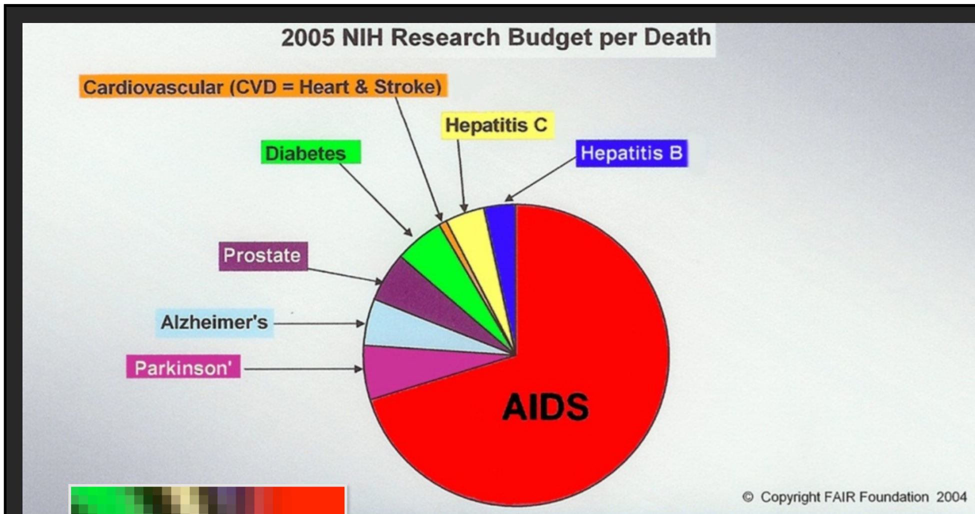
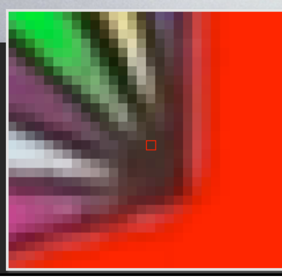
Color

Maneesh Agrawala

CS 448B: Visualization
Fall 2017

Last Time: Deconstructing Visualizations





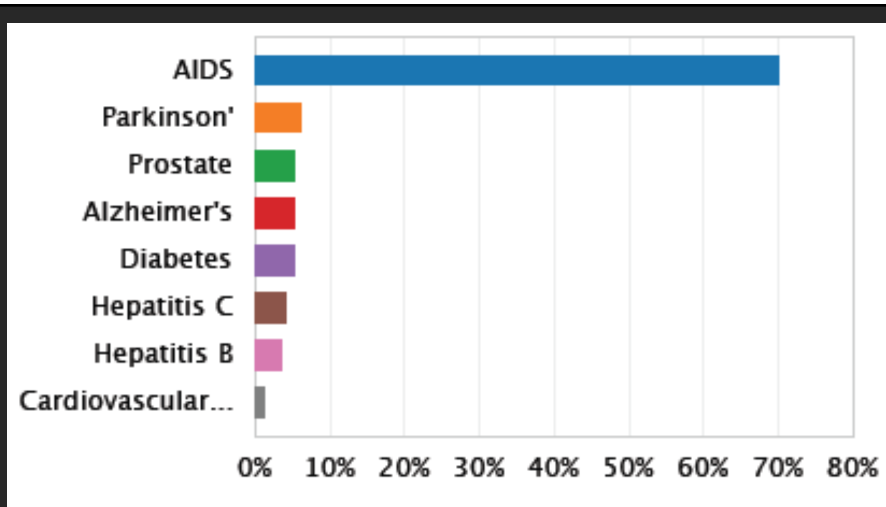
Data

Disease	Budget
Aids	70.0%
Alzheimer's	5.0%
Cardiovascular	1.1%
Diabetes	4.8%
Hepatitus B	4.1%
Hepatitus C	3.8%
Parkinson'	6.0%
Prostate	5.2%

Marks
Mappings

mark: areas

Budget → angle (Q)
Disease → color (N)



Data

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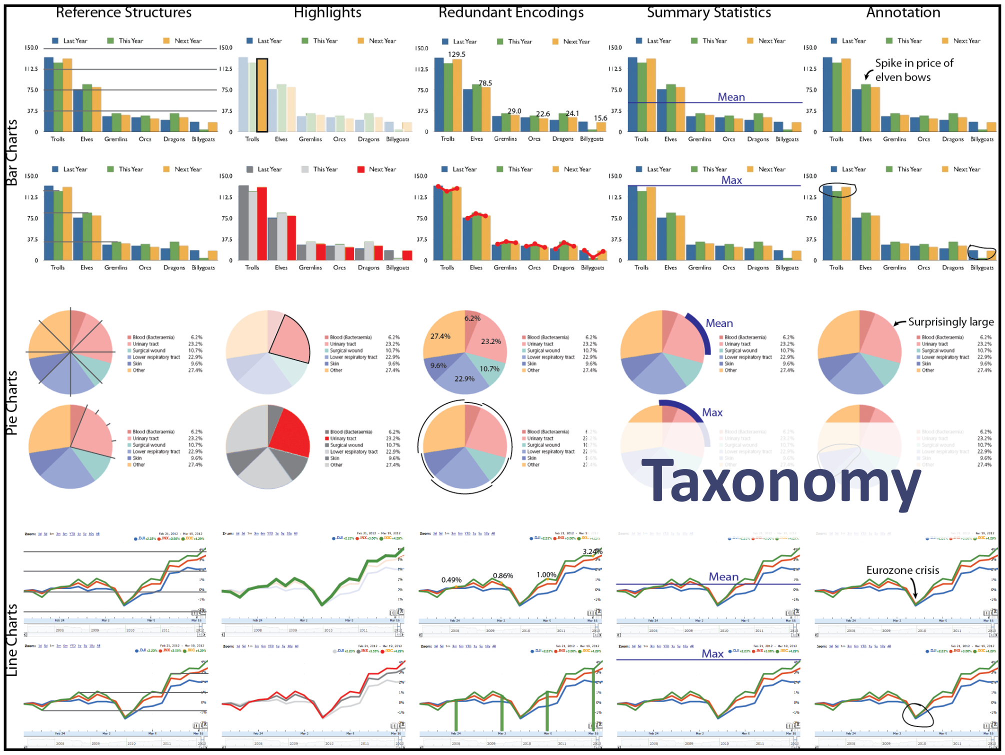
Hepatitus C	3.8%
Parkinson'	6.0%
Prostate	5.2%

Marks
Mappings

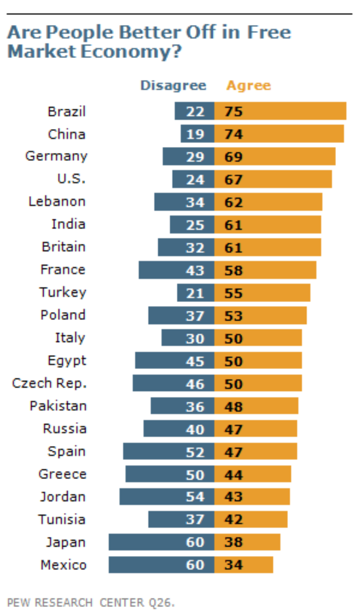
mark: lines

Budget → length (Q)
Disease → color (N)



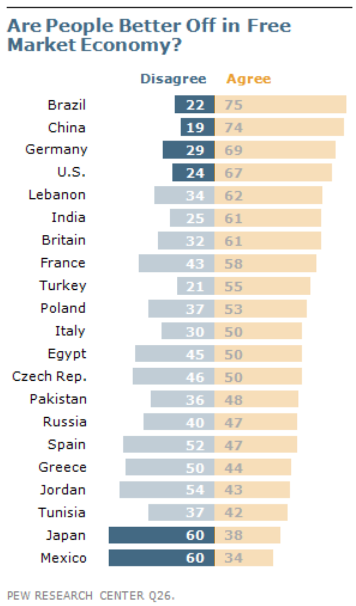
Taxonomy

Example 1: Pew Research



Skepticism for capitalism is lowest in Brazil (22%), China (19%), Germany (29%) (although East Germans are less supportive than West Germans) and the U.S. (24%). Skepticism for free markets is highest in Mexico (60%) and Japan (60%).

