Color

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CS 448B: Visualization
Spring 2016

Assignment 3: Dynamic Queries

Create a **small** interactive dynamic query application similar to Homefinder, but for SF Crime Data.

1. Storyboard interface
2. Implement interface and produce final writeup
3. Submit the application and a final writeup on the wiki

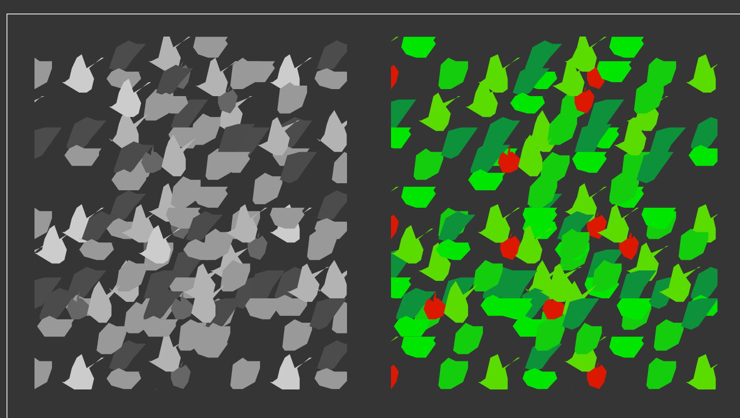
Can work alone or in pairs

Final write up due before class on **May 4, 2016**

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

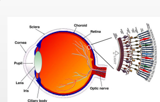
Using Color in Visualization

Color Perception

Physical World, Visual System, Mental Models

What is Color?

Physical World		Visual System		Mental Models
Lights, surfaces, objects	→	Eye, optic nerve, visual cortex	→	Red, green, brown Bright, light, dark, vivid, colorful, dull Warm, cool, bold, blah, attractive, ugly, pleasant, jarring



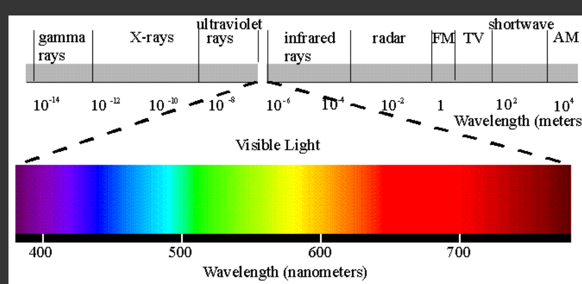
"Yellow"

Color Models

Physical World	Visual System		Mental Models	
Light Energy →	Cone Response →	Opponent Encoding →	Perceptual Models →	Appearance Models
Spectral distribution functions	Encode as three values (L,M,S)	Separate lightness, chroma	Color "Space"	Color in Context
F(λ)	CIE (X,Y,Z)	(A,R-G,Y-B)	Hue lightness saturation	Adaptation Background Size …
			CIELAB Munsell (HVC)	CIECAM02

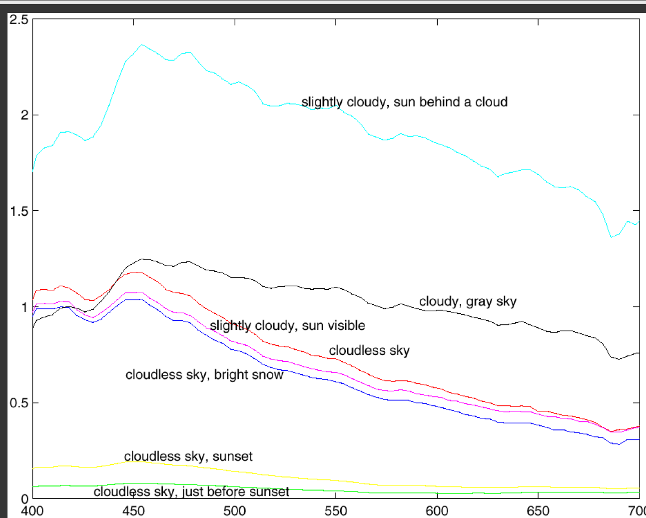
Physical World

Light is radiation in range of wavelengths



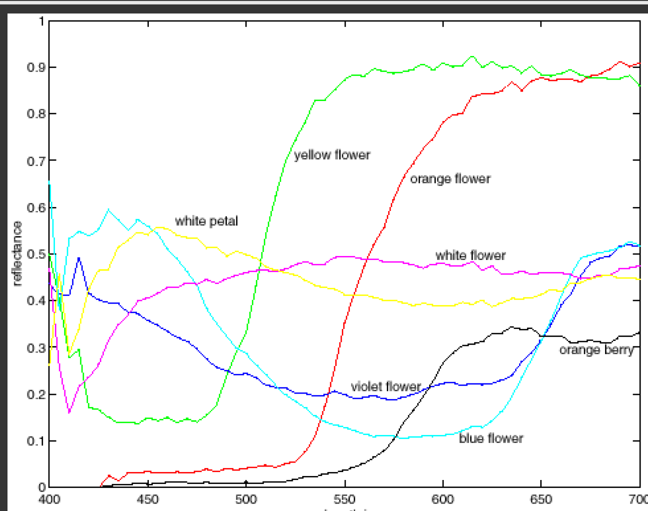
Light of single wavelength is *monochromatic*

Most Colors not Monochromatic



Curves describe spectral composition $\Phi(\lambda)$ of stimulus

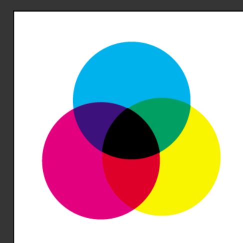
Most Colors not Monochromatic



Curves describe spectral composition $\Phi(\lambda)$ of stimulus

Emissive vs. reflective light

Additive
(digital displays)



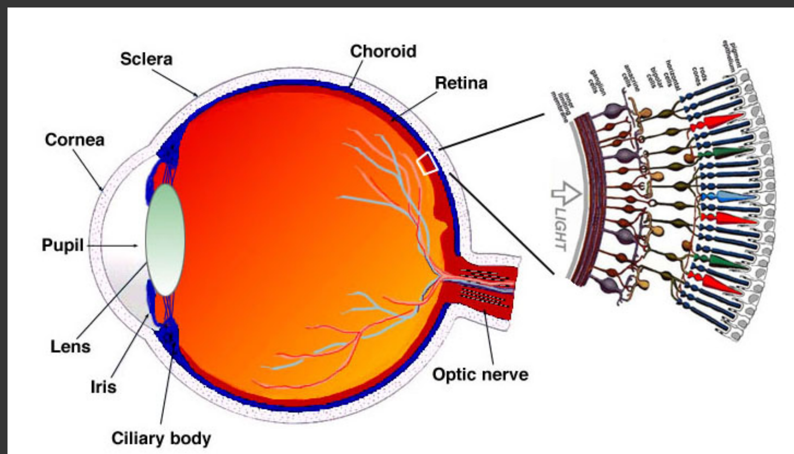
Subtractive
(print, e-paper)

