COLOR

CS 448B | Fall 2023

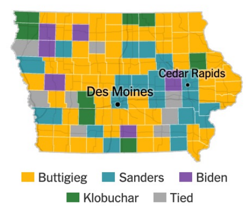
MANEESH AGRAWALA

1

LIVE **Iowa Caucus Results ›**

Candidate	Total*	Pct.	Del.
Buttigieg	363	26.9%	10
Sanders	338	25.1	10
Warren	246	18.3	4
Biden	210	15.6	0

6:29 PM ET 62% reporting



*The vote totals for the Iowa Democratic Party are state delegate equivalents, which are the estimated number of state convention delegates that the candidates would have based on caucus results.

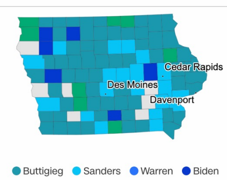
Iowa Caucuses

CANDIDATE	STATE DELEGATES
BUTTIGIEG	26.9%
SANDERS	25.1%
WARREN	18.3%
BIDEN	15.6%
KLOBUCHAR	12.6%

MORE CANDIDATES › Next update in: 00:00:04

Precincts reporting: 62% updated 5:11 PM ET, Tue Feb 4, 2020

Who is leading

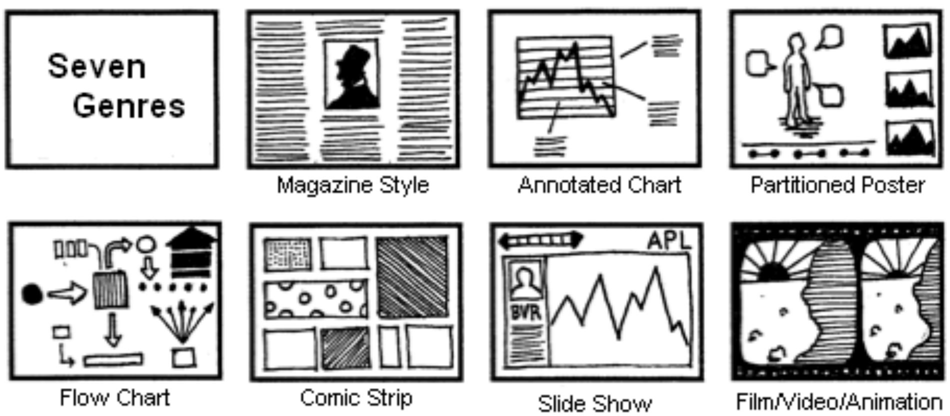


Precincts Reporting: 62% Updated 5:11 PM ET, Tue Feb 4, 2020

2

LAST TIME: VISUAL EXPLAINERS

4



Genres for Narrative Visualization [Segel & Heer 2010]

5

6

SECTIONS HOME SEARCH The New York Times Account

NEW YORK SHARE 104

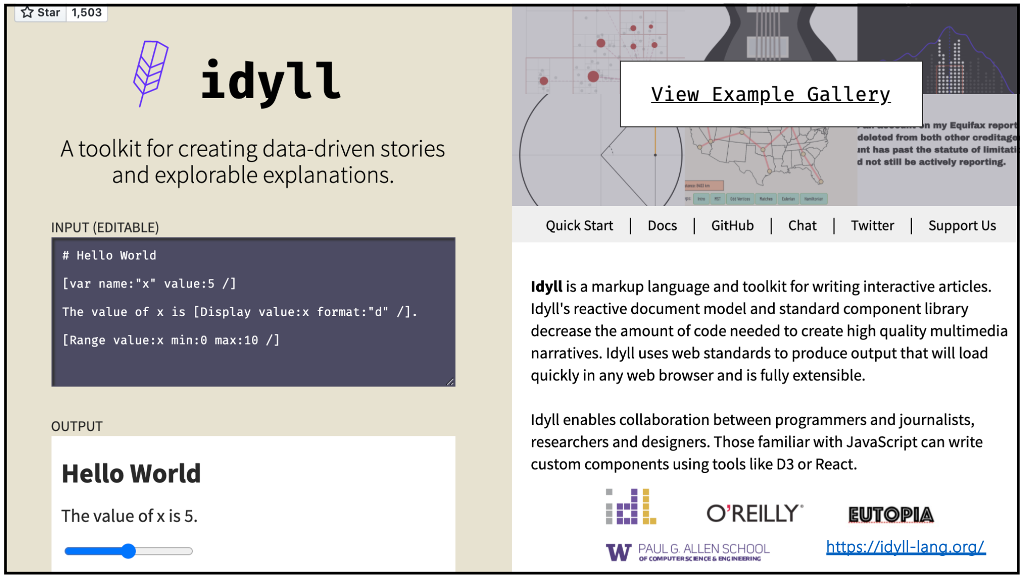
How 2 M.T.A. Decisions Pushed the Subway Into Crisis

By ADAM PEARCE MAY 9, 2018

Source: M.T.A. on-time performance data

By now, New York City commuters are familiar with the wait. We descend from the bitter cold or the stifling heat to find subway platforms teeming with other bodies trying to make it to work on time. Delays ripple through the system, so there's barely room to squeeze into the next train that

7



8

SUMMARY

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

Specific strategies can be identified by studying what expert designers make

Tools to facilitate construction of effective explainers is an active area of Visualization research

9

ANNOUNCEMENTS

10

FINAL PROJECT

Proposal due 11/6 11:30am

Data analysis/explainer

Analyze dataset in depth & make a visual explainer

Deliverables

An article with multiple different interactive visualizations
Short video (2 min) demoing and explaining the project

Schedule

Project proposal: Mon 11/6
Design Review and Feedback: 9th week of quarter
Final code and video: Sun 12/10 8pm

Grading

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

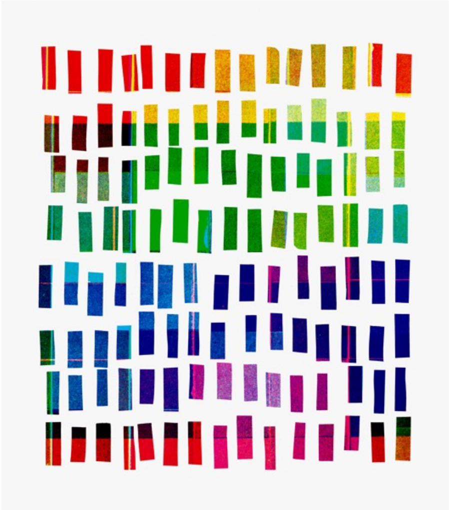
11

PURPOSE OF COLOR

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

"Above all, do no harm."