Example 1: Pew Research



Skepticism for capitalism is lowest in **Brazil (22%), China (19%), Germany (29%)** (although East Germans are less supportive than West Germans) and the **U.S. (24%)**. Skepticism for free markets is highest in **Mexico (60%)** and **Japan (60%).**

Announcements

Final project

New visualization research or data analysis
- Pose problem, Implement creative solution
- Design studies/evaluations

Deliverables
- Implementation of solution
- 6-8 page paper in format of conference paper submission
- Project progress presentations

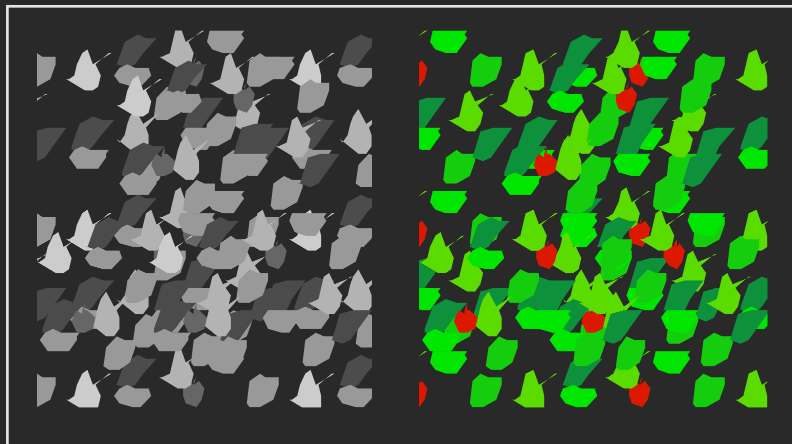
Schedule
- Project proposal: Mon 11/5
- Project progress presentation: 11/12 and 11/14 in class (3-4 min)
- Final poster presentation: 12/5 Location: Lathrop 282
- Final paper: 12/9 11:59pm

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

Color

Color in Visualization

Identify, Group, Layer, Highlight



Colin Ware

Purpose of Color

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

"Above all, do no harm."

- Edward Tufte

Topics

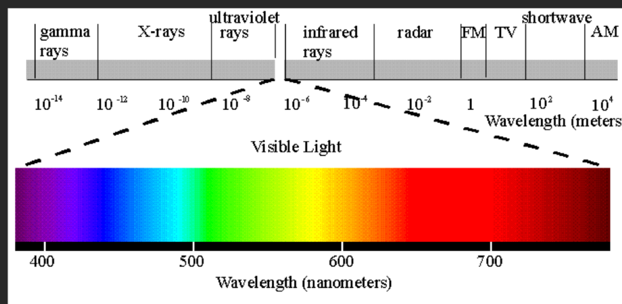
Color Perception
Color Naming
Using Color in Visualization

Color Perception

Physical World, Visual System, Mental Models

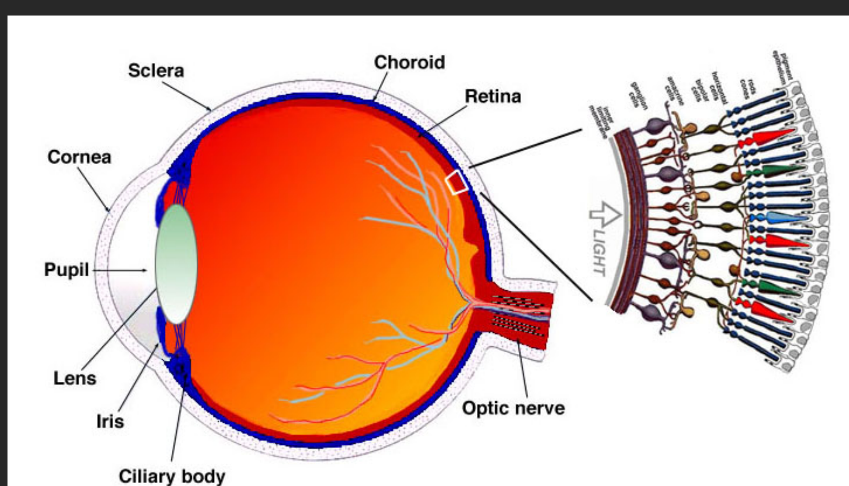
Physical World

Light is radiation in range of wavelengths



Light of single wavelength is *monochromatic*

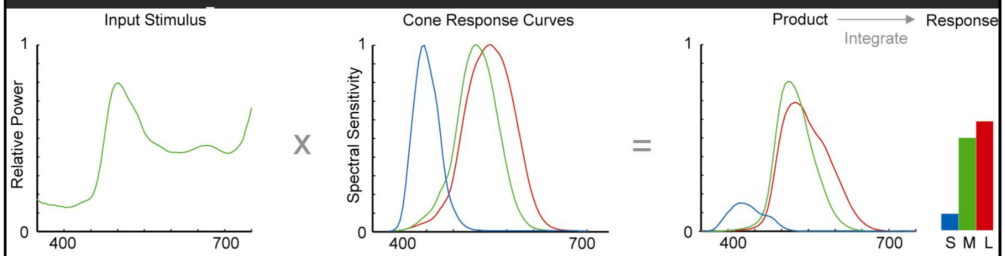
Retina



Simple Anatomy of the Retina, Helga Kolb

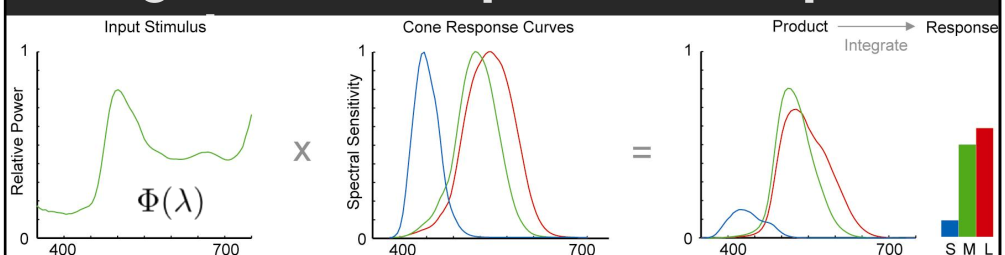
Cone Response

Integrate cone response with input



Computing Cone Response

Integrate cone response with input



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

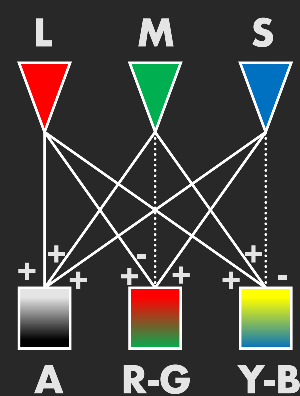
$$M = \int \Phi(\lambda) M(\lambda) \mathrm{d}\lambda$$

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

Opponent processing

LMS are linearly combined to create:

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

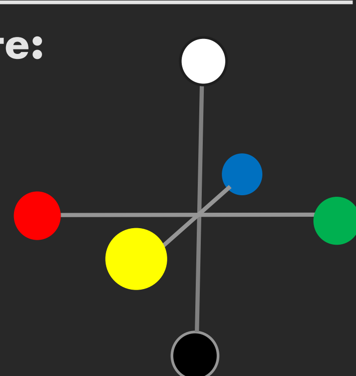


Fairchild

Opponent processing

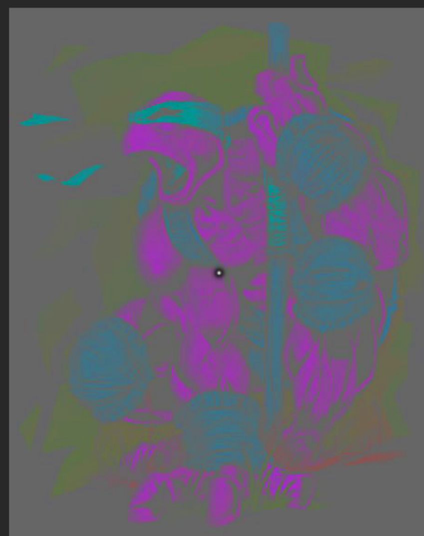
LMS are combined to create:

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



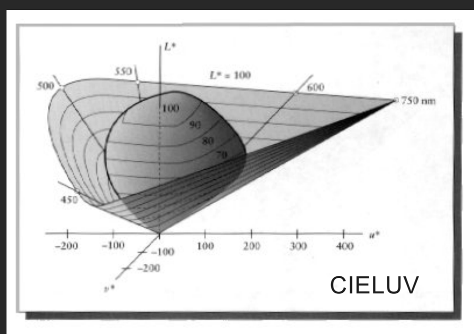
Experiments:

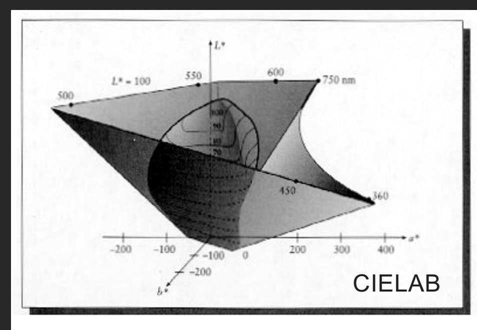
- No reddish green, no bluish yellow
- Color after images