Perception Vs. Measurement

You do not see the spectrum of light

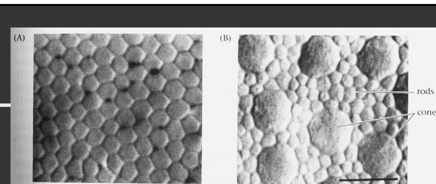
- Eyes make limited measurements
- Eyes physically adapt to circumstance
- You brain adapts in various ways
- Weird stuff also happens

Retina



Simple Anatomy of the Retina, Helga Kolb

Rods and Cones



Rods

- No color (sort of)
- Spread over the retina
- More sensitive

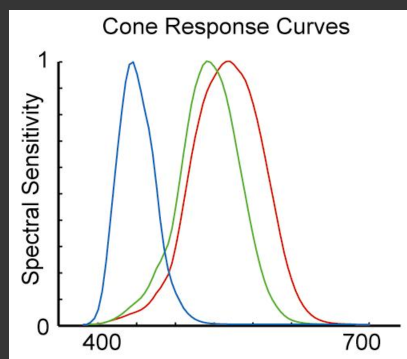
Cones

- 3 types sensitive to different frequencies
- Concentrated in fovea (center of the retina)
- Less sensitive

As light enters our cones…

LMS (Long, Middle, Short) Cones

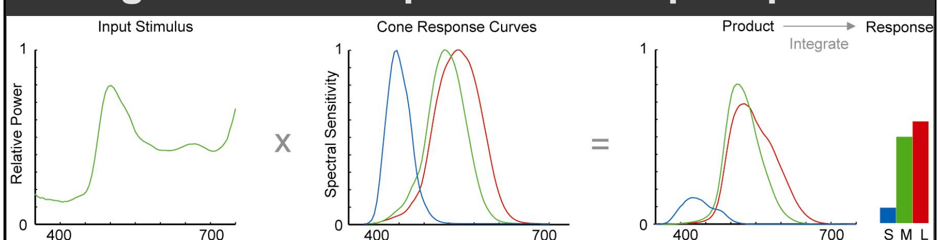
Sensitive to different wavelength



A Field Guide to Digital Color, Maureen Stone

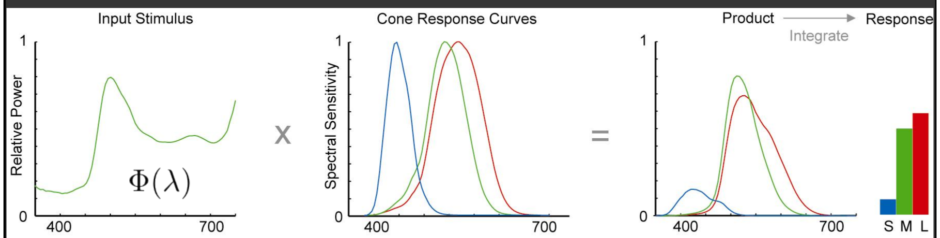
Cone Response

Integrate cone response with input spectra



Computing Cone Response

Integrate cone response with input spectra



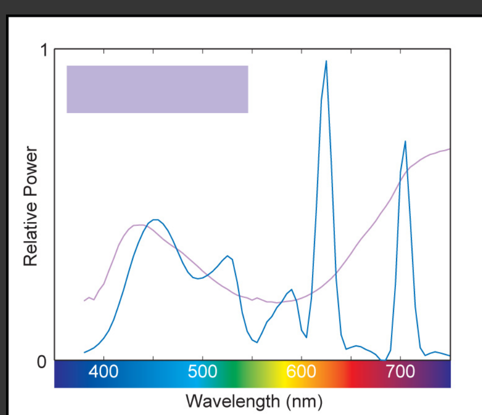
$$L = \int \Phi(\lambda) L(\lambda) \mathrm{d}\lambda$$

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

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

Metamers

All spectra that stimulate the same cone response are indistinguishable

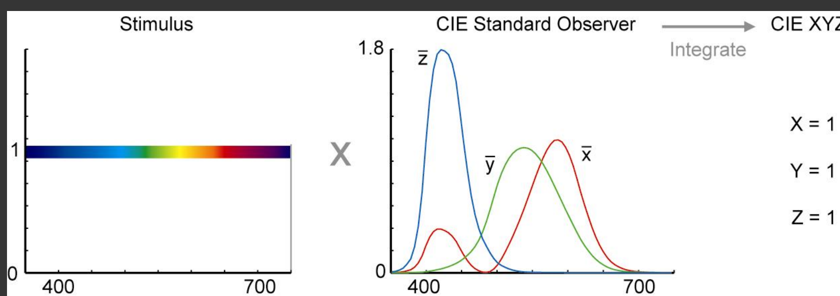


Two different spectra $\Phi_1(\lambda), \Phi_2(\lambda)$ produce same L,M,S response