- Edward Tufte



12

TODAY

Learning Objectives

1. Understand how people perceive color

2. Apply understanding of color perception to visualization design

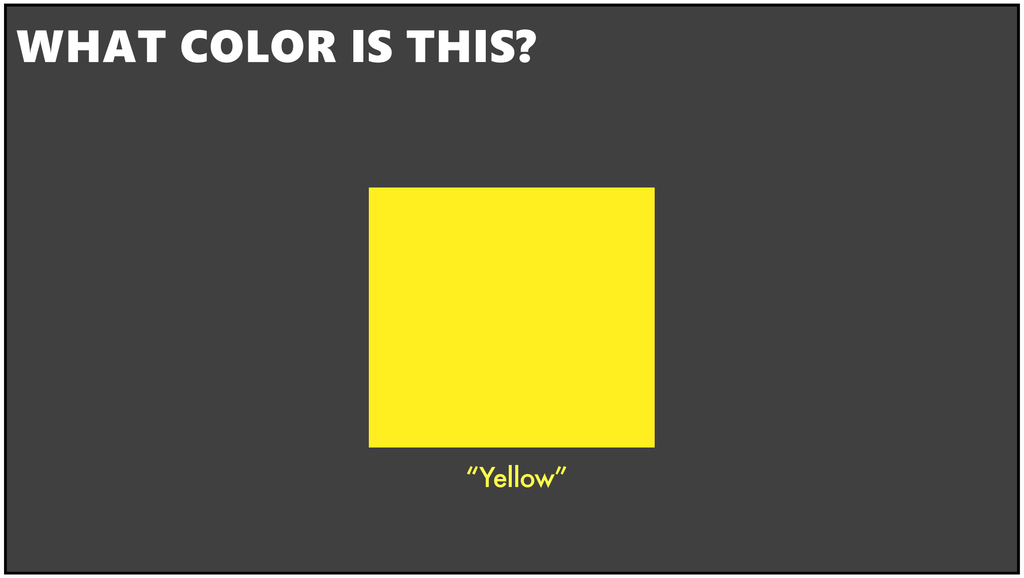
13

COLOR PERCEPTION

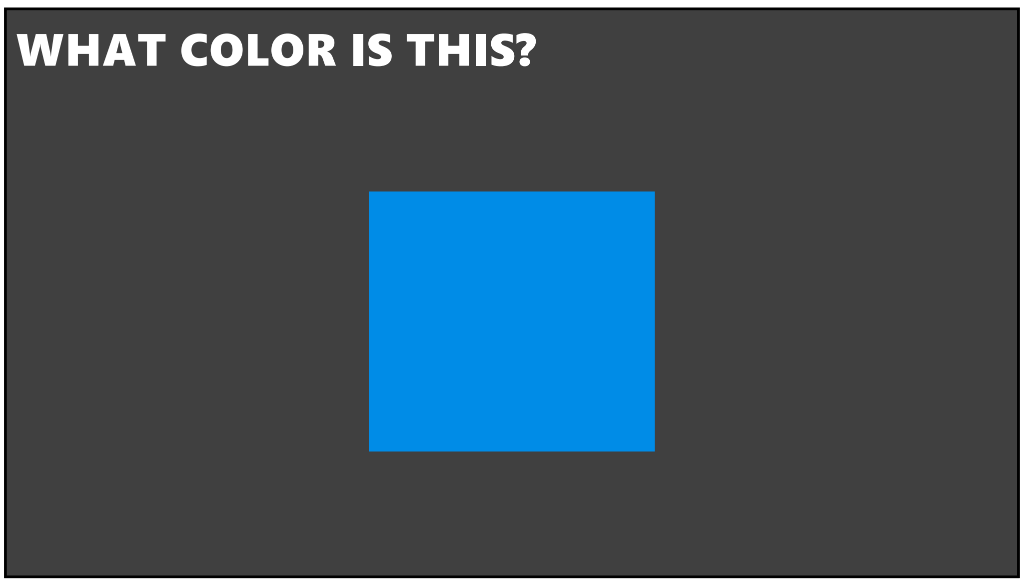
14

WHAT COLOR IS THIS?

15



16



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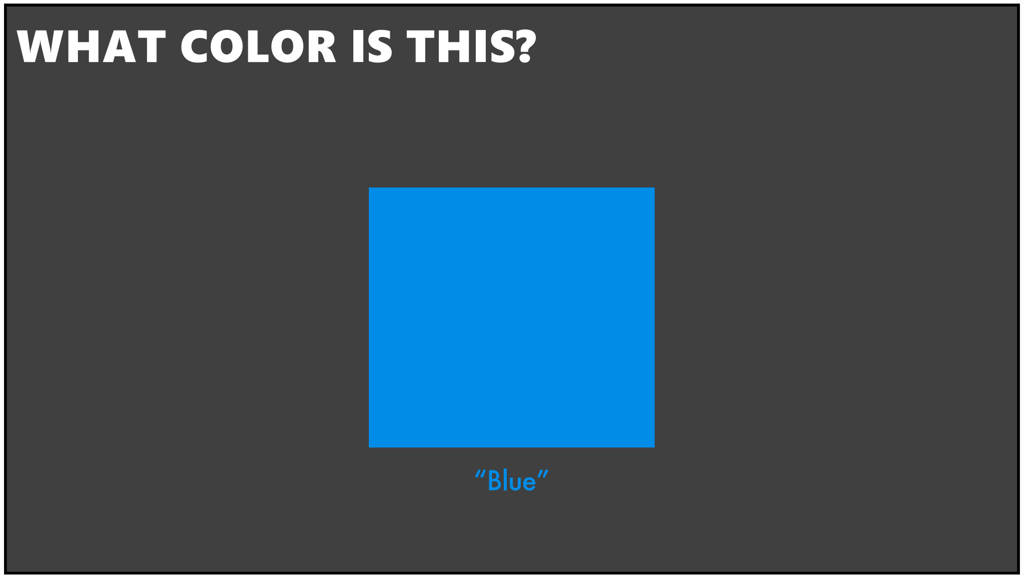
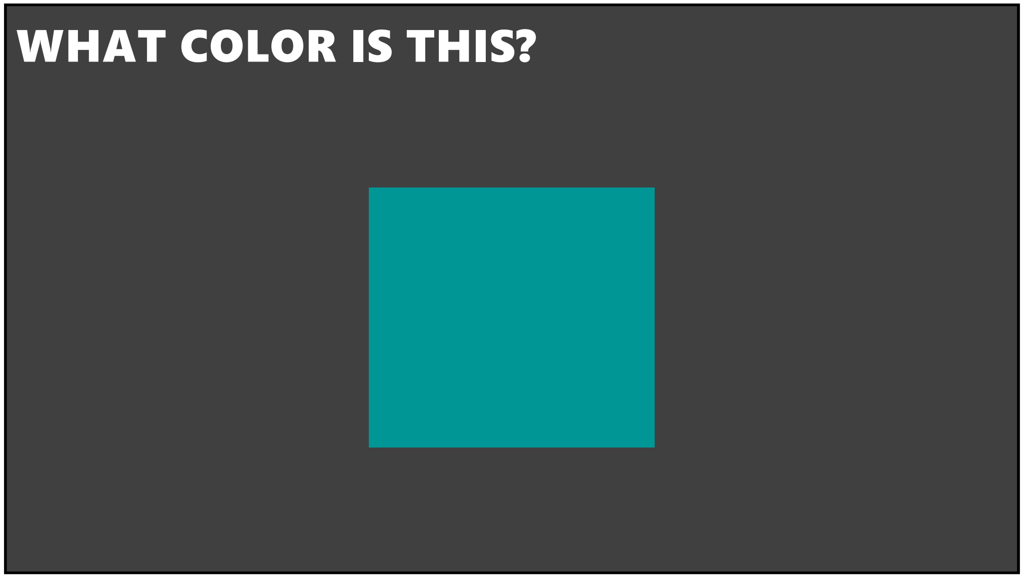
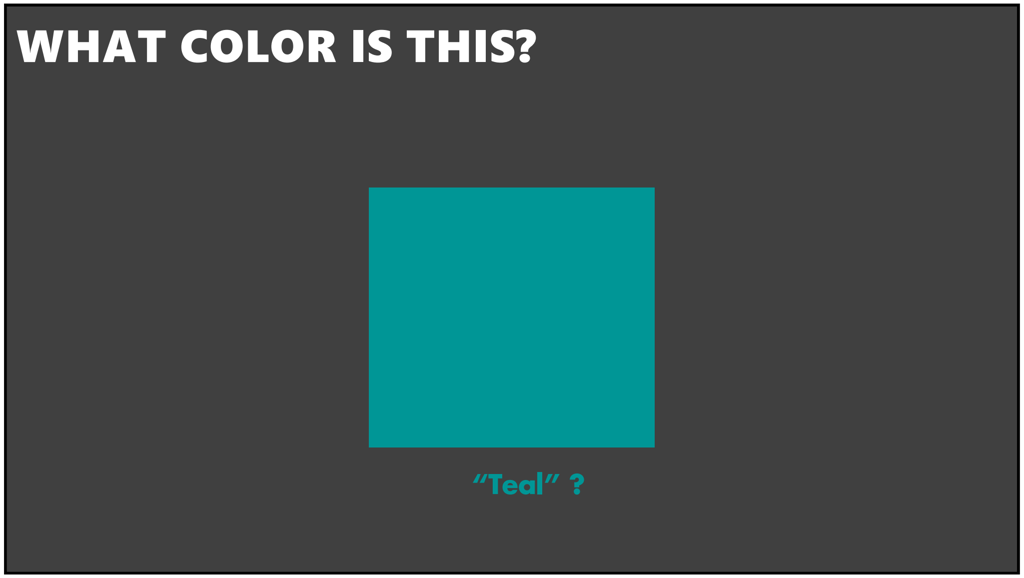


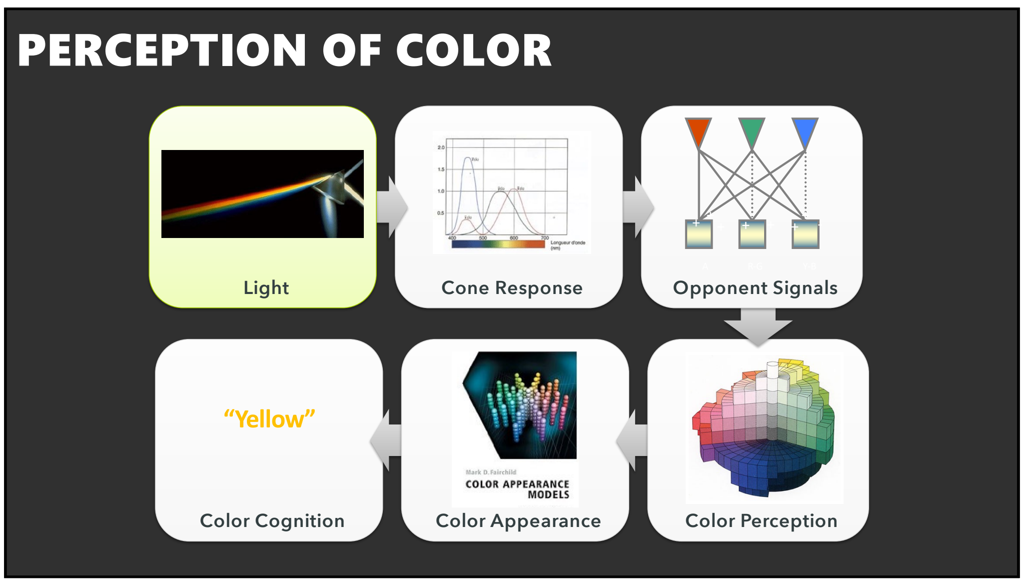
18



19


WHAT COLOR IS THIS?
“Teal” ?

