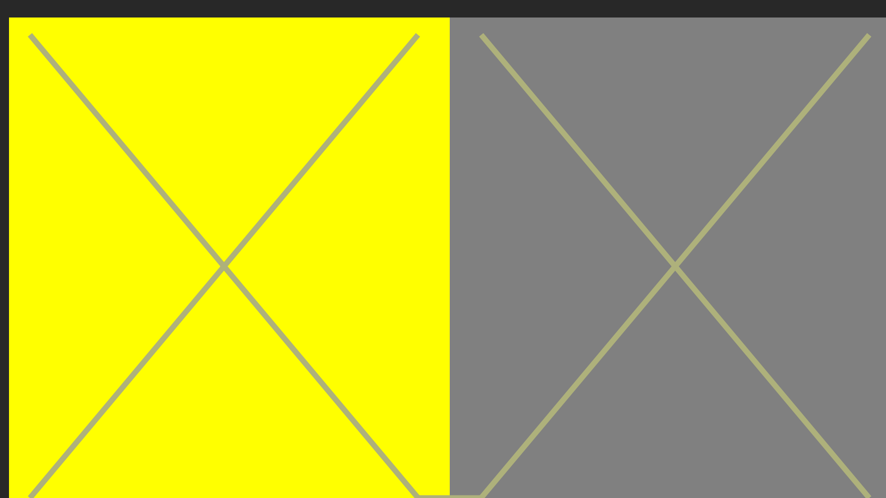
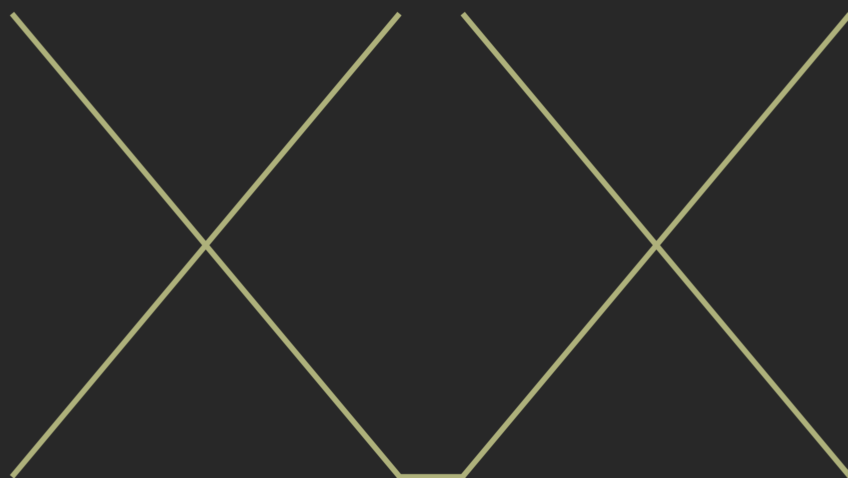
Simultaneous Contrast



Josef Albers

80

Simultaneous Contrast



Josef Albers

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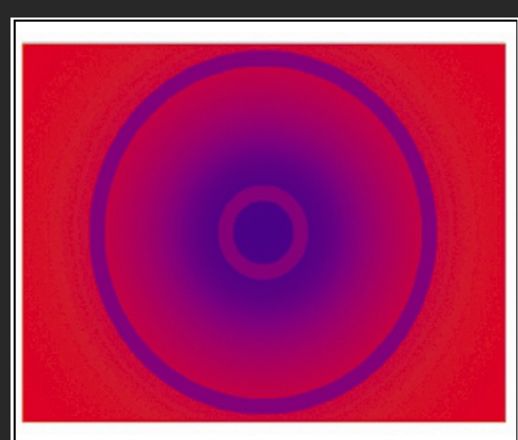
Simultaneous Contrast