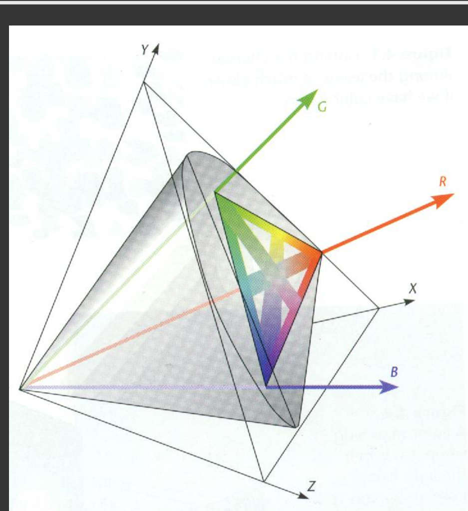
CIE XYZ Color Space

Standardized in 1931 to mathematically represent tri-stimulus response

"Standard observer" response curves



Chromaticity Diagram



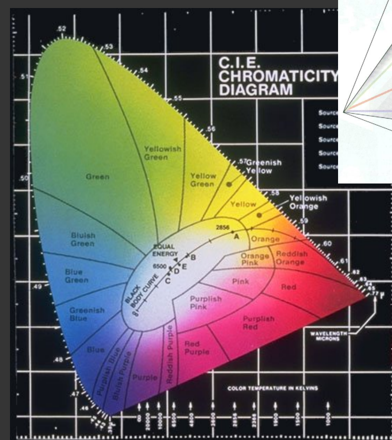
Colin Ware

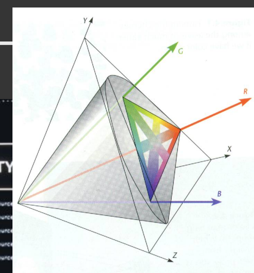
Chromaticity Diagram

Project X,Y,Z on a plane to separate colorfulness from brightness

$x = X/(X+Y+Z)$
$y = Y/(X+Y+Z)$
$z = Z/(X+Y+Z)$

$1 = x+y+z$

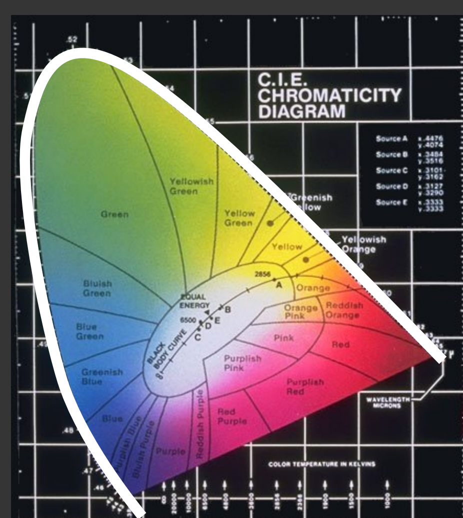




Courtesy of PhotoResearch, Inc.

CIE chromaticity diagram

Spectrum locus

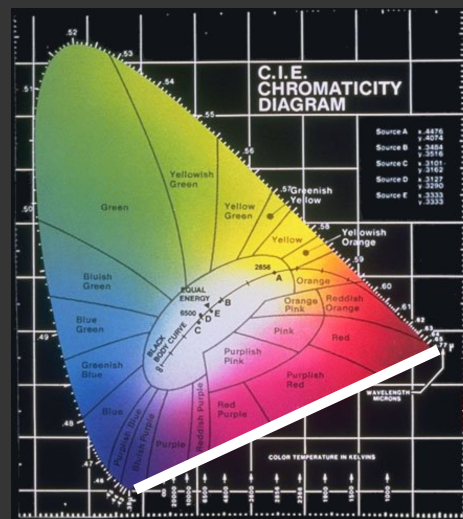


Courtesy of PhotoResearch, Inc.

CIE chromaticity diagram

Spectrum locus

Purple line



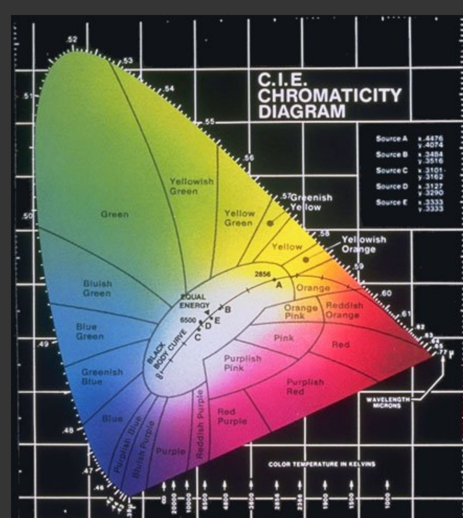
Courtesy of PhotoResearch, Inc.

CIE chromaticity diagram

Spectrum locus

Purple line

Mixture of two lights appears as a straight line



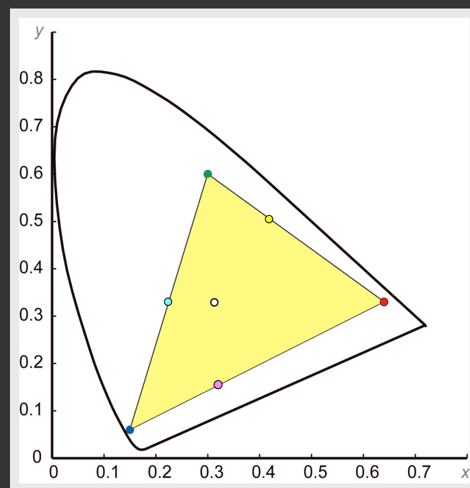
Courtesy of PhotoResearch, Inc.

Display Gamut

Typically defined by:

3 “Primaries”

Convex region



Other Gamuts

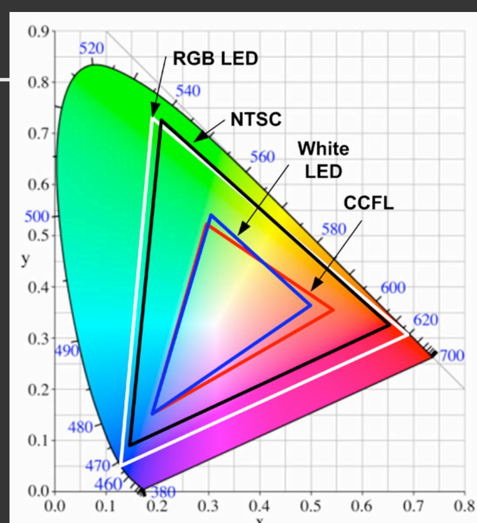


Fig. 3. The color gamut of LCDs with backlights employing CCFL, white LEDs and RGB LEDs are shown here along with the NTSC (television) color gamut.

Color Models

Physical World | Visual System | Mental Models

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F(λ)	CIE (X,Y,Z)	(A,R-G,Y-B)	Hue, lightness saturation	Adaptation, Background, Size, …
			CIELAB Munsell (HVC)	CIECAM02

Separate lightness, chroma

Color blindness

Image encoding

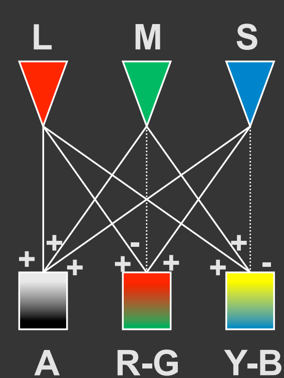
Opponent processing

LMS are linearly combined to create:

Lightness

Red-green contrast

Yellow-blue contrast



Fairchild

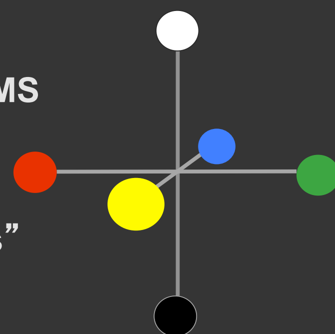
Opponent Color

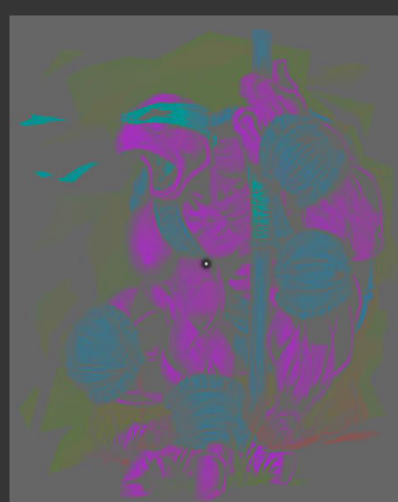
Definition

- Achromatic, lightness axis
- R-G and Y-B axis
- Separate lightness from chroma channels