20

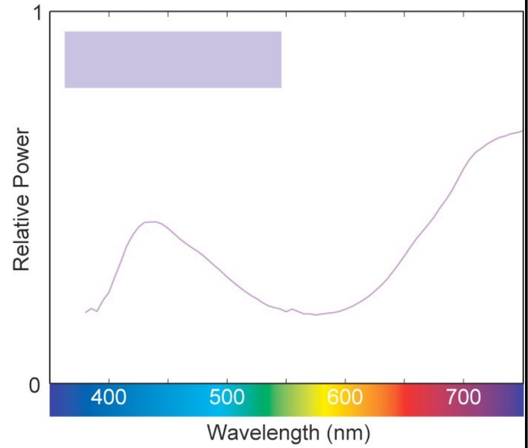

PERCEPTION OF COLOR
Light
Cone Response
Opponent Signals
“Yellow”
Color Cognition
Mark D. Fairchild
COLOR APPEARANCE MODELS
Color Appearance
Color Perception

21

PHYSICIST'S VIEW

Light as electromagnetic wave

Energy or "Relative power" across visible spectrum of wavelengths

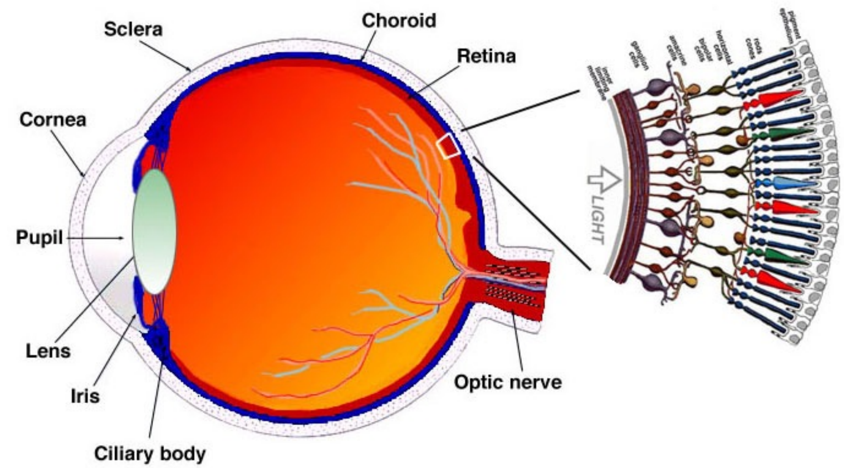


A Field Guide to Digital Color, Maureen Stone

23

PERCEPTION OF COLOR

30

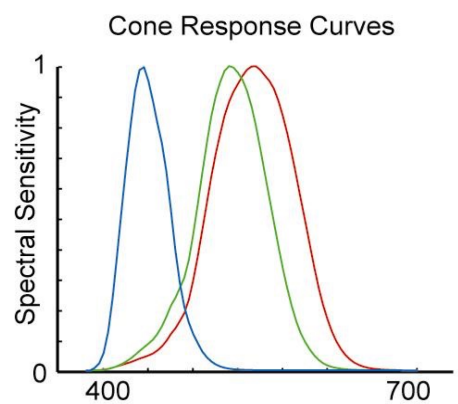


Simple Anatomy of the Retina, Helga Kolb

31

AS LIGHT ENTERS OUR RETINA

LMS (Long, Middle, Short) Cones
Sensitive to different wavelength

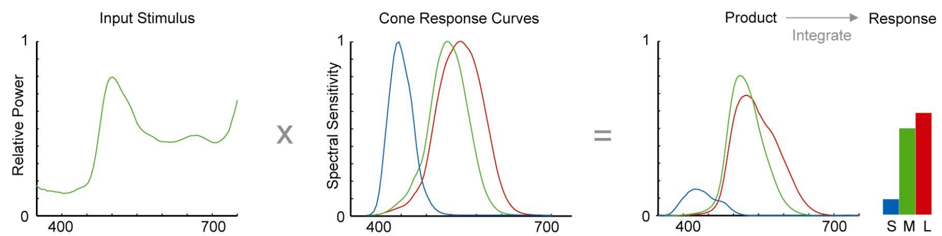


A Field Guide to Digital Color, Maureen Stone

34

CONE RESPONSE

LMS (Long, Middle, Short) Cones
- Sensitive to different wavelength
- Integration with input stimulus



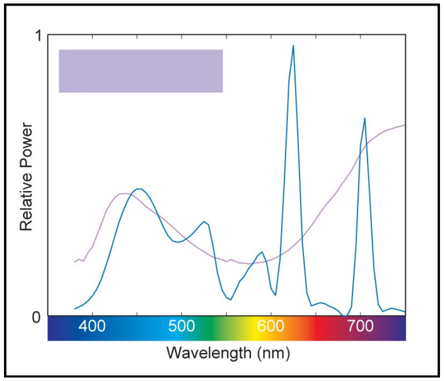
$$L = \int \Phi(\lambda)L(\lambda)\mathrm{d}\lambda$$
$$M = \int \Phi(\lambda)M(\lambda)\mathrm{d}\lambda$$
$$S = \int \Phi(\lambda)S(\lambda)\mathrm{d}\lambda$$

35

EFFECTS OF RETINAL ENCODING

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

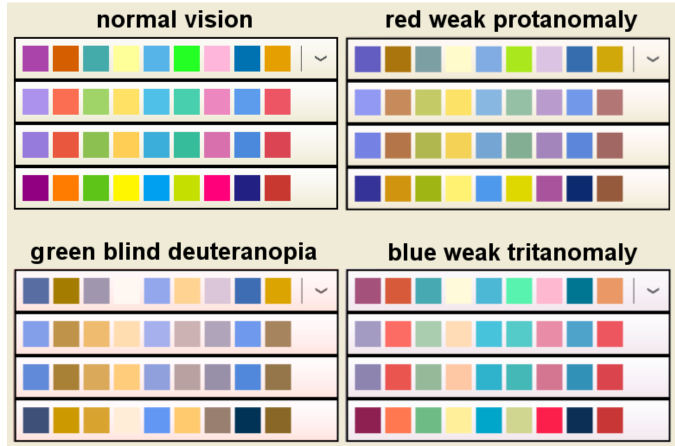
Tri-stimulus response
- Computer displays
- Digital scanners
- Digital cameras