Inner and outer thin rings are same purple



Donald MacLeod

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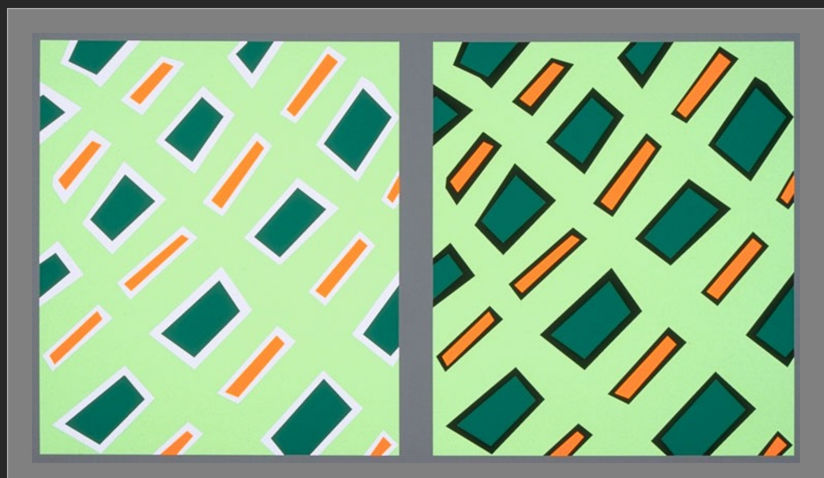
Bezold Effect

Color appearance depends on adjacent colors



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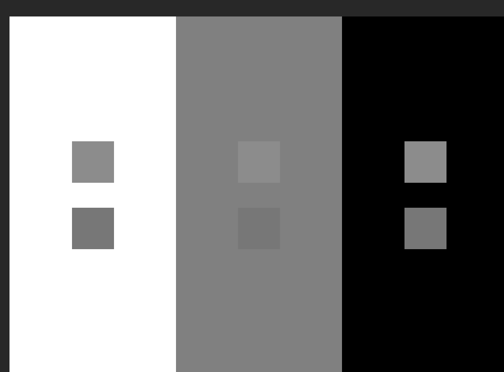
Crispening

Perceived difference depends on background



From Fairchild, *Color Appearance Models*

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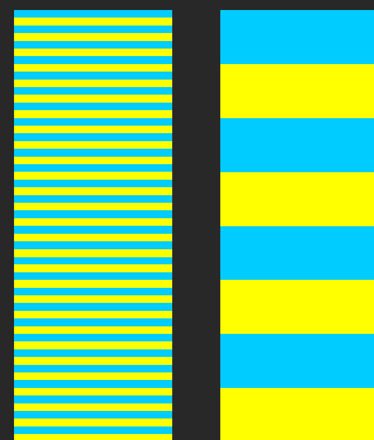
Spreading

Adjacent colors blend

Spatial frequency
- The paint chip problem
- Small text, lines, glyphs
- Image colors



Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University

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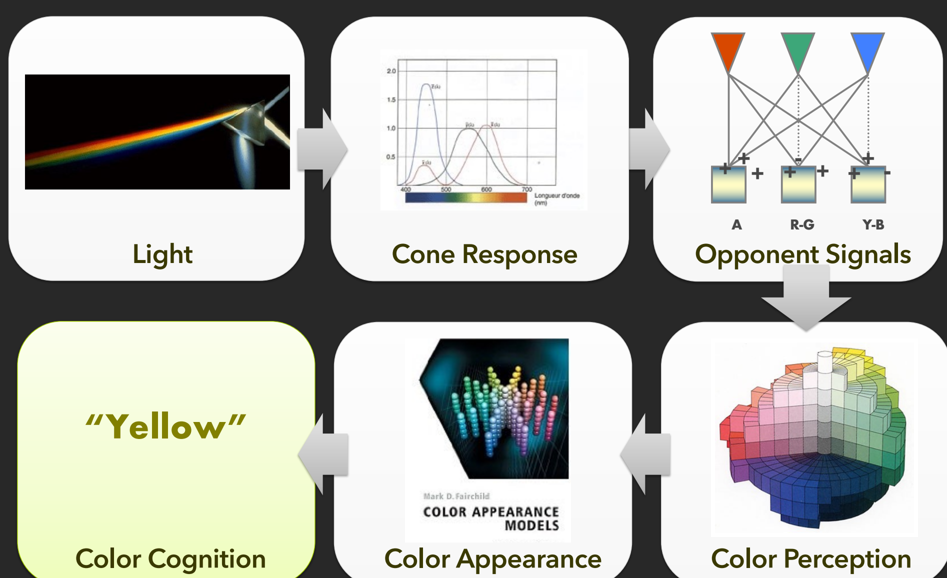
Perception of Color