First level encoding

- Linear combination of LMS
- Before optic nerve
- Basis for perception
- Defines “color blindness”





Color blindness

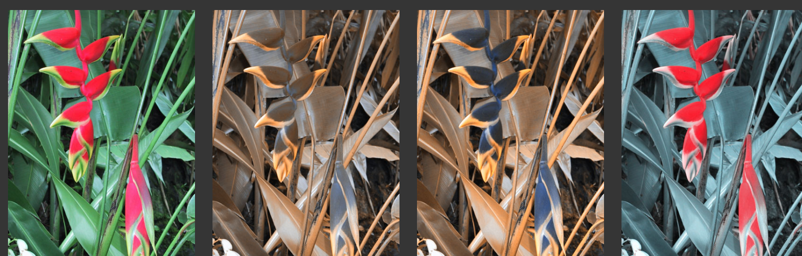
Missing one or more retina cones or rods

Vischeck

Simulates color vision deficiencies

- Web service or Photoshop plug-in
- Robert Dougherty and Alex Wade

www.vischeck.com



Deuteranope Protanope Tritanope

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Color differences
"Intuitive" color spaces

Color scales

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"

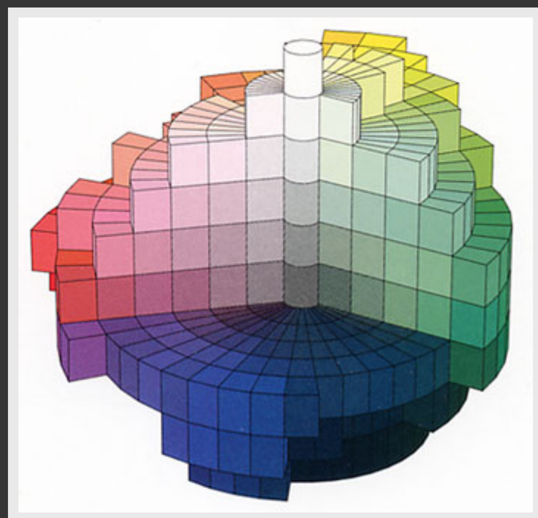
JND = Just noticeable difference (~2.3 units)

Munsell Atlas

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

Courtesy Gretag-Macbeth

Hue, Value, Chroma



Hue, Value, Chroma

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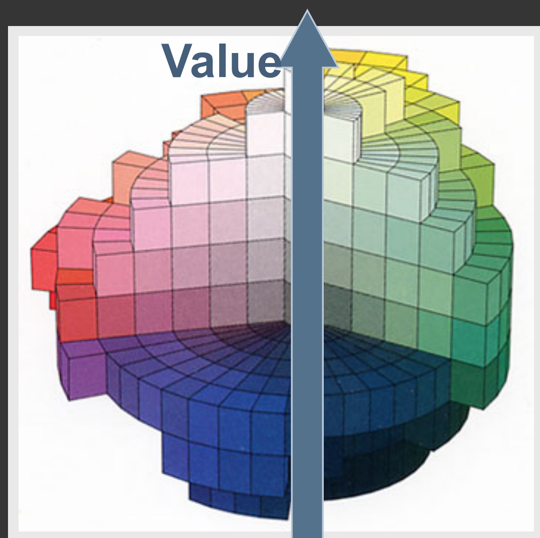
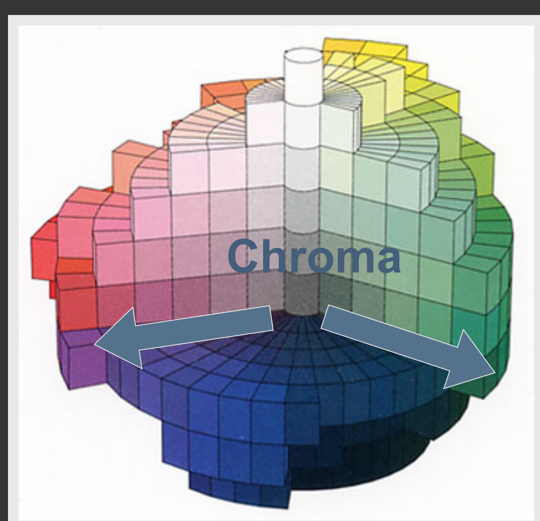


Hue, Value, Chroma



Psuedo-Perceptual Models

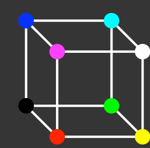
HLS, HSV, HSB

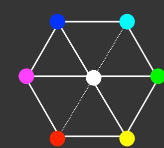
NOT perceptual models

Simple renotation 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

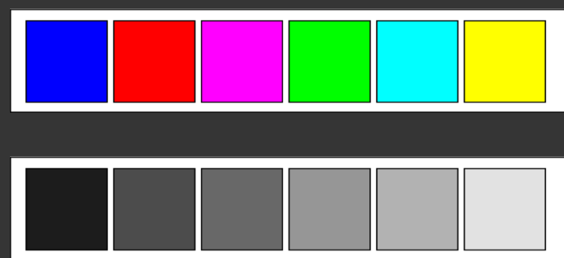
(Photoshop)

Perceptual brightness

Color palette

Luminance Y

(CIE XYZ)

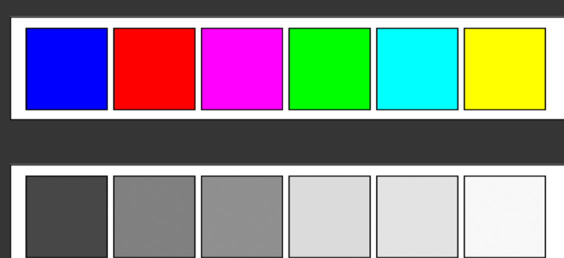


Perceptual brightness

Color palette

Munsell Value

L* (CIE LAB)



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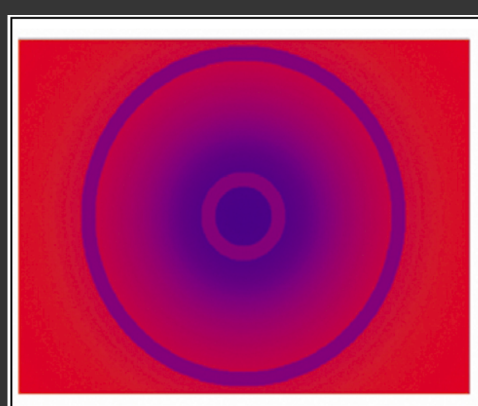
				Adaptation Contrast effects Image appearance Complex matching