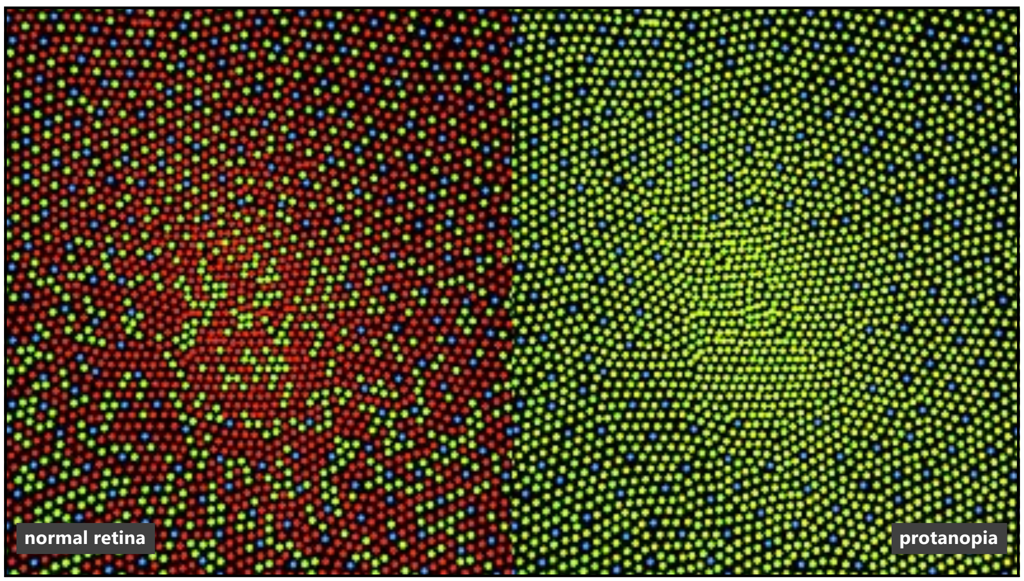
38

COLOR VISION DEFICIENCY

Missing cones



42

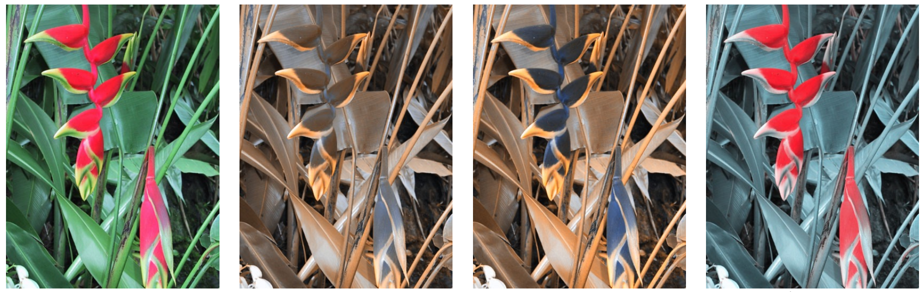


43

COLOR VISION SIMULATORS

Simulates color vision deficiencies

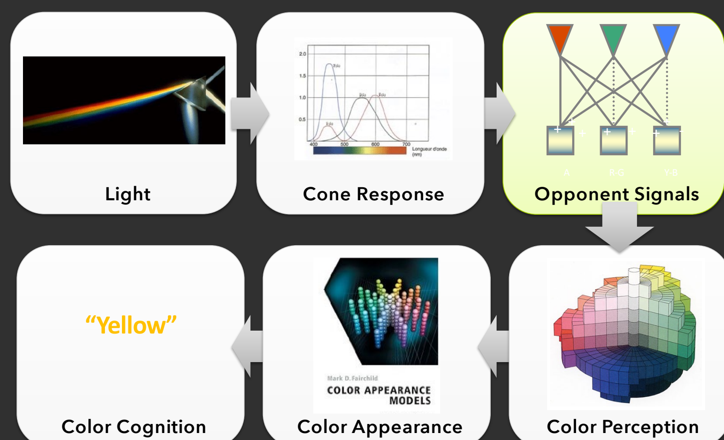
- Browser plugins
- Photoshop plugins, etc.



Deuteranope Protanope Tritanope

44

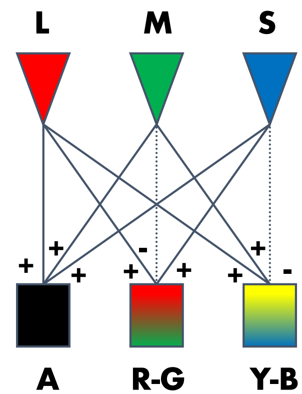
PERCEPTION OF COLOR



45

OPPONENT PROCESSING

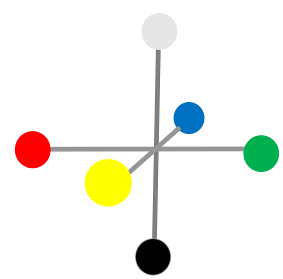
LMS responses linearly combined to form:
- Lightness
- Red-green contrast
- Yellow-blue contrast



47

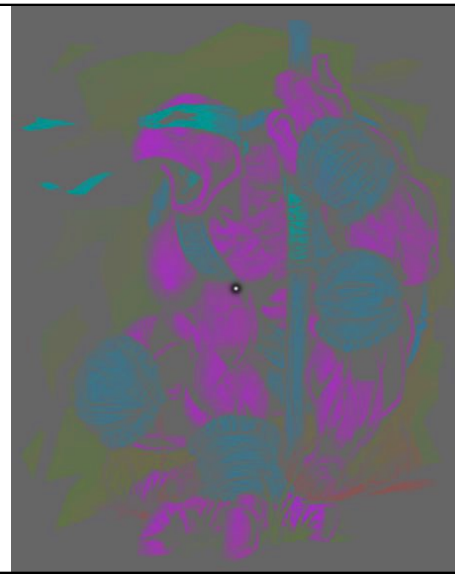
OPPONENT PROCESSING

LMS responses linearly combined to form:
- Lightness
- Red-green contrast
- Yellow-blue contrast



Expriments:
- No reddish green color seen
- No bluish-yellow color seen
- Color after images

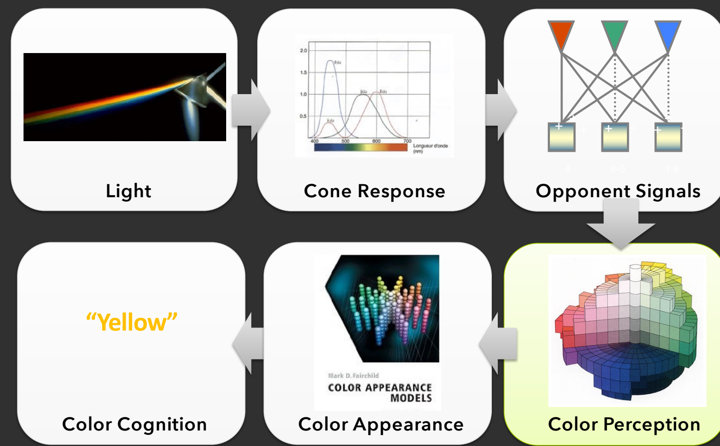
49



51

52

PERCEPTION OF COLOR



56

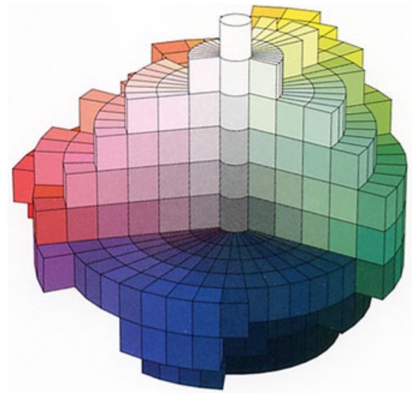
MUNSELL ATLAS

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

Courtesy Gretag-Macbeth

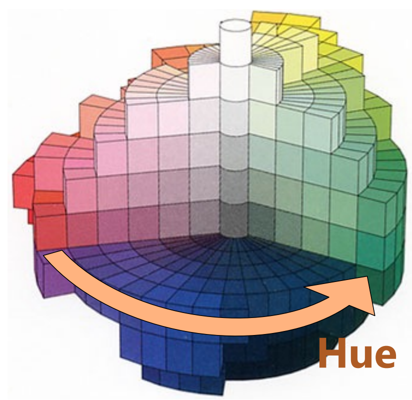
57

HUE, VALUE, CHROMA



58

HUE, VALUE, CHROMA



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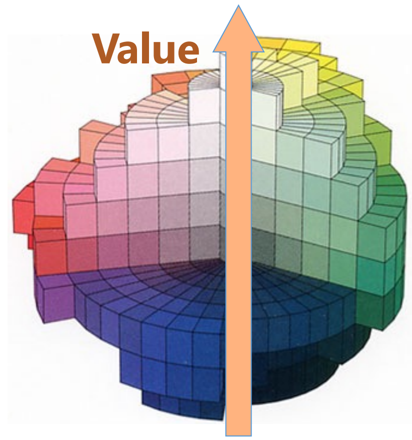
HUE, VALUE, CHROMA



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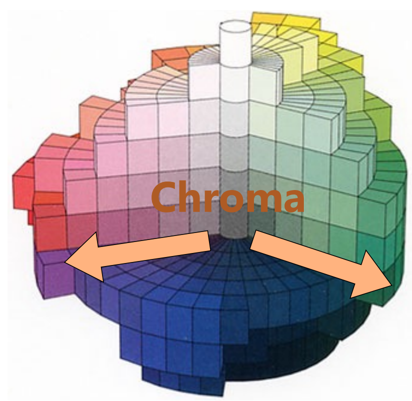
HUE, VALUE, CHROMA



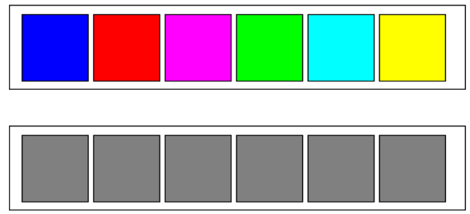
61

PERCEPTUAL BRIGHTNESS

Color palette

HSL Lightness

(Photoshop)



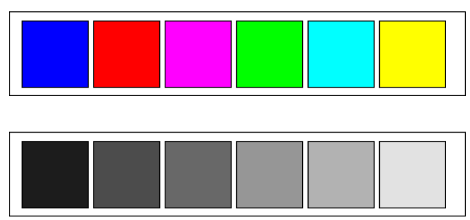
63

PERCEPTUAL BRIGHTNESS

Color palette

Luminance Y

(CIE XYZ)