CIE LUV and LAB color spaces

Standardized in 1976 to mathematically represent opponent processing theory



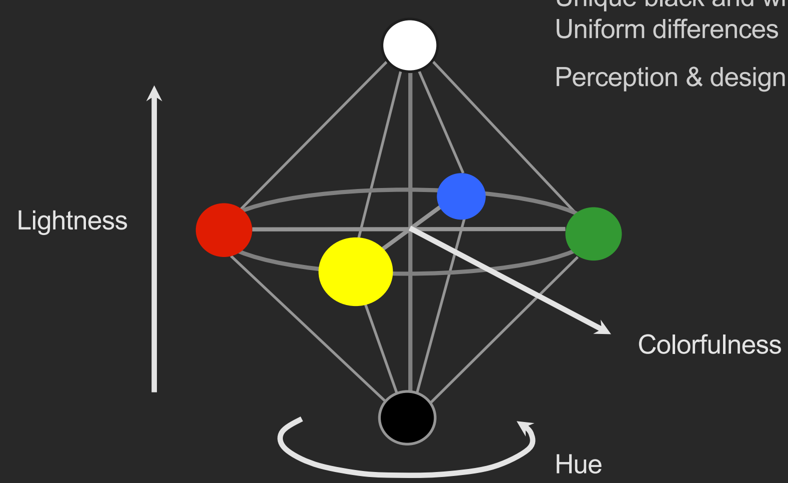


Axes of CIE LAB

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)

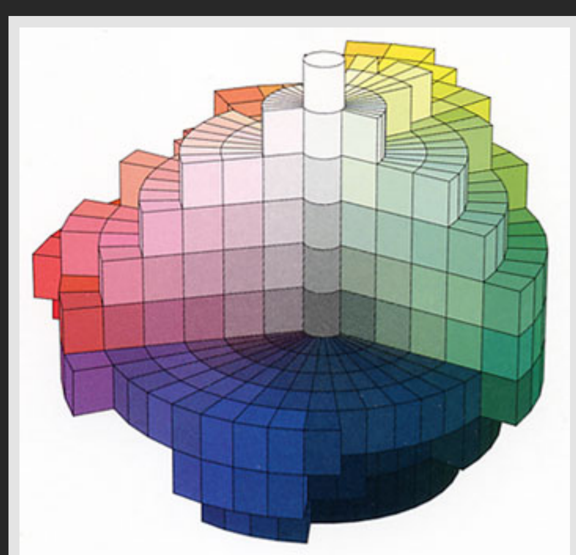
Pseudo-Perceptual Color Spaces



Unique black and white
Uniform differences

Perception & design

Hue, Value, Chroma



Psuedo-Perceptual Models

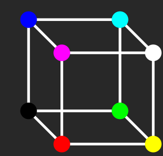
HLS, HSV, HSB

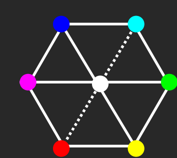
NOT perceptual models

Simple re-notation of RGB

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

Cannot predict perceived lightness





Perceptual brightness

Color palette

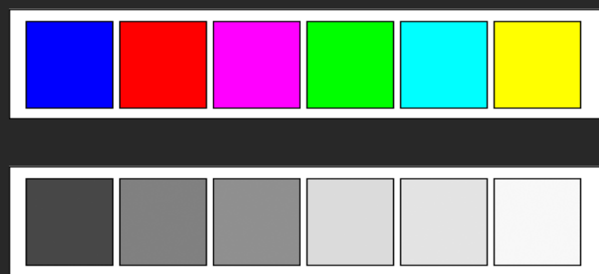
HSL Lightness *(Photoshop)*

Perceptual brightness

Color palette

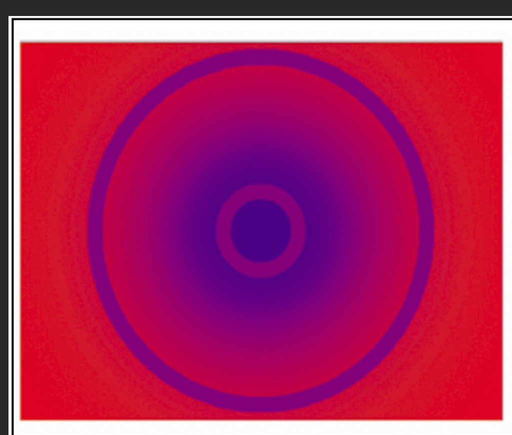
Munsell Value

L* (CIE LAB)



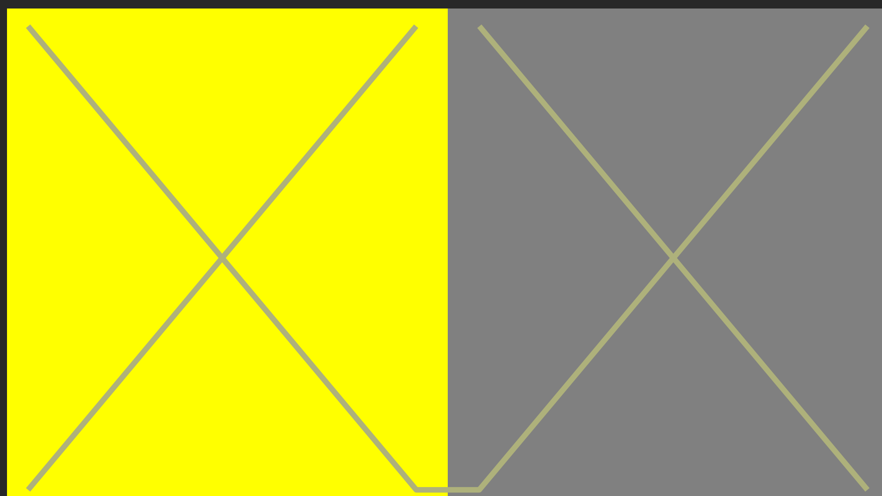
Simultaneous Contrast

The inner and outer thin rings are the physical purple



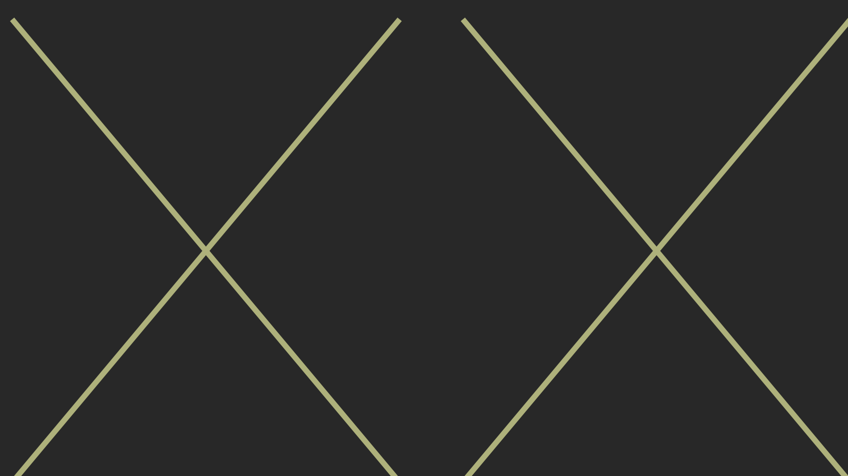
Donald MacLeod

Simultaneous Contrast



Josef Albers

Simultaneous Contrast



Josef Albers

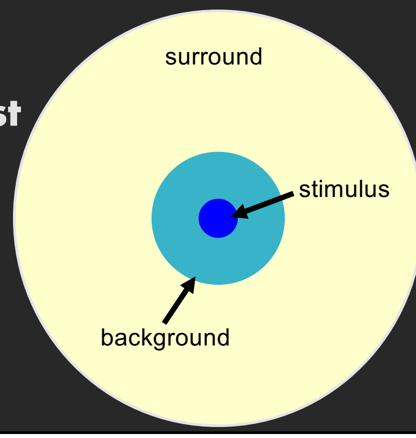
Color Appearance

More than a single color
- Adjacent colors (background)
- Viewing environment (surround)

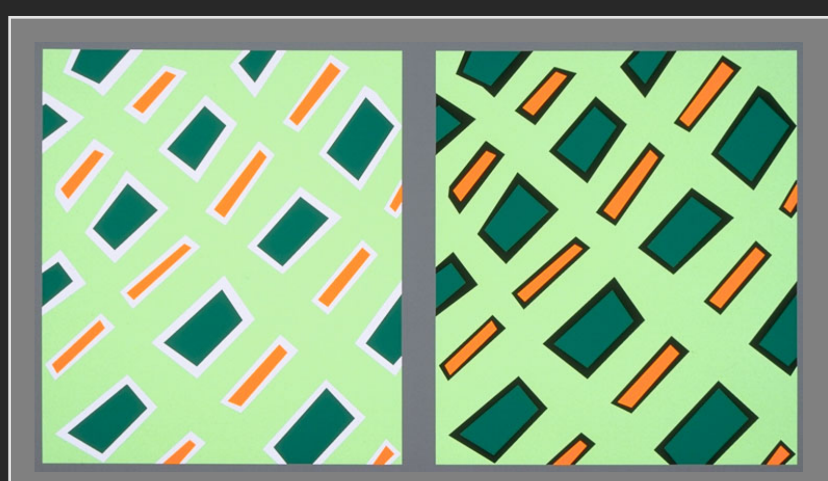
Appearance effects
- Adaptation
- Simultaneous contrast
- Spatial effects