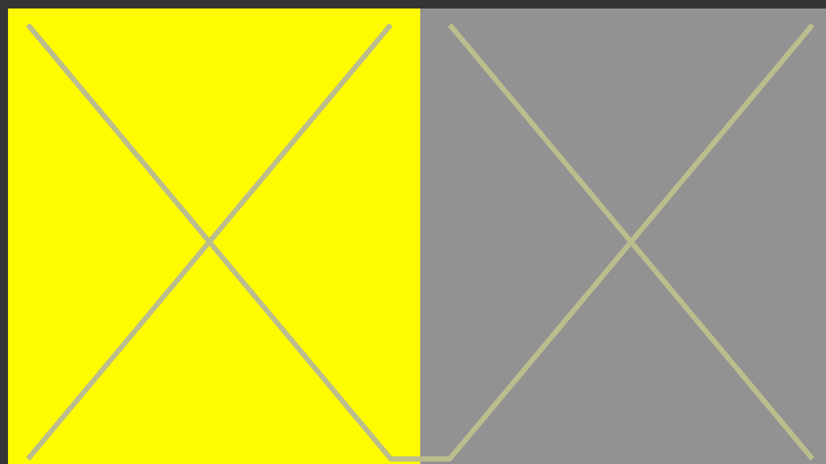
Simultaneous Contrast

The inner and outer thin rings are the physical purple



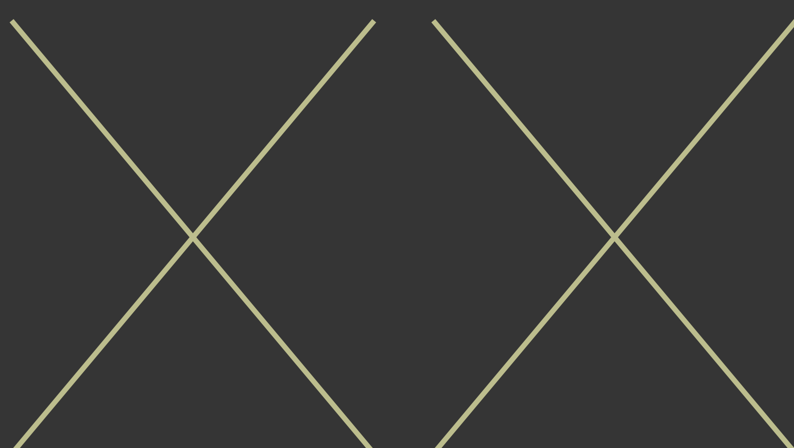
Donald MacLeod

Simultaneous Contrast



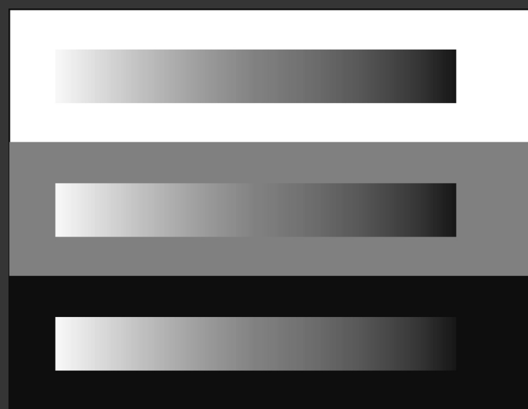
Josef Albers

Simultaneous Contrast

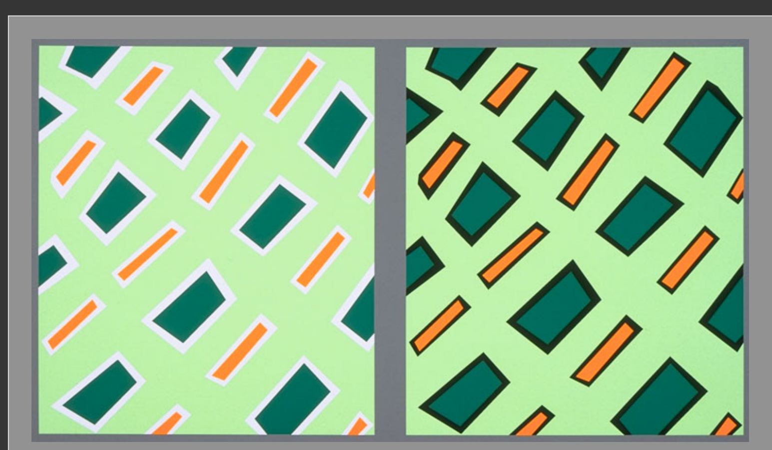


Josef Albers

Affects Lightness Scale

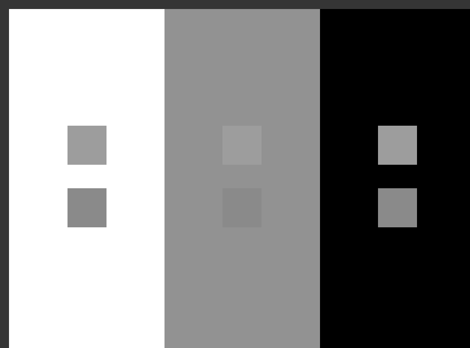


Bezold Effect



Crispening

Perceived difference depends on background



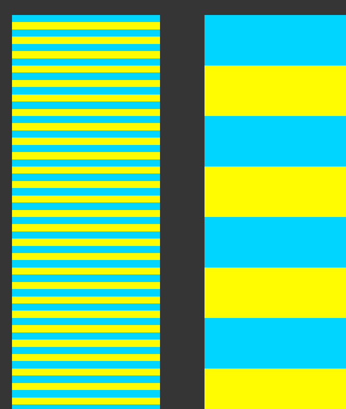
From Fairchild, *Color Appearance Models*