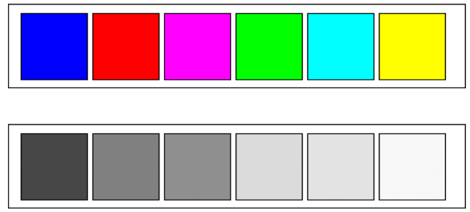
64

PERCEPTUAL BRIGHTNESS

Color palette

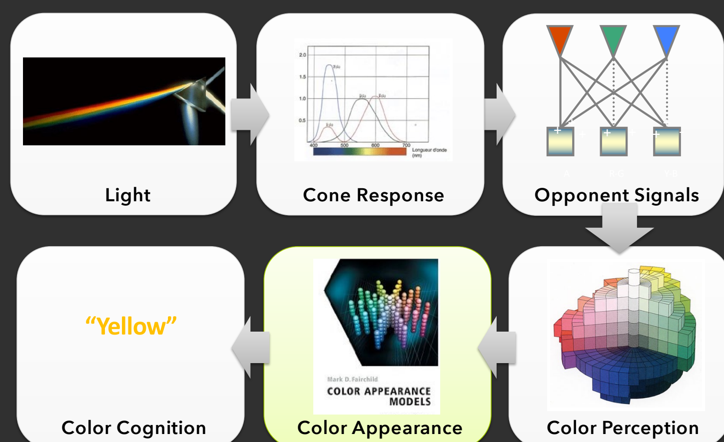
Munsell Value

L* (CIE LAB)



65

PERCEPTION OF COLOR



71

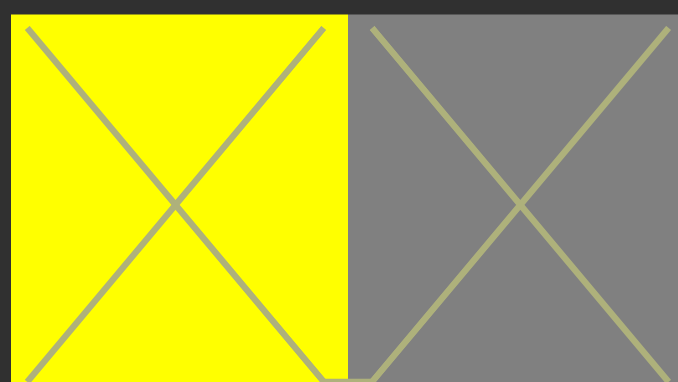
If we have a perceptually-uniform color space, can we predict how we perceive colors?

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

- Josef Albers, *Interaction of Color*

72

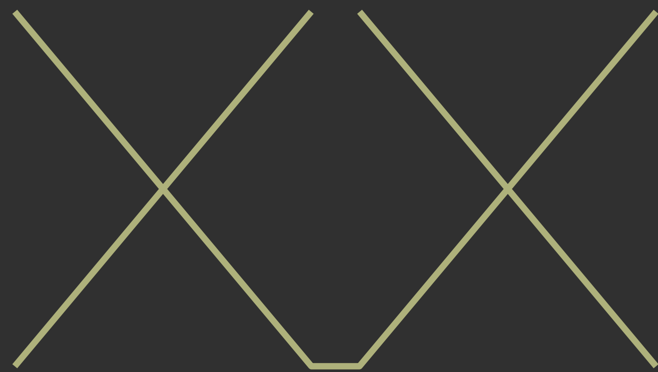
SIMULTANEOUS CONTRAST



Josef Albers

73

SIMULTANEOUS CONTRAST

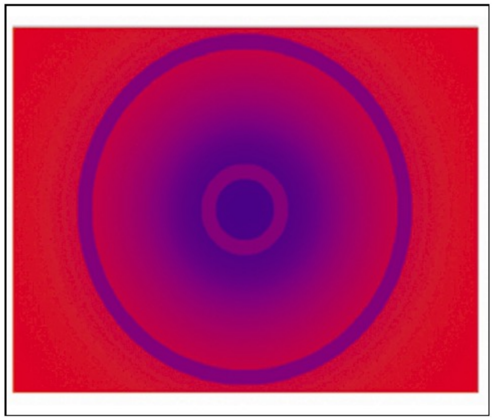


Josef Albers

74

SIMULTANEOUS CONTRAST

Inner and outer thin rings are same purple

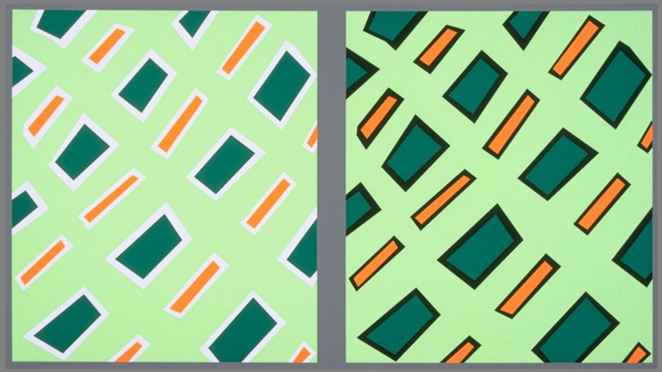


Donald MacLeod

75

BEZOLD EFFECT

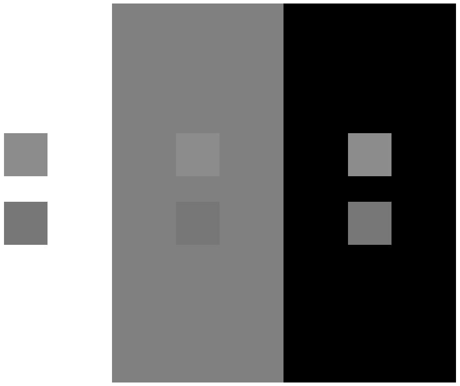
Color appearance depends on adjacent colors



85

CRISPENING

Perceived difference depends on background



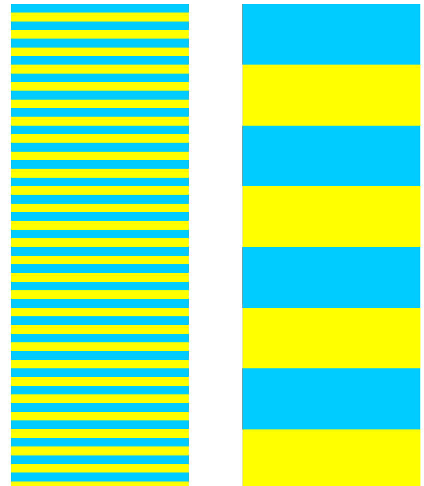
From Fairchild, *Color Appearance Models*

86

SPREADING

Adjacent colors blend

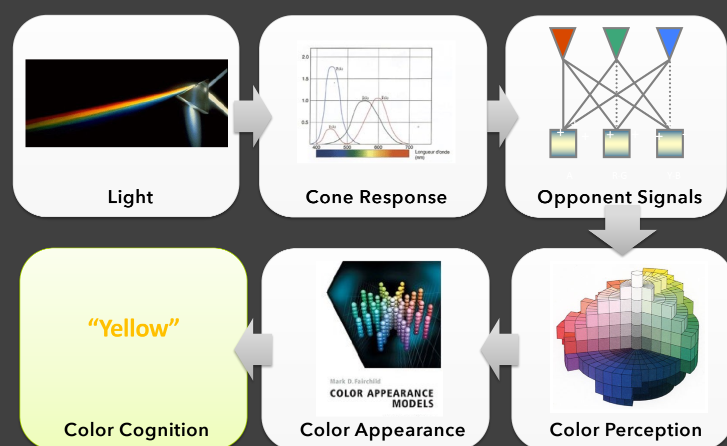
Spatial frequency
- The paint chip problem
- Small text, lines, glyphs
- Image colors