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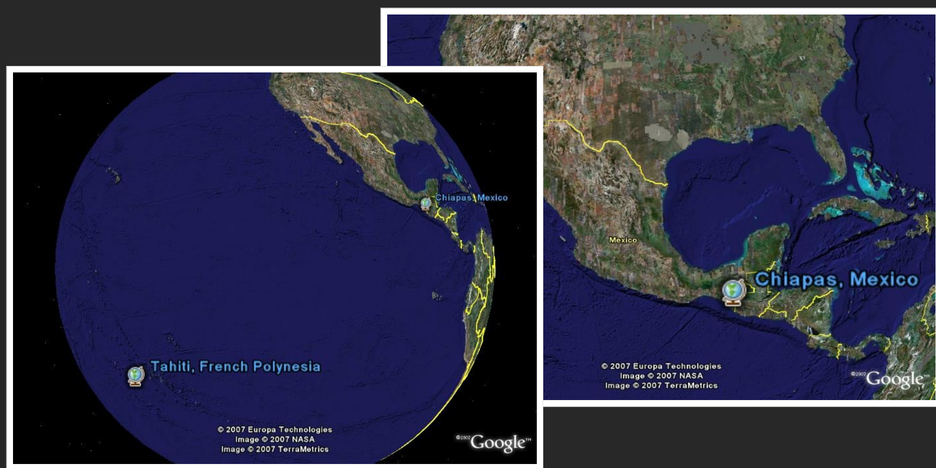
Basic color terms

Chance discovery by Brent Berlin and Paul Kay



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Basic Color Terms

Chance discovery by Brent Berlin and Paul Kay

Initial study in 1969
Surveyed speakers from 20 languages
Literature from 69 languages

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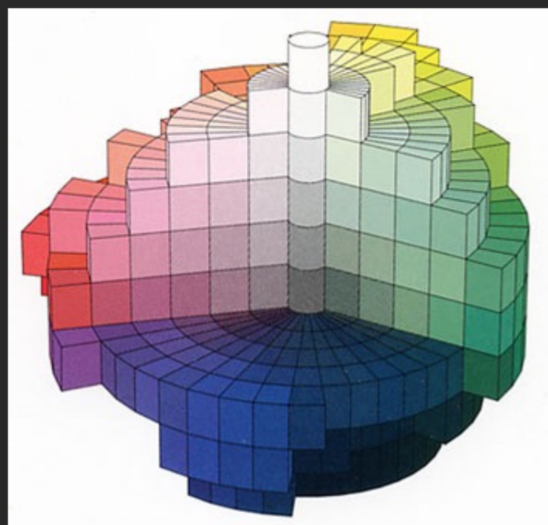
World color survey