Color in context

Color Appearance Models
Mark Fairchild

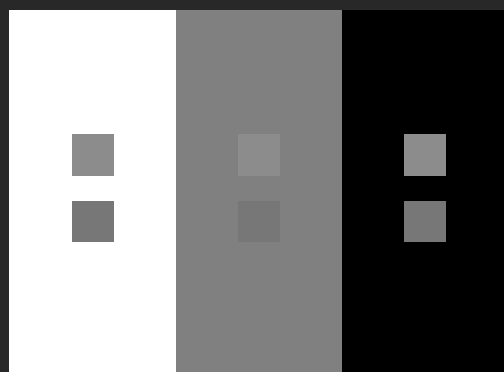


Bezold Effect



Crispening

Perceived difference depends on background



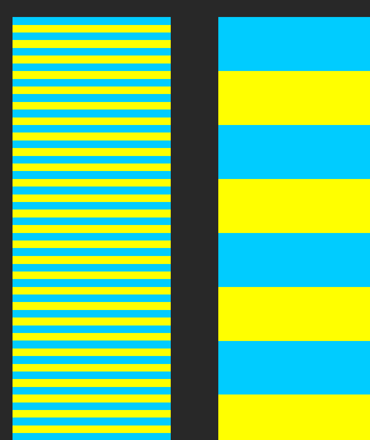
From Fairchild, *Color Appearance Models*

Spreading

Adjacent colors blend

Spatial frequency

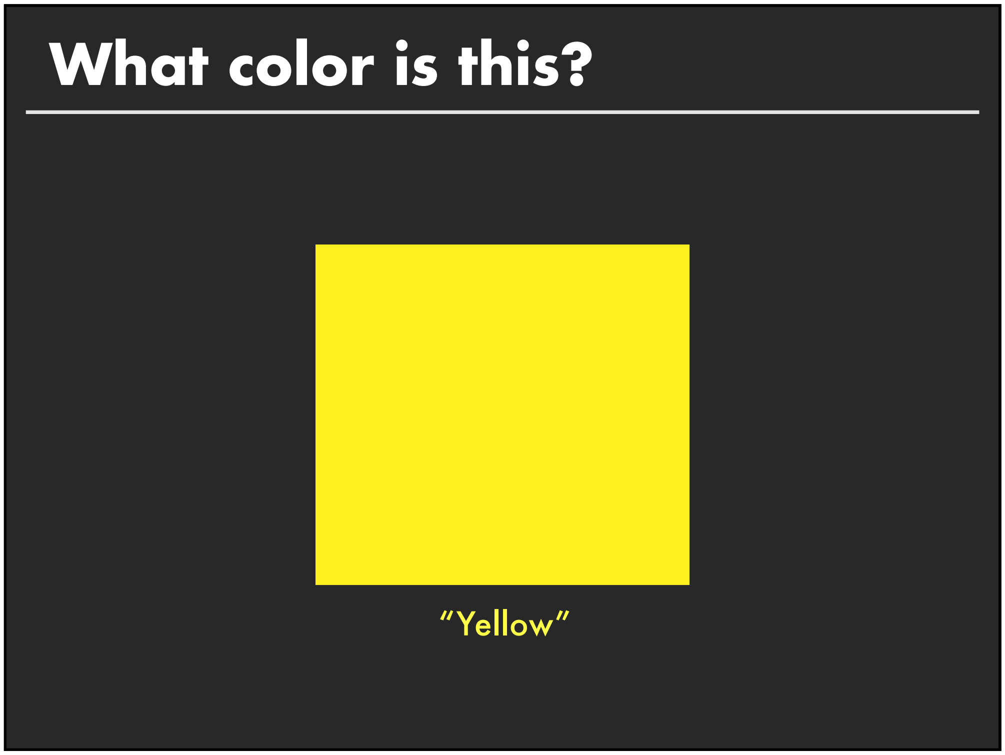
- **The paint chip problem**
- **Small text, lines, glyphs**
- **Image colors**

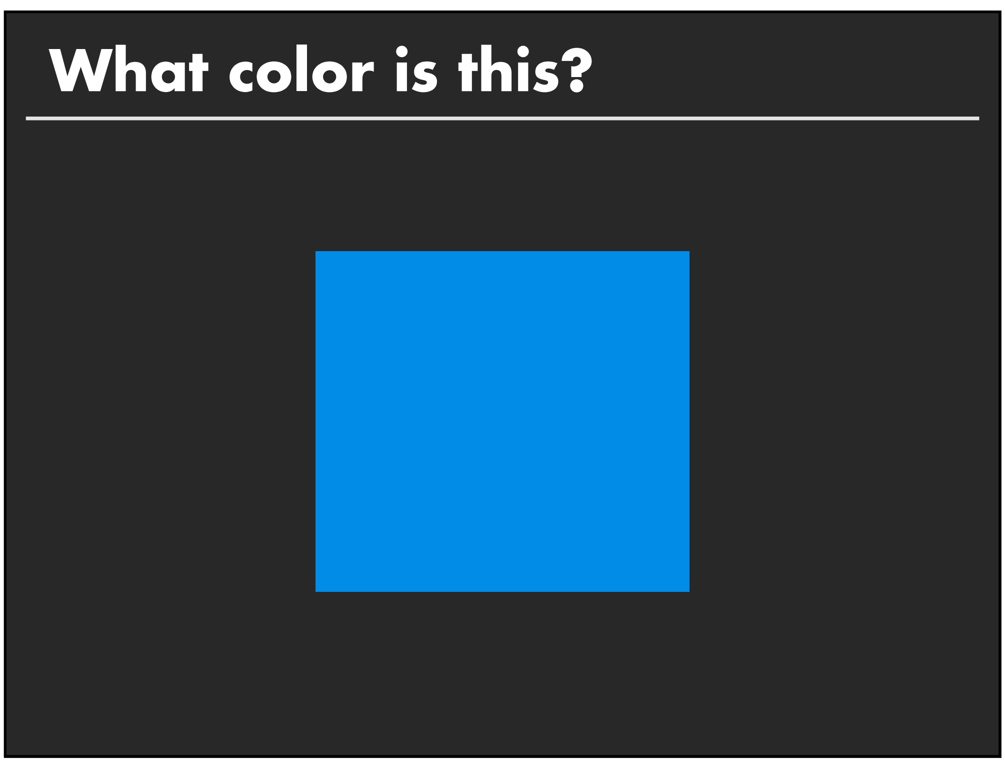


Redrawn from *Foundations of Vision*
© Brian Wandell, Stanford University

Color Naming

What color is this?

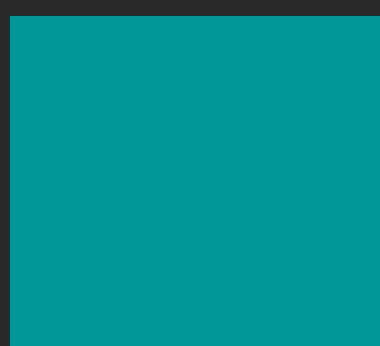

What color is this?
“Yellow”


What color is this?

What color is this?

"Blue"

What color is this?



What color is this?

"Teal" ?