Redrawn from *Foundations of Vision,* Brian Wandell

87

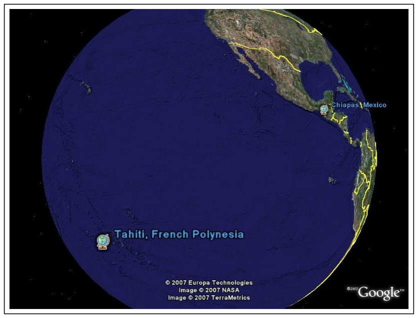
PERCEPTION OF COLOR



88

BASIC COLOR TERMS

Chance discovery by Brent Berlin and Paul Kay



90

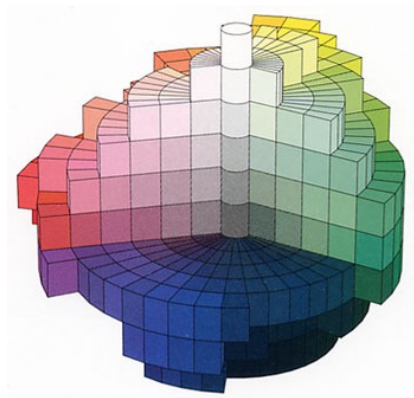
BASIC COLOR TERMS

Chance discovery by Brent Berlin and Paul Kay

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

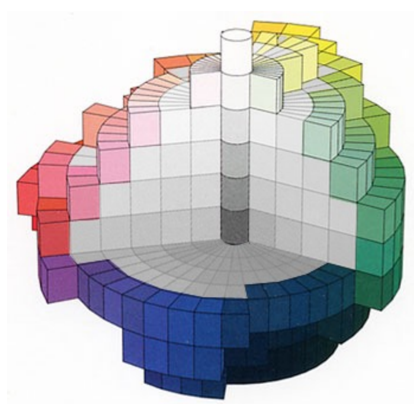
91

WORLD COLOR SURVEY



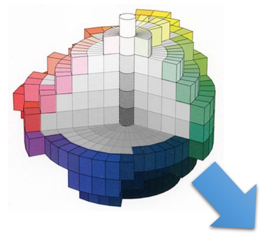
92

WORLD COLOR SURVEY

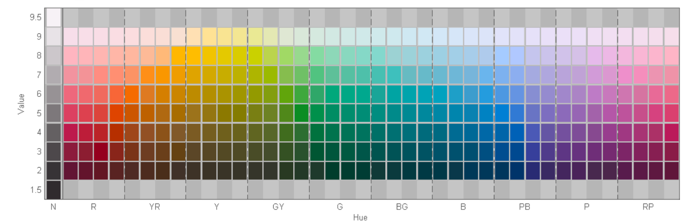


93

WORLD COLOR SURVEY

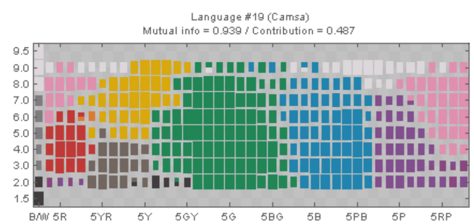


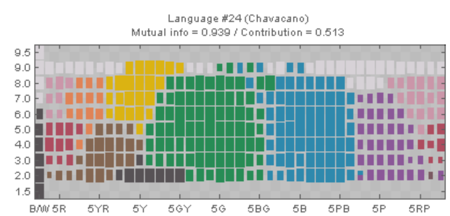
Naming information from 2616 speakers from 110 languages on 330 Munsell color chips



94

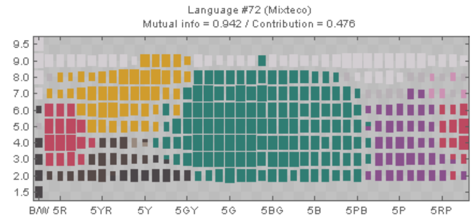
RESULTS FROM WCS (SOUTH PACIFIC)

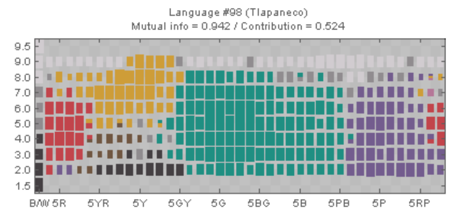




95

RESULTS FROM WCS (MEXICO)





96

UNIVERSAL (?) BASIC COLOR TERMS

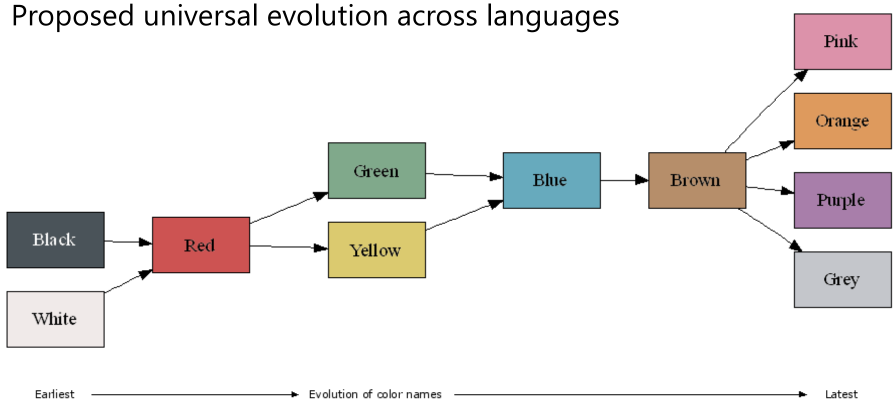
Basic color terms recur across languages

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

97

EVOLUTION OF BASIC COLOR TERMS

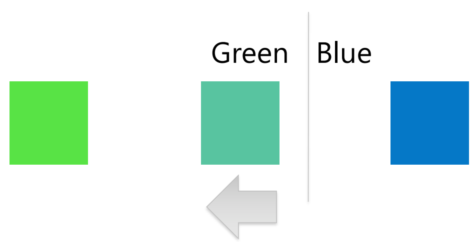
Proposed universal evolution across languages



98

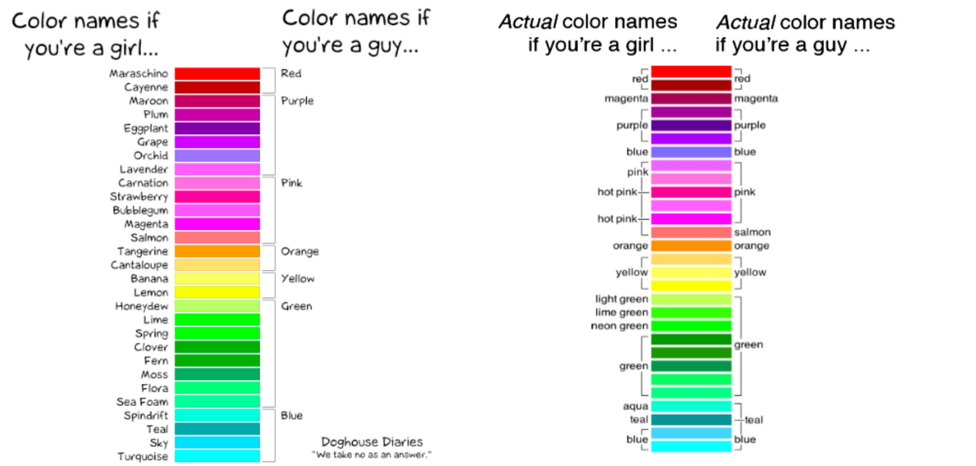
NAMING AFFECTS COLOR PERCEPTION

Color name boundaries



99

COLORS ACCORDING TO XKCD



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

104

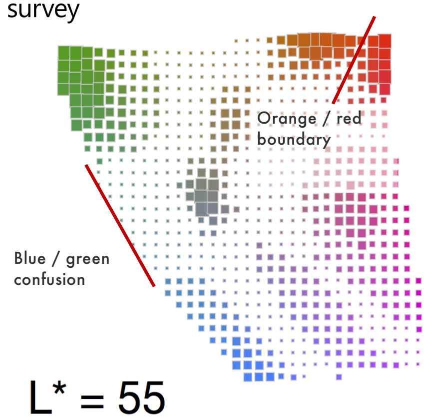
COLORS NAMING MODELS [Heer 2012]

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)*



105

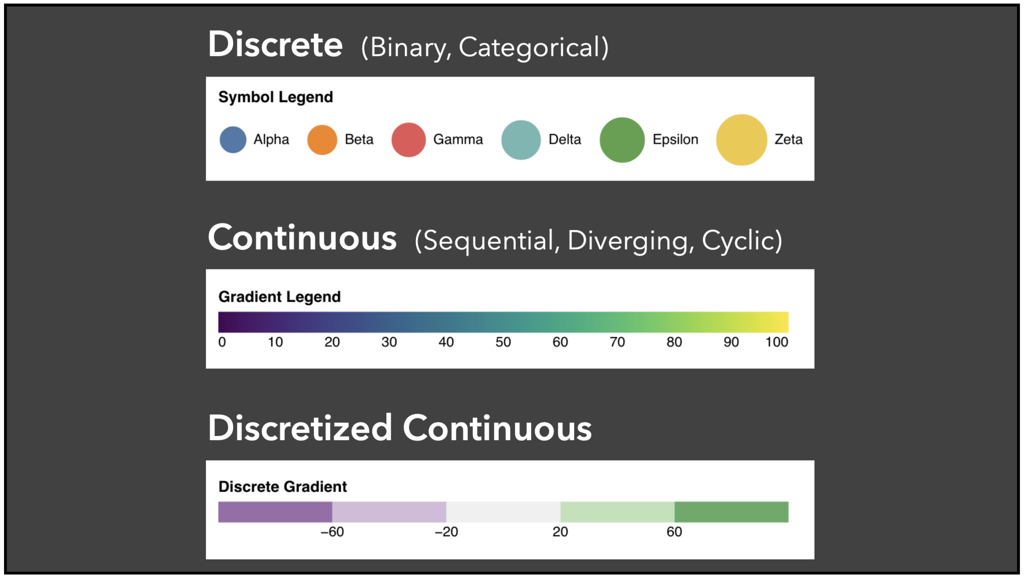
USING COLOR IN VISUALIZATION

106

COLORMAP DESIGN CONSIDERATIONS

1. Perceptually distinguishable colors
2. Value distance matches perceptual distance
3. Colors and concepts properly align
4. Aesthetically pleasing, intriguing
5. Respect color vision deficiencies
6. Should survive printing to black & white
7. Don’t overwhelm people’s capability!