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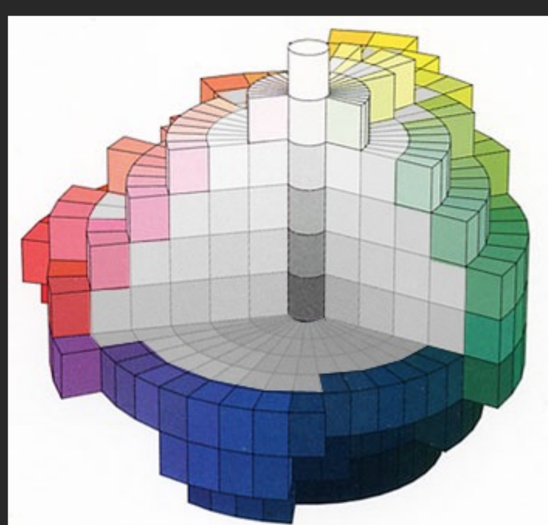
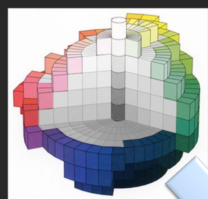
World color survey

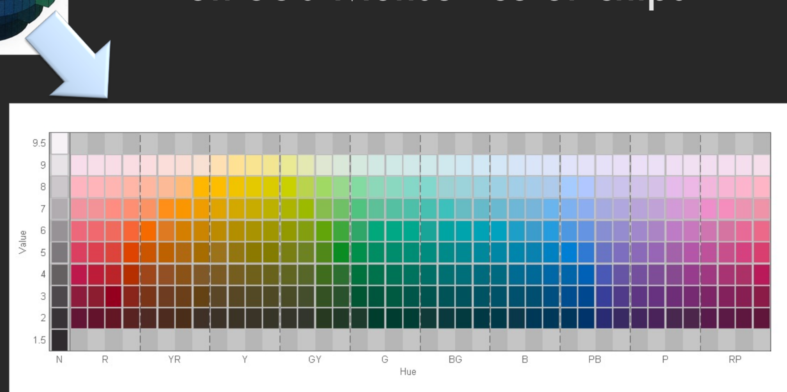


100

World color survey



Naming information from 2616 speakers from 110 languages on 330 Munsell color chips



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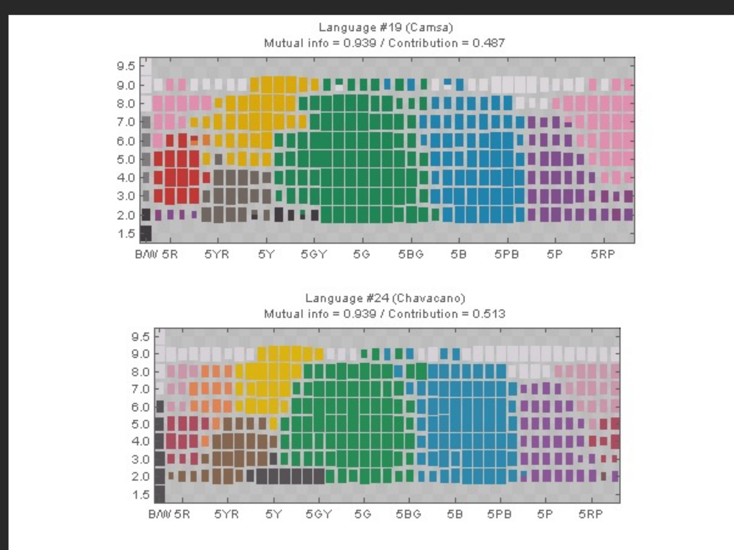
Results from WCS (South Pacific)