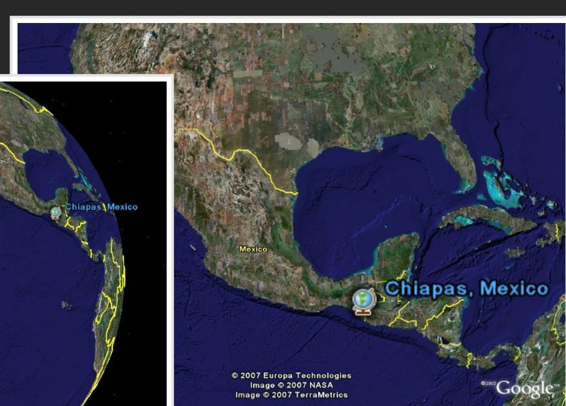
Colors according to XKCD…

Basic color terms

Chance discovery by Brent Berlin and Paul Kay

Basic color terms

Chance discovery by Brent Berlin and Paul Kay

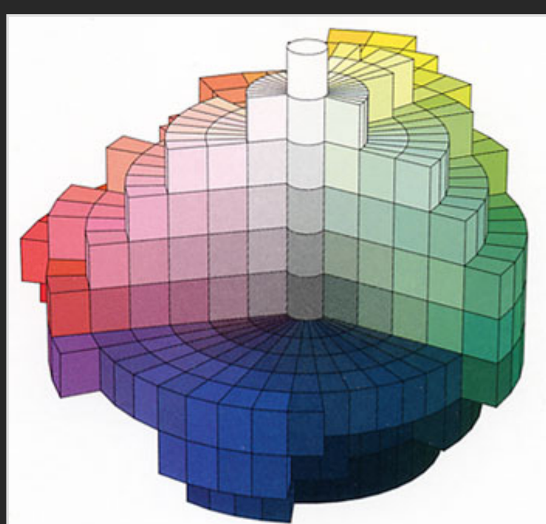


Basic Color Terms

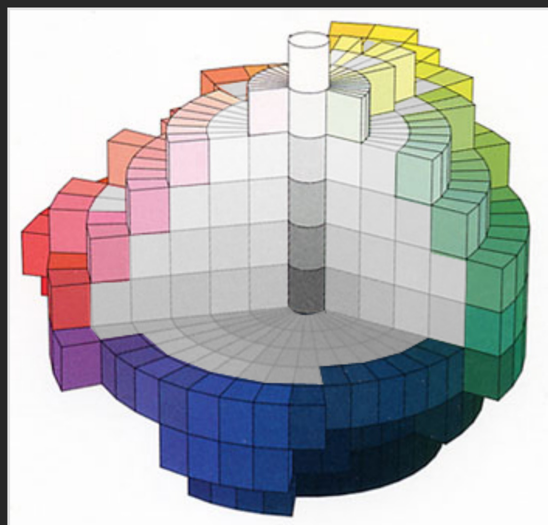
Chance discovery by Brent Berlin and Paul Kay

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

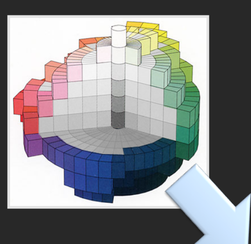
World color survey



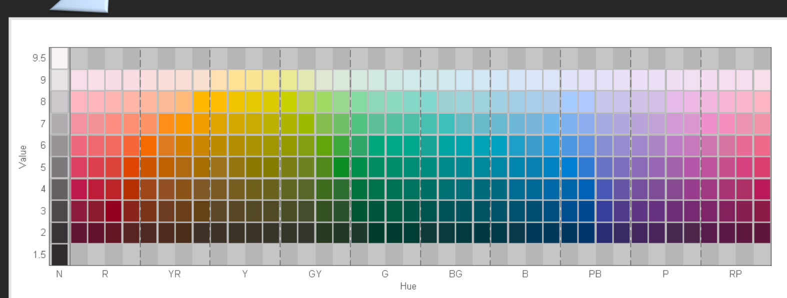
World color survey



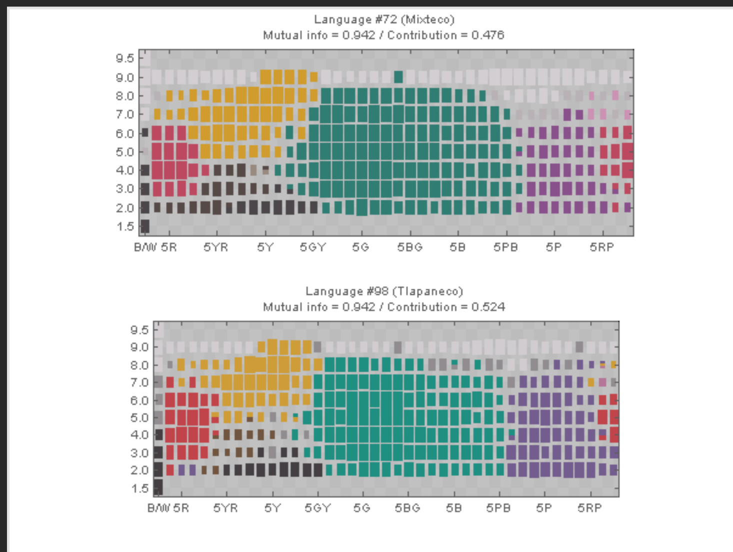
World color survey



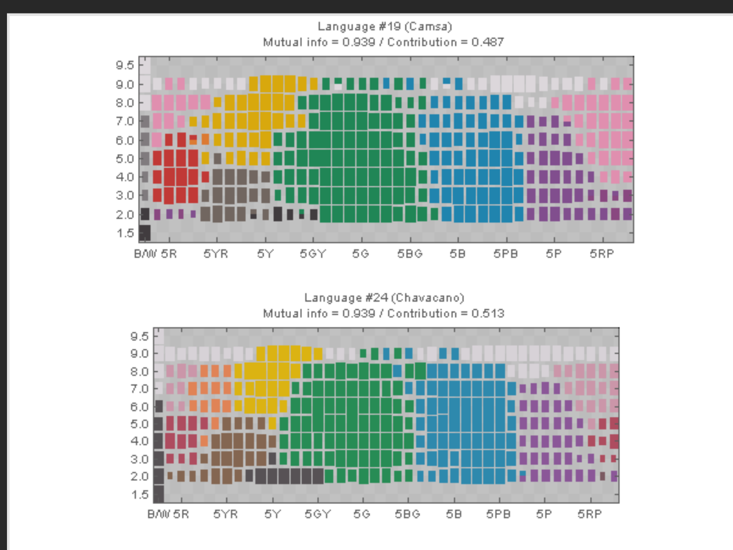
Naming information from 2616 speakers from 110 languages on 330 Munsell color chips



Results from WCS (Mexico)



Results from WCS (South Pacific)



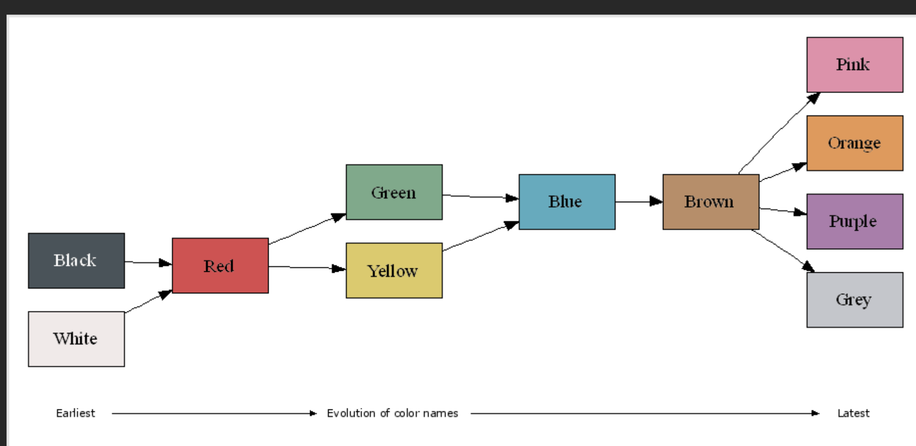
Universal (?) Basic Color Terms

Basic color terms recur across languages

White	Red	Pink
Grey	Yellow	Brown
Black	Green	Orange
	Blue	Purple

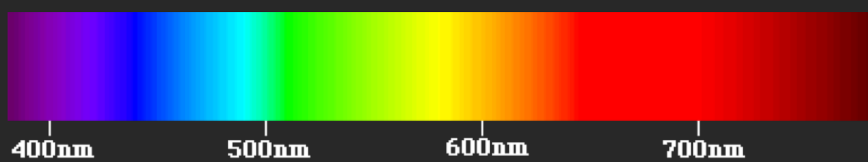
Evolution of Basic Color Terms

Proposed universal evolution across languages



Rainbow color ramp

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



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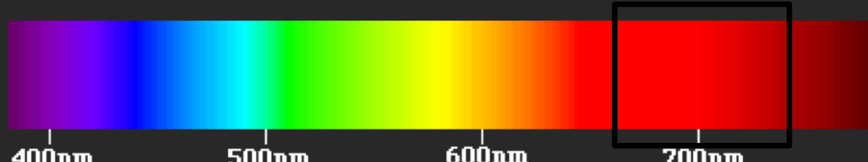

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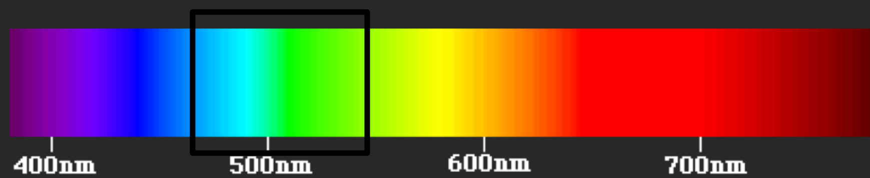
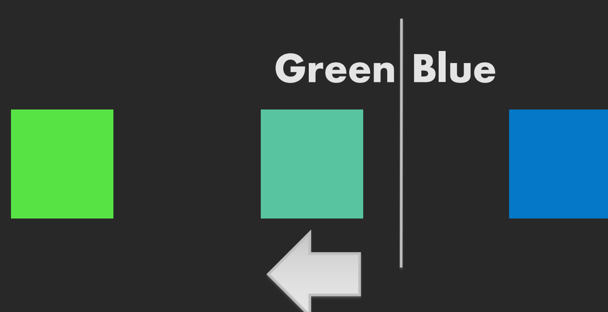