107

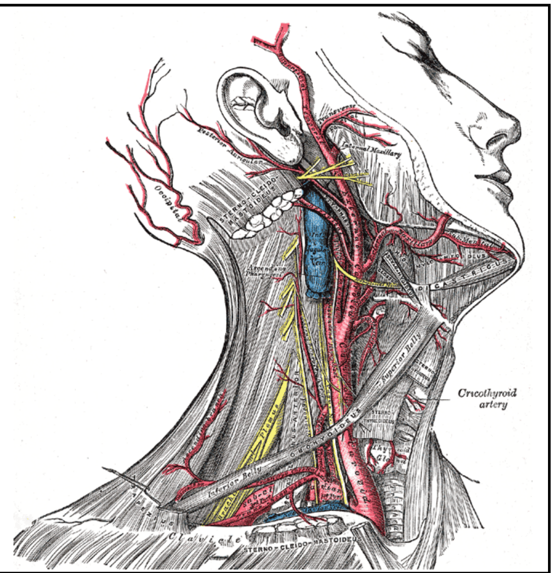


108

DISCRETE/CATEGORICAL COLOR

109

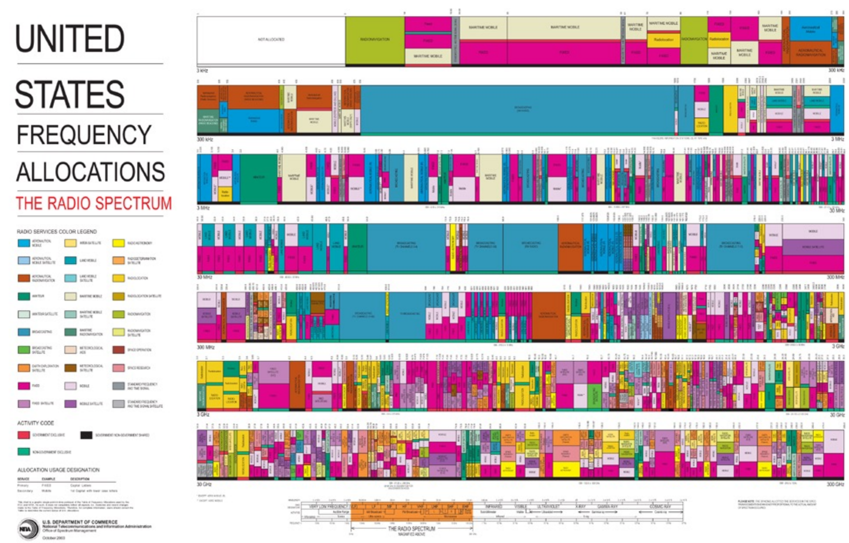
GRAY'S ANATOMY



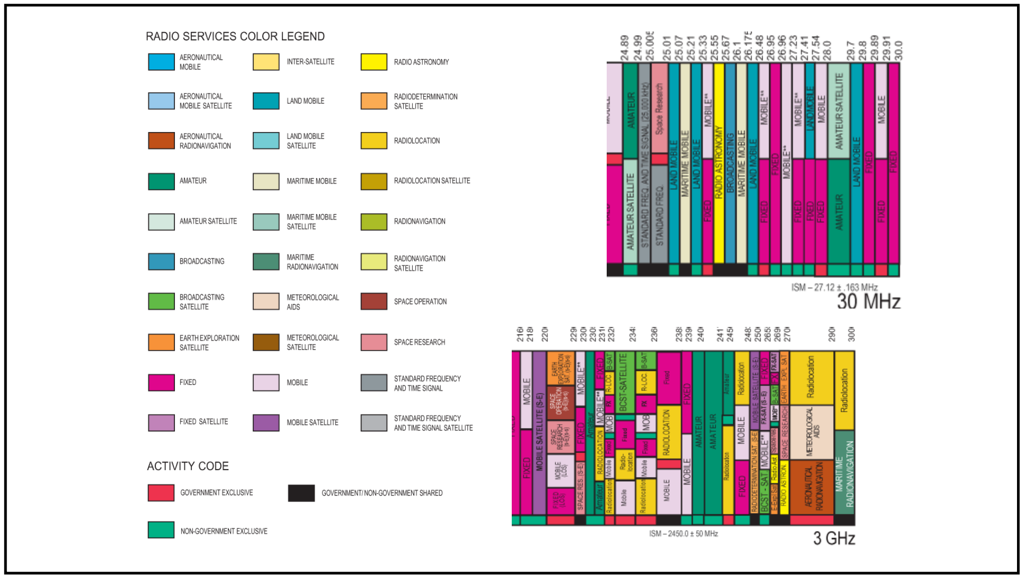
Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries

http://www.bartleby.com/107/illus520.html

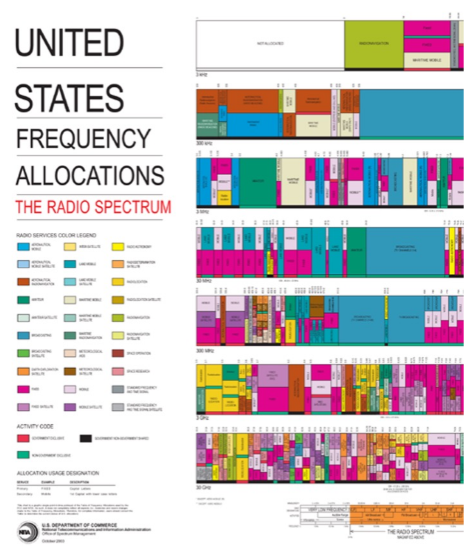
110



111



112



ISSUES

1. Too many colors (33 colors)
2. Hard to remember mapping
3. Colors not distinctive
4. Poor grouping; similar bands with dissimilar colors
5. Labels cause clutter
6. Color surround effects
7. Color interactions; adjacent colors don't look good next to each other

113

PALLETTE DESIGN & COLOR NAMES

Minimize overlap and ambiguity of color names

Color Name Distance

										Salience	Name
0.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	0.20	.47	**blue** 62.9%
1.00	0.00	1.00	0.97	1.00	1.00	1.00	1.00	0.96	1.00	.90	**orange** 93.9%
1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	0.90	0.99	.67	**green** 79.8%
1.00	0.97	1.00	0.00	1.00	0.95	0.99	1.00	1.00	1.00	.66	**red** 80.4%
0.98	1.00	1.00	1.00	0.00	0.96	0.91	0.97	1.00	0.99	.47	**purple** 51.4%
1.00	1.00	1.00	0.95	0.96	0.00	0.97	0.93	0.98	1.00	.37	**brown** 54.0%
1.00	1.00	1.00	0.99	0.91	0.97	0.00	1.00	1.00	1.00	.58	**pink** 71.7%
1.00	1.00	1.00	1.00	0.97	0.93	1.00	0.00	1.00	1.00	.67	**grey** 79.4%
1.00	0.96	0.90	1.00	1.00	0.98	1.00	1.00	0.00	1.00	.18	**yellow** 31.2%
0.20	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	0.00	.25	**blue** 25.4%
Tableau-10								*Average*	*0.97*	*.52*	

http://vis.stanford.edu/color-names

119

PALLETTE DESIGN & COLOR NAMES

Minimize overlap and ambiguity of color names

Color Name Distance

										Salience	Name
0.00	1.00	1.00	0.89	0.07	1.00	0.35	0.99	1.00	0.89	.30	**blue** 50.5%
1.00	0.00	0.99	1.00	1.00	0.92	1.00	0.84	0.98	0.99	.21	**red** 27.8%
1.00	0.99	0.00	1.00	0.98	1.00	1.00	1.00	0.17	1.00	.34	**green** 36.8%
0.89	1.00	1.00	0.00	0.98	1.00	0.71	0.93	1.00	0.32	.55	**purple** 67.3%
0.07	1.00	0.98	0.98	0.00	1.00	0.36	1.00	0.97	0.95	.20	**blue** 36.6%
1.00	0.92	1.00	1.00	1.00	0.00	1.00	0.97	0.99	1.00	.39	**orange** 51.9%
0.35	1.00	1.00	0.71	0.36	1.00	0.00	0.95	0.92	0.42	.13	**blue** 15.7%
0.99	0.84	1.00	0.93	1.00	0.97	0.95	0.00	0.98	0.85	.16	**pink** 29.4%
1.00	0.98	0.17	1.00	0.97	0.99	0.92	0.98	0.00	0.97	.12	**green** 21.7%
0.89	0.99	1.00	0.32	0.95	1.00	0.42	0.85	0.97	0.00	.30	**purple** 23.9%
Excel-10								*Average*	*0.87*	*.27*	