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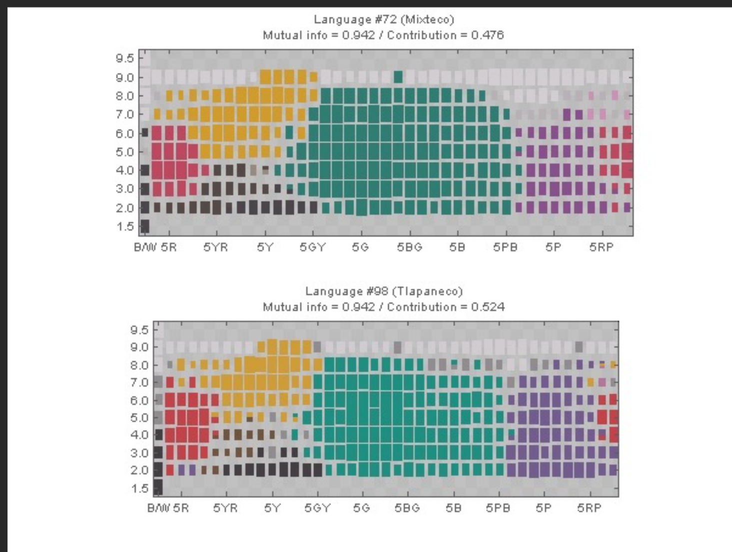
Results from WCS (Mexico)



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Universal (?) Basic Color Terms

Basic color terms recur across languages

White | Red | Pink
Grey | Yellow | Brown
Black | Green | Orange
Blue | Purple

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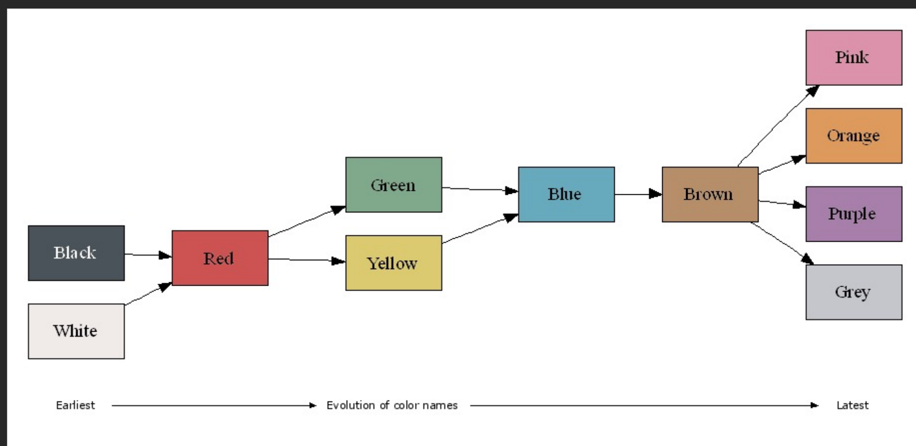
Evolution of Basic Color Terms

Proposed universal evolution across languages



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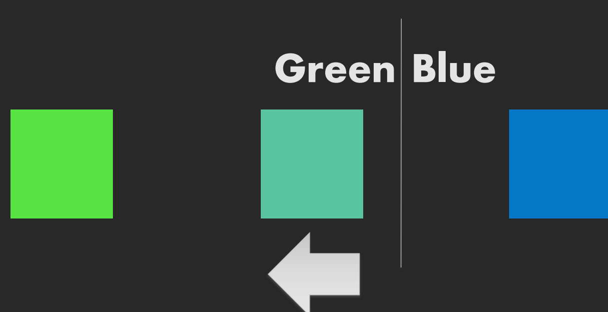
Naming affects color perception

Color name boundaries



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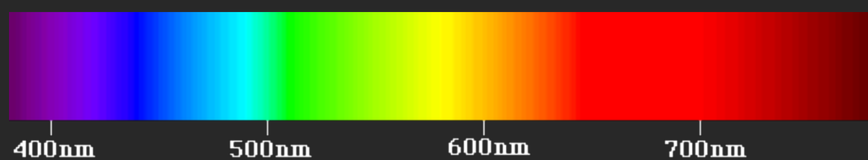
Rainbow color ramp

We associate and group colors together, often using the name we assign to the colors



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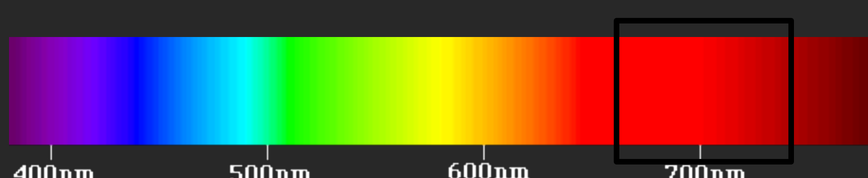
Rainbow color ramp