Naming affects color perception

Color name boundaries



Color naming models

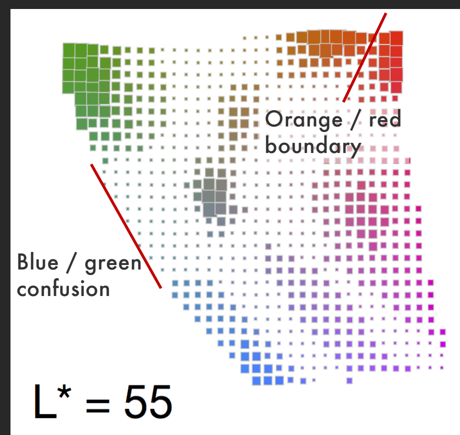
[Heer & Stone]

Model 3 million responses from XKCD survey

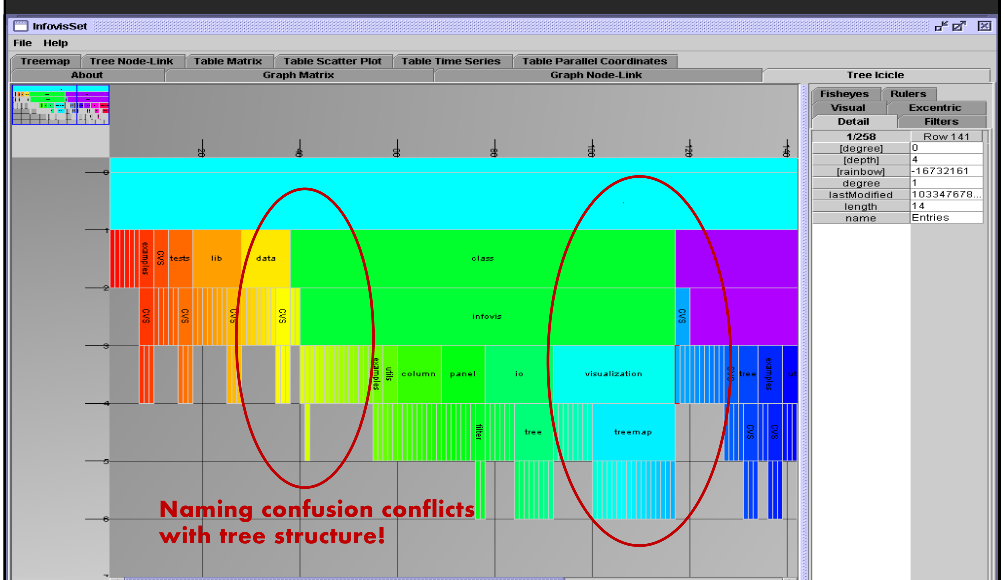
Bins in LAB space sized by *saliency*:

How much do people agree on color name?

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

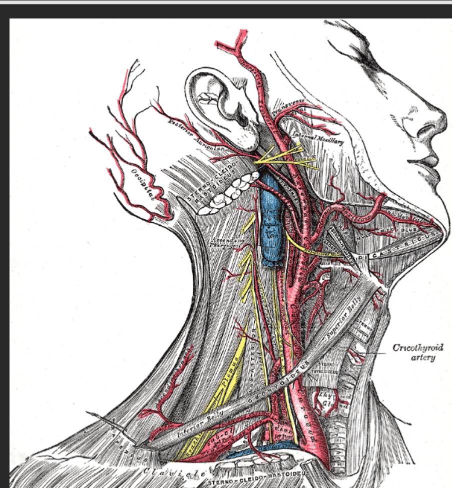


Icicle tree with colors



Using Color in Visualization

Gray's Anatomy



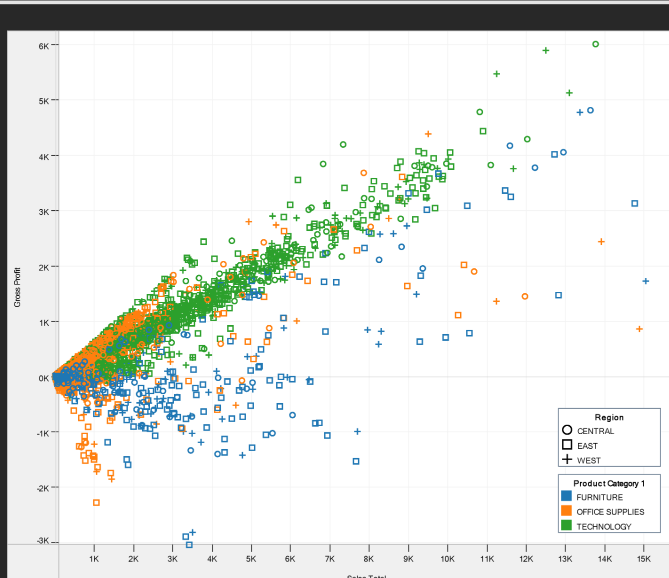
Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries

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

Molecular Models

Organic Chemistry Molecular Model Set
http://www.indigo.com/models/gphmodel/62003.html

Product Categories



Created by Tableau - Visual Analysis for Databases™

Grouping, Highlighting

	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
red	25.37	13.70	0.05	26.27	14.13	0.04	18.41	10.16	0.05	17.43	9.30	0.00
green	22.14	51.24	0.35	20.68	49.17	0.44	21.11	46.00	0.20	16.36	37.95	0.12
blue	13.17	3.71	74.89	15.38	5.20	86.83	11.55	3.37	65.53	9.96	3.44	56.14
gray	63.46	73.30	78.05	64.66	71.99	90.08	52.96	62.49	67.99	45.54	53.65	58.14
black	0.66	0.70	0.77	0.63	0.66	1.09	0.47	0.58	0.70	0.44	0.54	0.71

	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
red	25.37	13.70	0.05	26.27	14.13	0.04	18.41	10.16	0.05	17.43	9.30	0.00
green	22.14	51.24	0.35	20.68	49.17	0.44	21.11	46.00	0.20	16.36	37.95	0.12
blue	13.17	3.71	74.89	15.38	5.20	86.83	11.55	3.37	65.53	9.96	3.44	56.14
gray	63.46	73.30	78.05	64.66	71.99	90.08	52.96	62.49	67.99	45.54	53.65	58.14
black	0.66	0.70	0.77	0.63	0.66	1.09	0.47	0.58	0.70	0.44	0.54	0.71

Palette 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

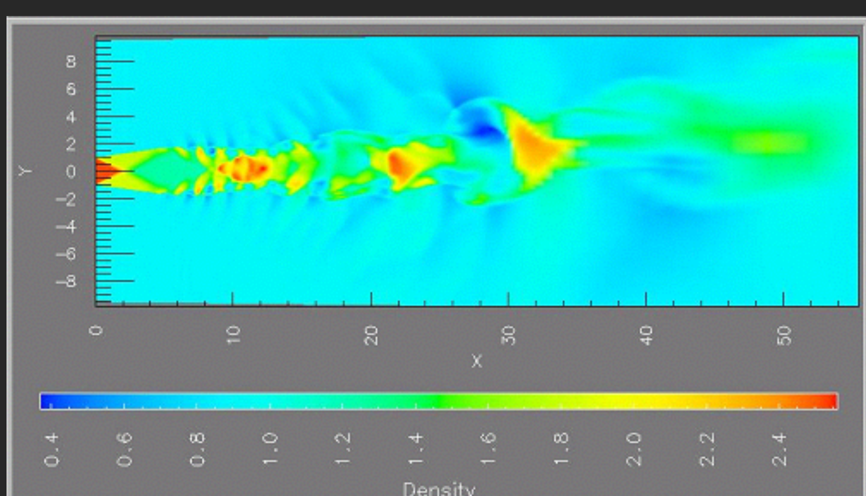
Palette Design + Color Names

Minimize overlap and ambiguity of color names

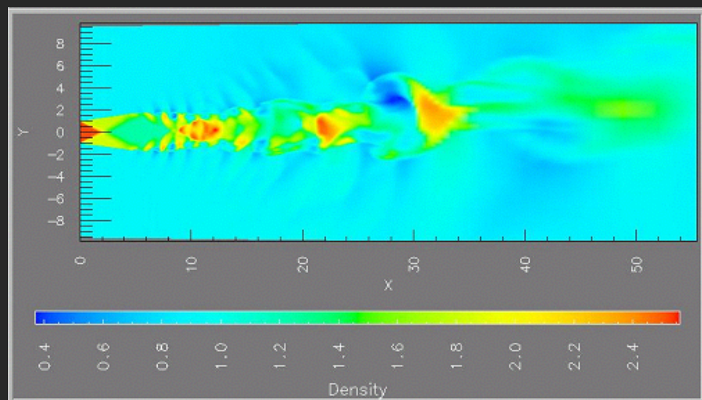
Color Name Distance										Salience	Name
0.00	1.00	1.00	0.89	0.07	1.00	0.35	0.99	1.00	0.89	.30	**blue** 50.5%
1.00	0.00	0.99	1.00	1.00	0.92	1.00	0.84	0.98	0.99	.21	**red** 27.8%
1.00	0.99	0.00	1.00	0.98	1.00	1.00	1.00	0.17	1.00	.34	**green** 36.8%
0.89	1.00	1.00	0.00	0.98	1.00	0.71	0.93	1.00	0.32	.55	**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