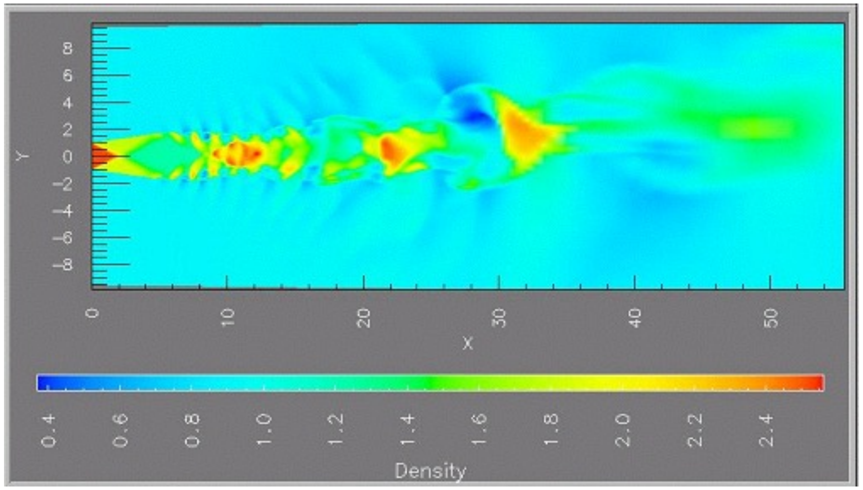
http://vis.stanford.edu/color-names

120

CONTINUOUS/QUANTITATIVE COLOR

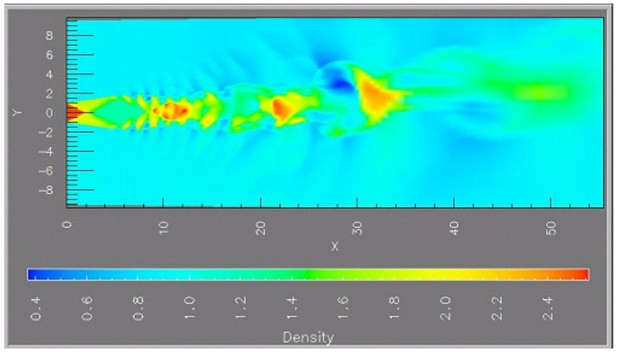
135

RAINBOW COLOR MAPS



136

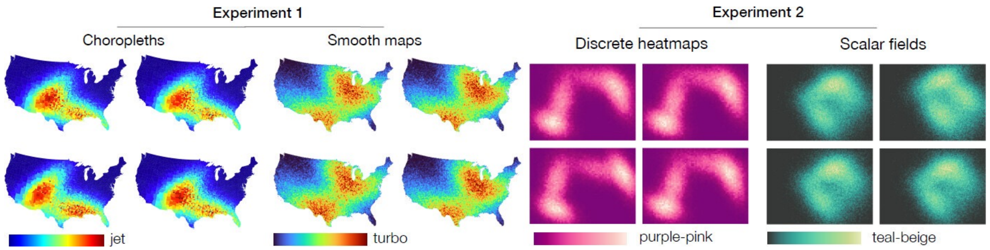
BE WARY OF NAÏVE RAINBOWS?



1. Hues are not naturally ordered
2. People segment colors into classes, perceptual banding
3. Naïve rainbows unfriendly to color blind viewers
4. Low luminance colors (blue) hide high frequencies

137

BUT, RAINBOWS HELP WITH INFERENCE?



Reda et al. 2021: Color Nameability Predicts Inference Accuracy in Spatial Visualizations

Rainbows found **ineffective** for *value comparison* [Liu 2018]

… but color name salience found to **improve performance** on *task* of distinguishing distributions [Reda 2021]

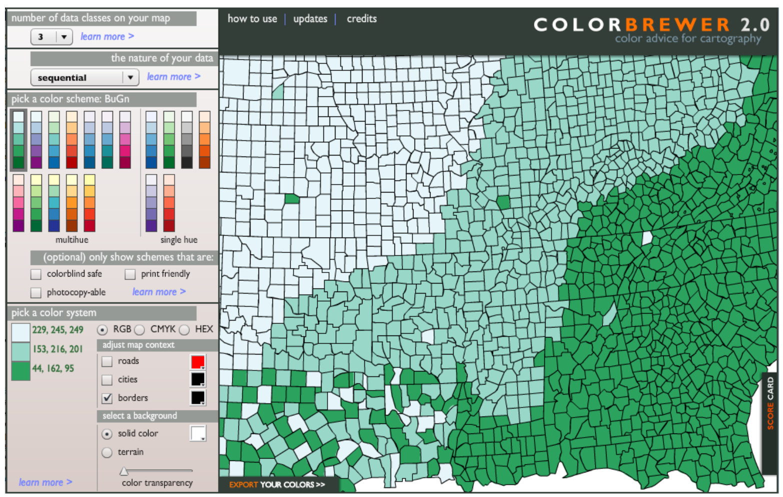
Task matters!

138

DISCRETIZED CONTINUOUS COLOR

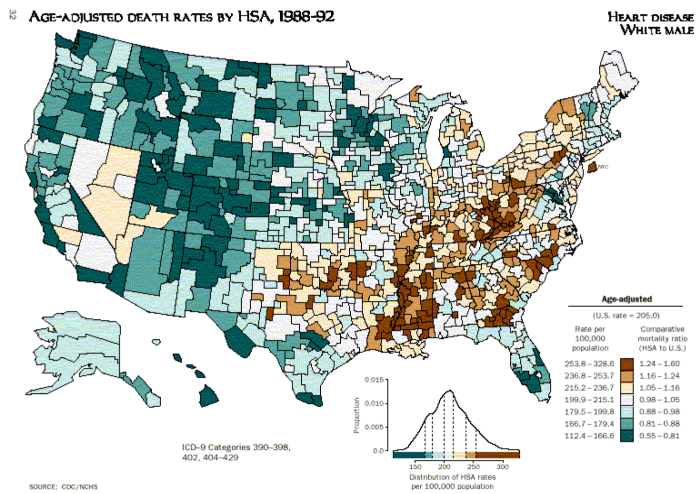
146

STEPS RATHER THAN GRADIENTS?



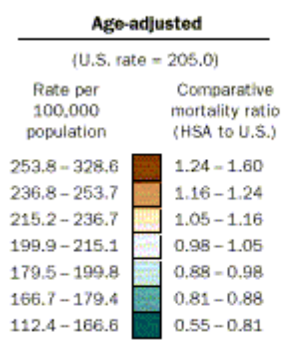
www.colorbrewer2.org

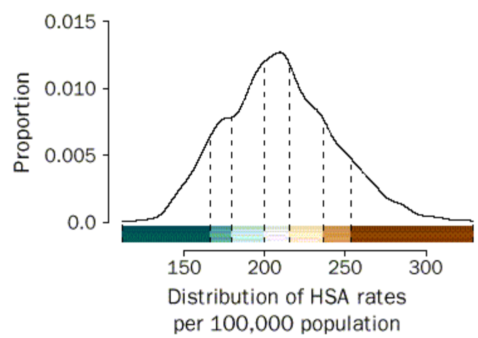
147



148

CLASSING CONTINUOUS/QUANT. DATA





Age-adjusted mortality rates for the United States

Common option: break into 5 to 7 quantiles

149

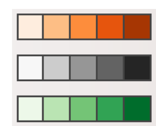
CLASSING CONTINUOUS/QUANT. DATA

1. Equal interval (arithmetic progression)
2. Quantiles *(recommended)*
3. Standard deviations
4. Clustering (Jenks' natural breaks / 1D K-Means)
   - Minimize within group variance
   - Maximize between group variance

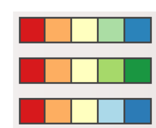
150

DISCRETE CONTINUOUS COLOR ENCODING

Sequential color scale
- Ramp in luminance, possibly also hue
- Typically higher values map to darker colors



Diverging color scale
- Useful when data has a meaningful "midpoint"
- Use neutral color (e.g., grey) for midpoint
- Use saturated colors for endpoints



Limit number of steps in color to 3-9 (why?)

151

SUMMARY

Color perception

Better acuity for luminance than for hue

Beware of simultaneous contrast, crispening, spreading

Color naming

Use colors that are easily distinguished by name

Color palettes

Use small number of hues (about 6)

Avoid rainbow palette except in special cases

Steal well designed palettes (e.g. ColorBrewer)

Consider sequential and diverging scales for Quantitative data

164