Spreading

Adjacent colors blend

Spatial frequency

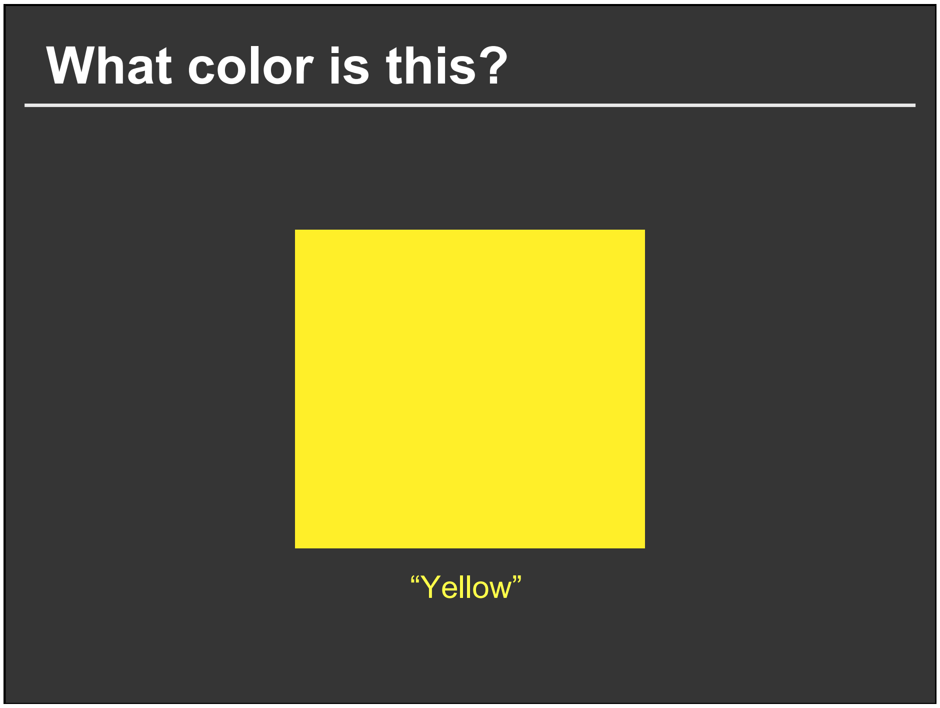
- **The paint chip problem**
- **Small text, lines, glyphs**
- **Image colors**

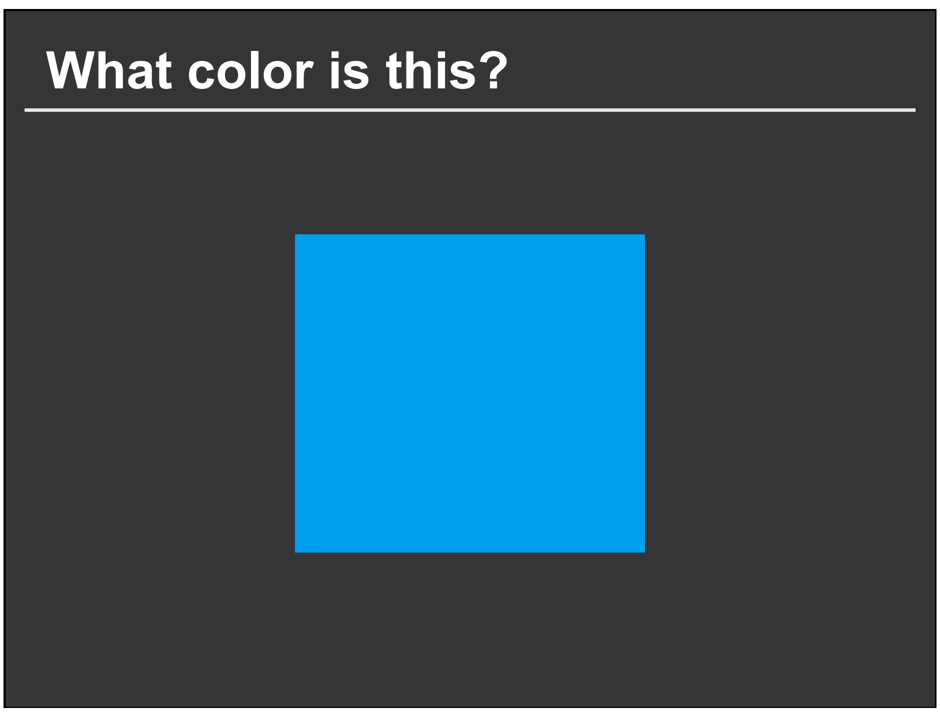


Redrawn from *Foundations of Vision*

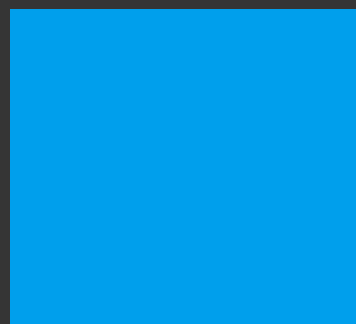
Color Naming

What color is this?


What color is this?
“Yellow”


What color is this?

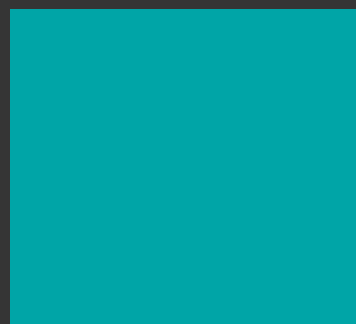
What color is this?



“Blue”

What color is this?

What color is this?



“Teal” ?

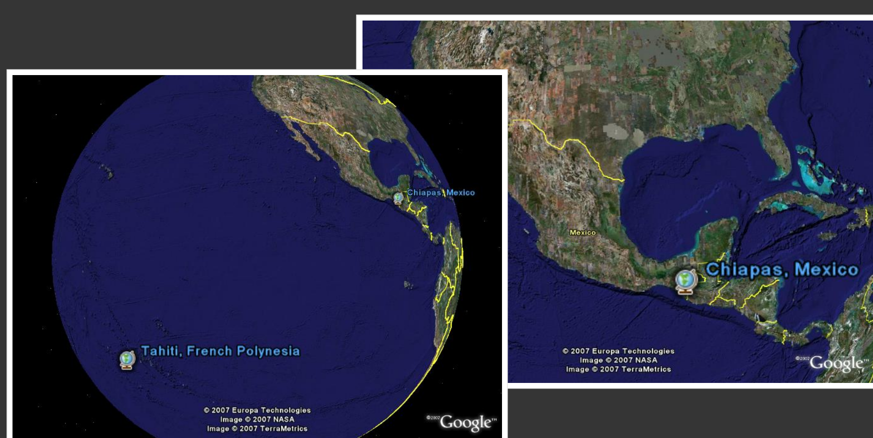
Colors according to XKCD…

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

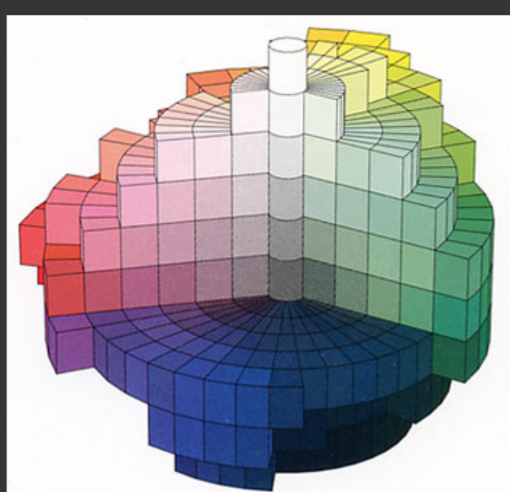
Chance discovery by Brent Berlin and Paul Kay