Mapping Data to Color (Rainbows)

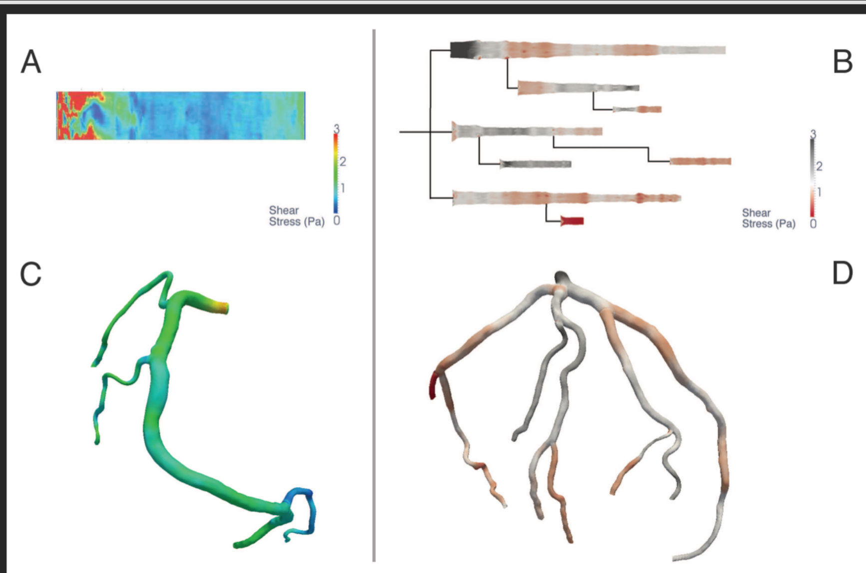


Avoid rainbow color maps!



1. People segment colors into classes
2. Hues are not naturally ordered
3. Different lightness emphasizes certain scalar values
4. Low luminance colors (blue) hide high frequencies

Rainbow vs. Diverging Color Scale



[Borkin 11]

Rainbow vs. Diverging Color Scale

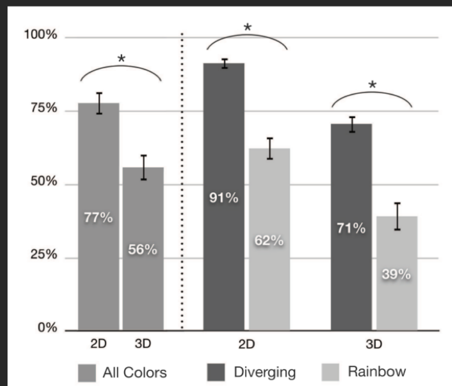
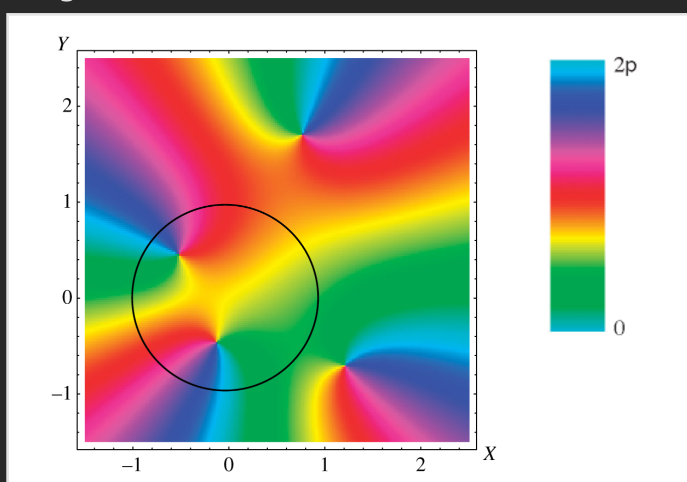


Fig. 7. **Average percent of low ESS regions identified** broken down by 2D and 3D representation, and color. Error bars correspond to the standard error and the asterisks indicate results of statistical significance. Participants were more accurate in 2D and when using the diverging color map.

[Borkin 11]

Phase Diagrams (hue scale)

Singularities occur where all colors meet



The optical singularities of bianisotropic crystals, by M. V. Berry

Phases of the Tides

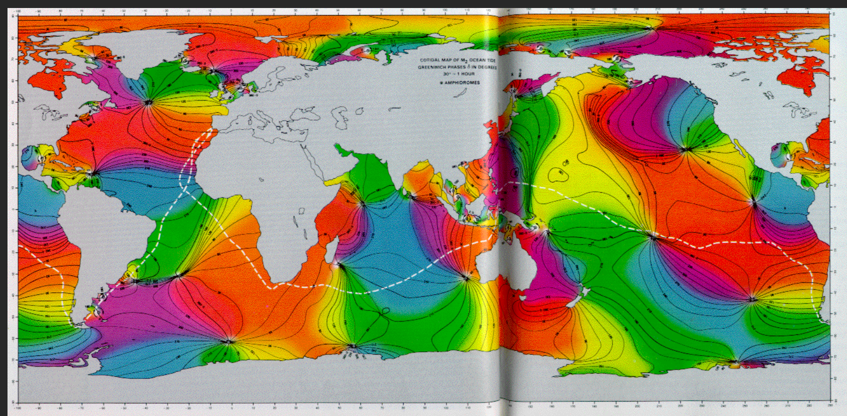
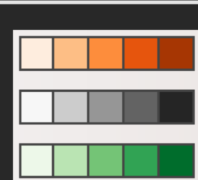


Figure 1.9. Cotidal chart. Tide phases relative to Greenwich are plotted for all the world's oceans. Phase progresses from red to orange to yellow to green to blue to purple. The lines converge on anphidromic points, singularities on the earth's surface where there is no defined tide. [Winfree, 1987 #1195 , p. 17].

Quantitative color encoding



Sequential color scale

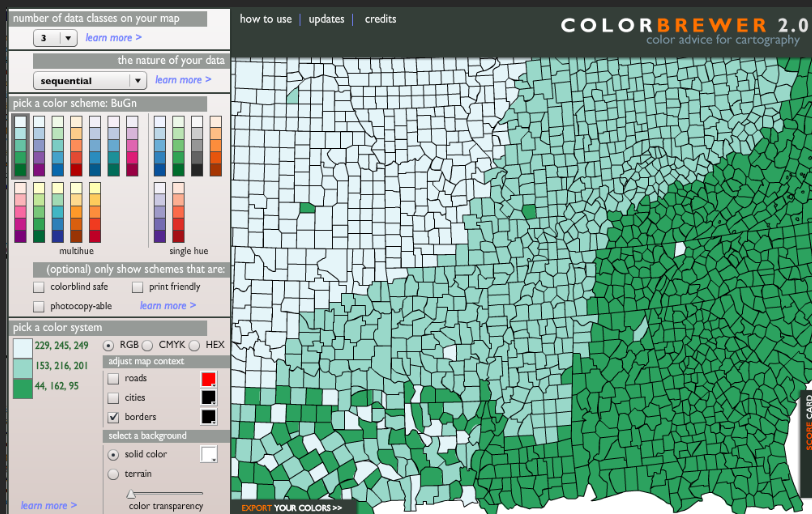
- Constrain hue, vary luminance/saturation
- Map higher values to darker colors