We associate and group colors together, often using the name we assign to the colors



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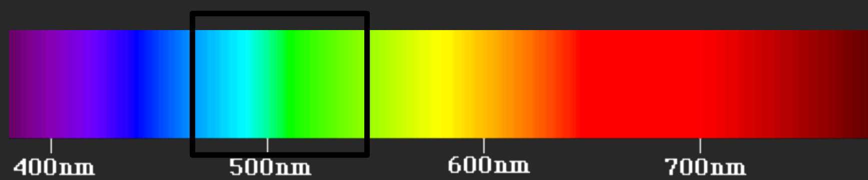
Rainbow color ramp

We associate and group colors together, often using the name we assign to the colors



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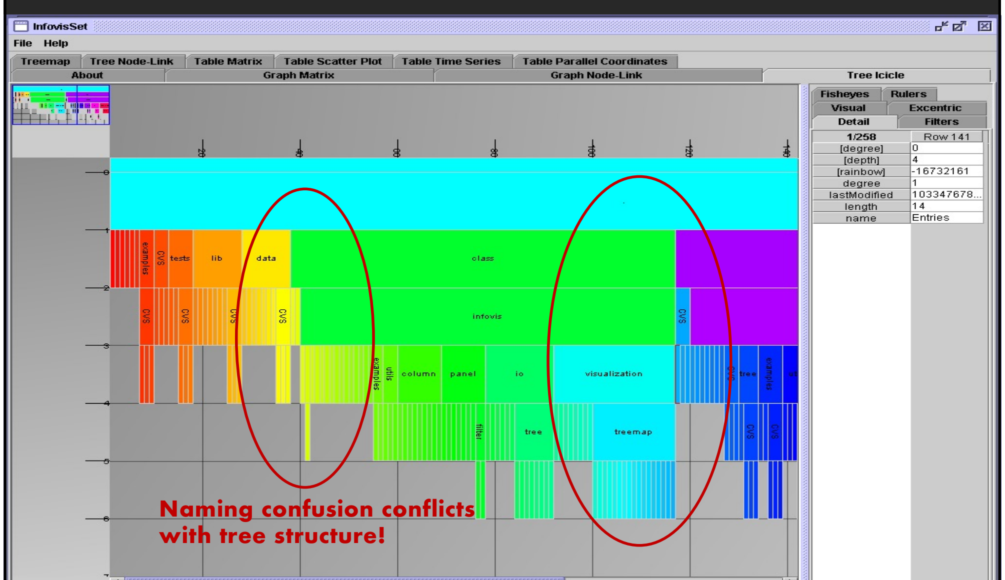
Icicle tree with rainbow colors



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Colors according to XKCD…

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Color naming models

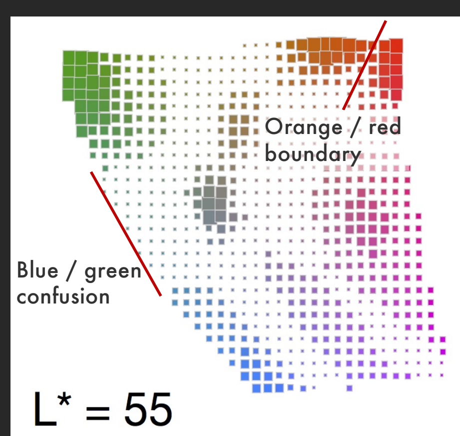
[Heer & Stone 2012]

Model 3 million responses from XKCD survey

Bins in LAB space sized by *saliency*:

How much do people agree on color name?

Modeled by entropy of *p(name | color)*



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Using Color in Visualization

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