Initial study in 1969

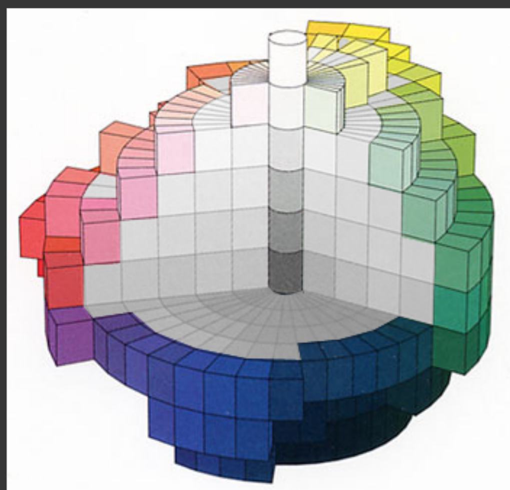
Surveyed speakers from 20 languages

Literature from 69 languages

World color survey



World color survey



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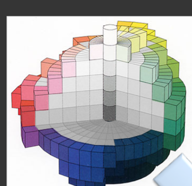
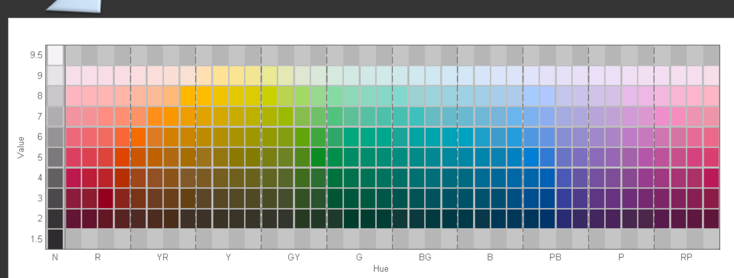
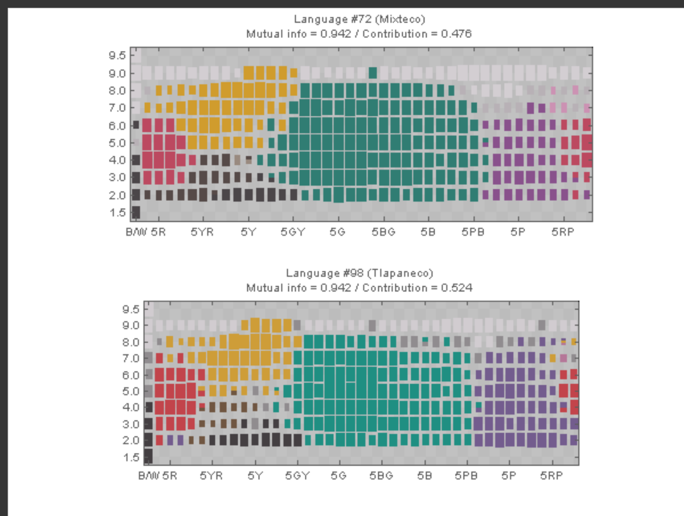


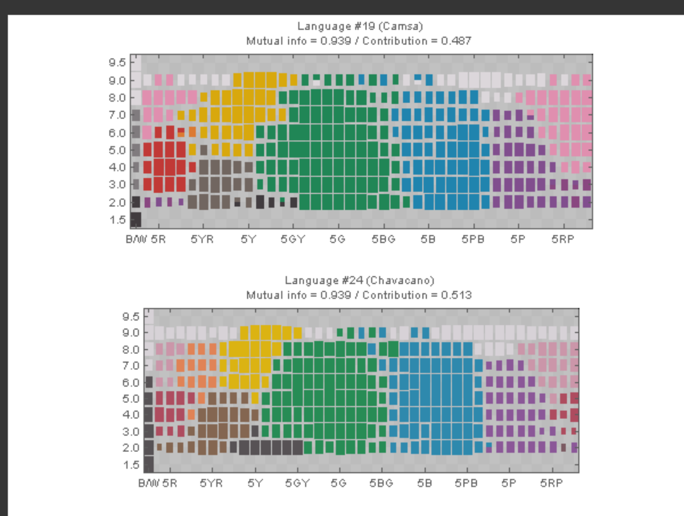
Naming information from 2616 speakers from 110 languages on 330 Munsell color chips



Results from WCS (Mexico)



Results from WCS (South Pacific)



Universal (?) Basic Color Terms

Basic color terms recur across languages

White Red Pink

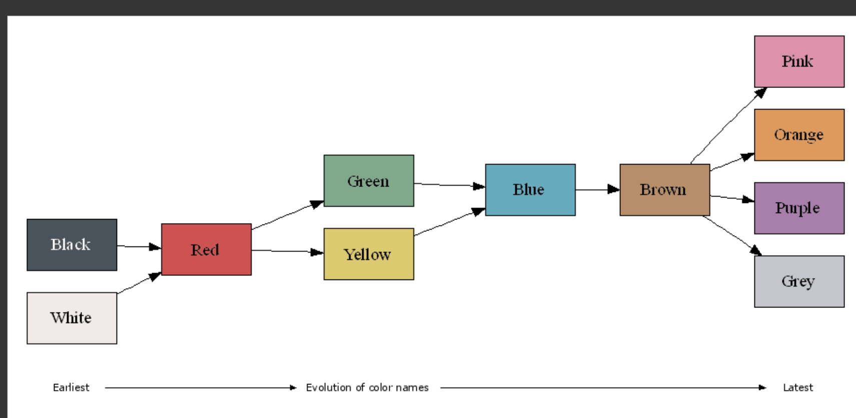
Grey Yellow Brown

Black Green Orange

Blue Purple

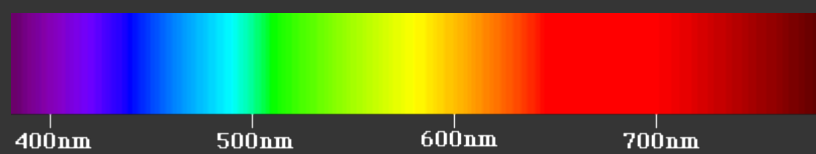
Evolution of Basic Color Terms

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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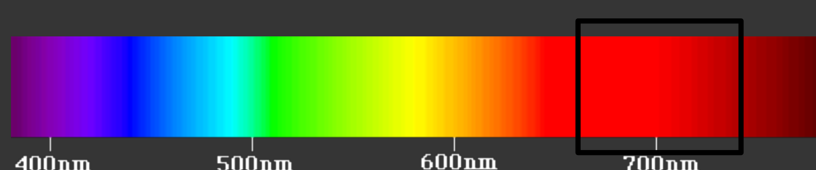