Diverging color scale

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

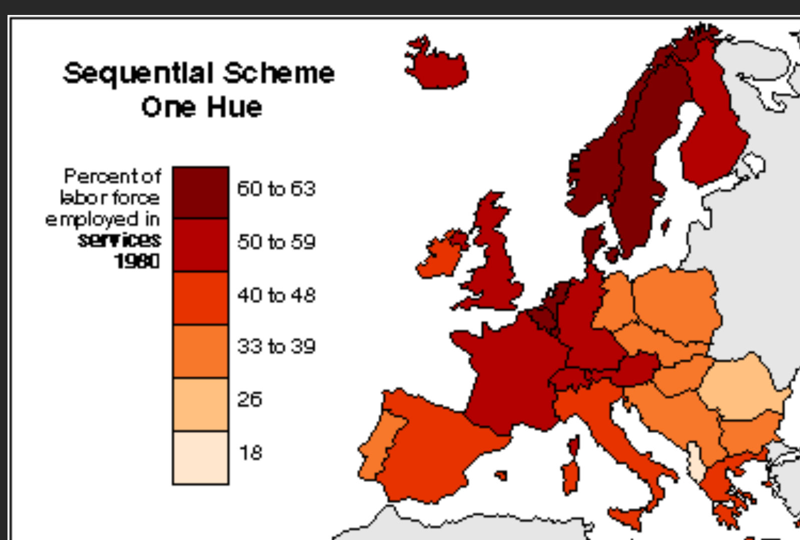
Limit number of steps in color to 3-9

Color Brewer

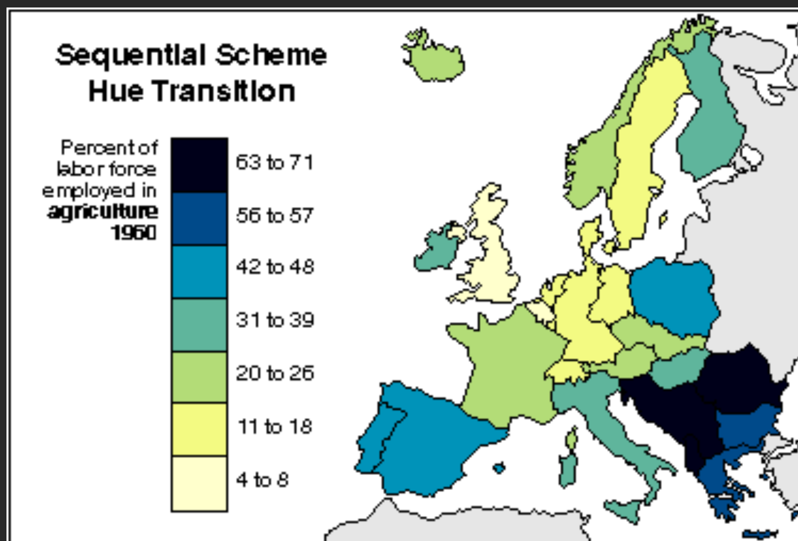


www.colorbrewer.org

Sequential color scheme



Sequential color scheme



Design of sequential color scales

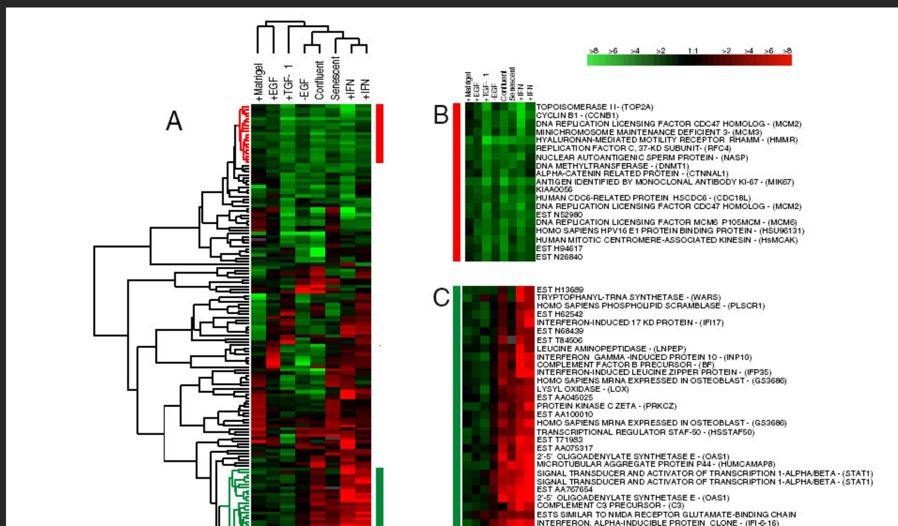
Hue-Lightness ***(Recommended)***

- Higher values mapped to darker colors
- ColorBrewer schemes have 3-9 steps

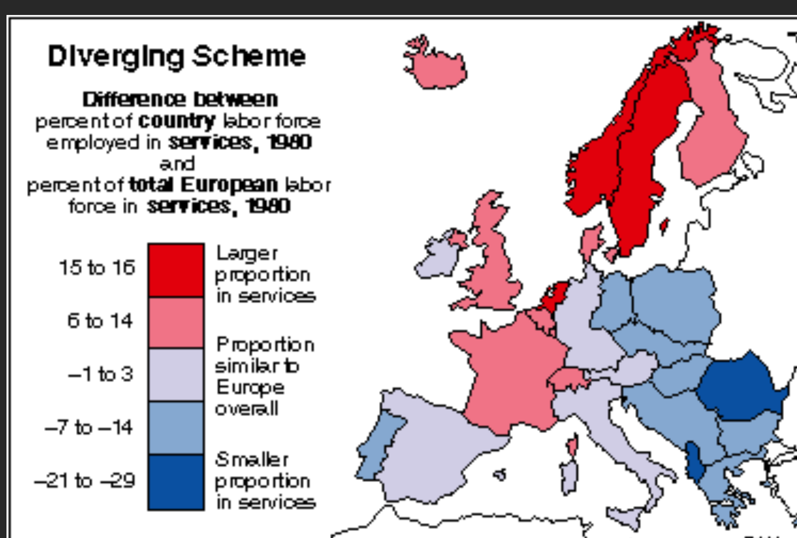
Hue Transition

- Two hues
- Neighboring hues interpolate better
- Couple with change in lightness

Diverging color scheme



Diverging color scheme



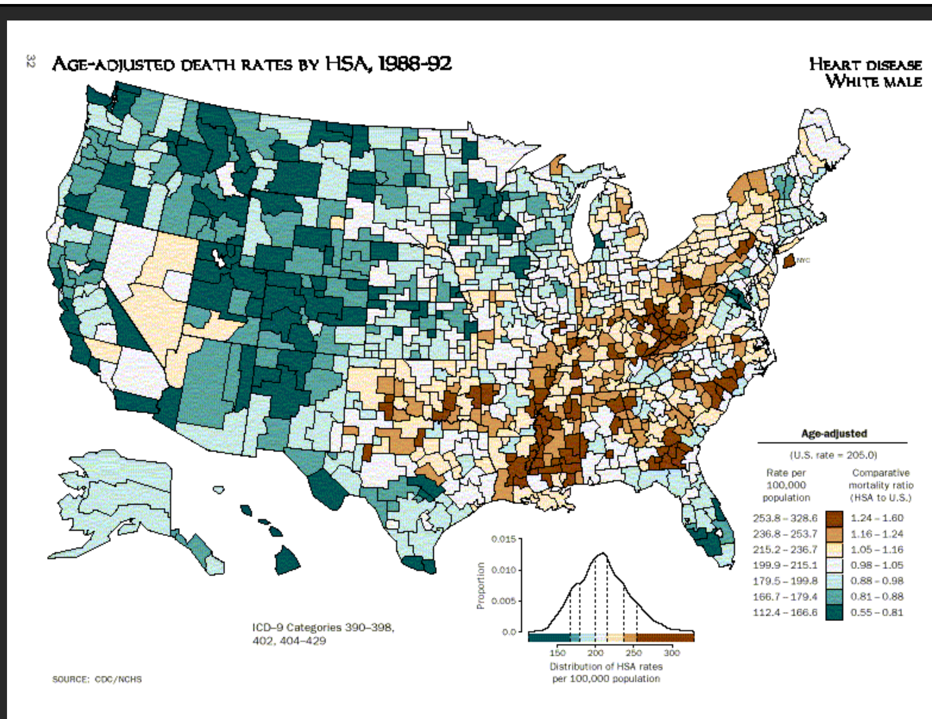
Diverging color scheme

Hue Transition

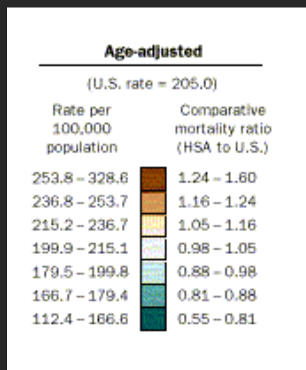
Carefully handle midpoint

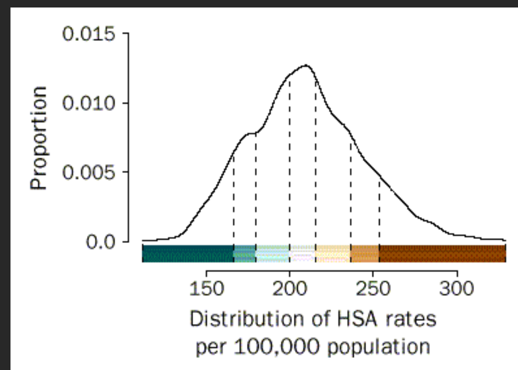
- **Critical class**
  - Low, Average, High
  - ‘Average’ should be gray
- **Critical breakpoint**
  - Defining value e.g. 0
  - Positive & negative should use different hues

Extremes saturated, middle desaturated



Classing quantitative data





Age-adjusted mortality rates for the United States

Hints for the colorist

Use only a few colors (~6 ideal)
Colors should be distinctive and namable
Get it right in black and white
Respect the color blind