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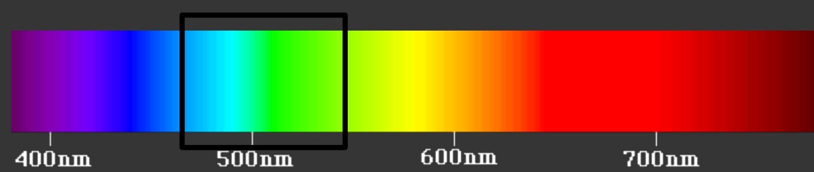
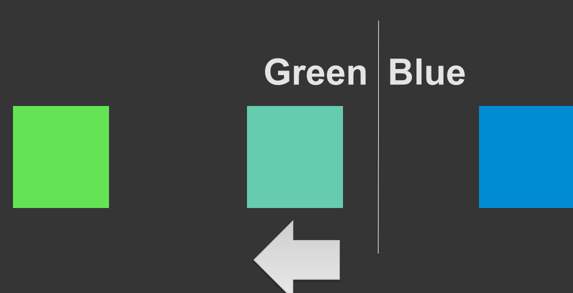


Naming affects color perception

Color name boundaries



Color naming models

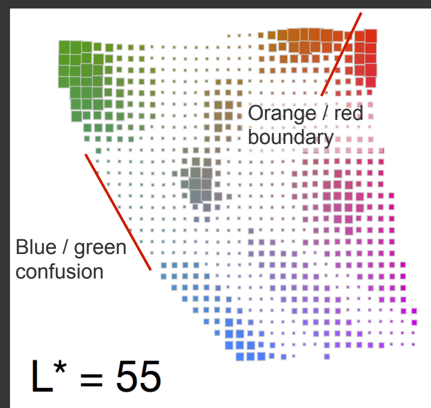
[Heer & Stone]

Model 3 million responses from XKCD survey

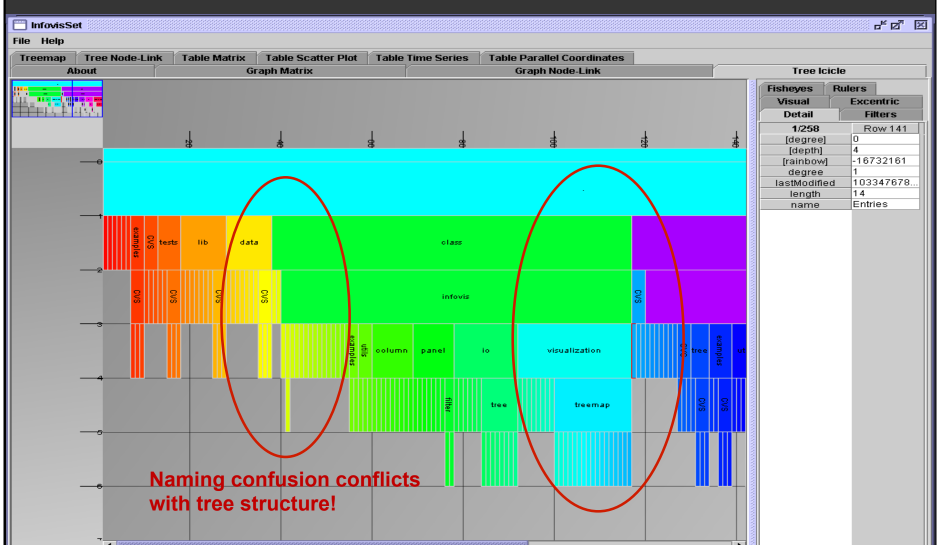
Bins in LAB space sized by *saliency*:

How much do people agree on color name?

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

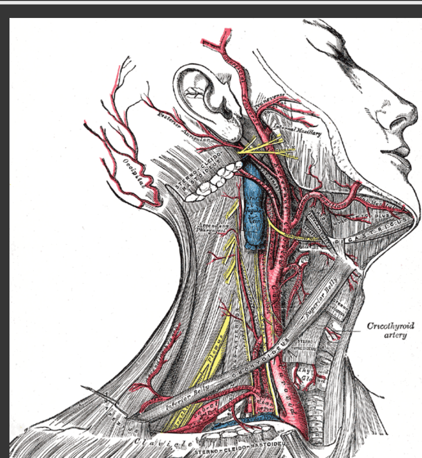


Icicle tree with colors



Using Color in Visualization

Gray’s Anatomy



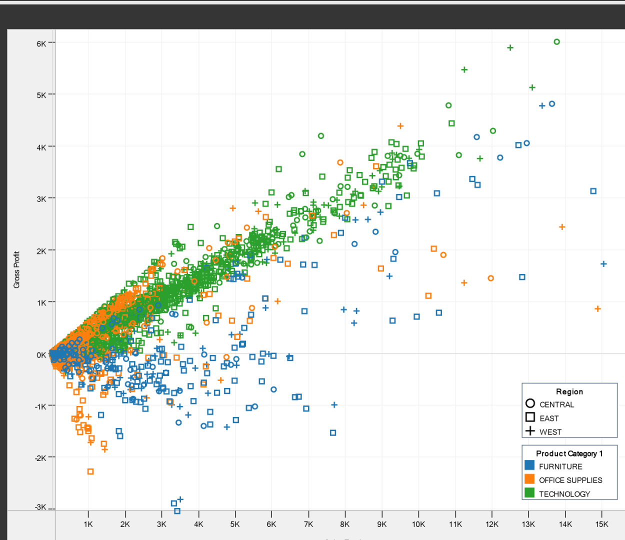
Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries

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

Molecular Models

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

Product Categories



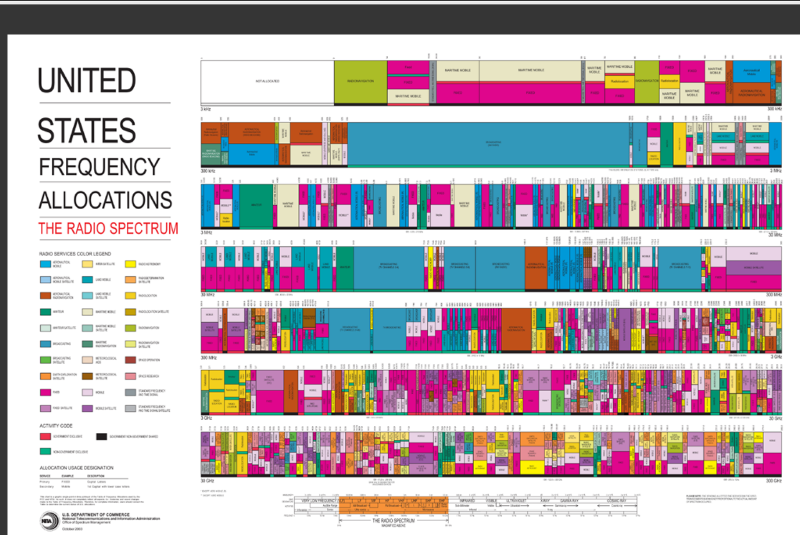
Created by Tableau - Visual Analysis for Databases™

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

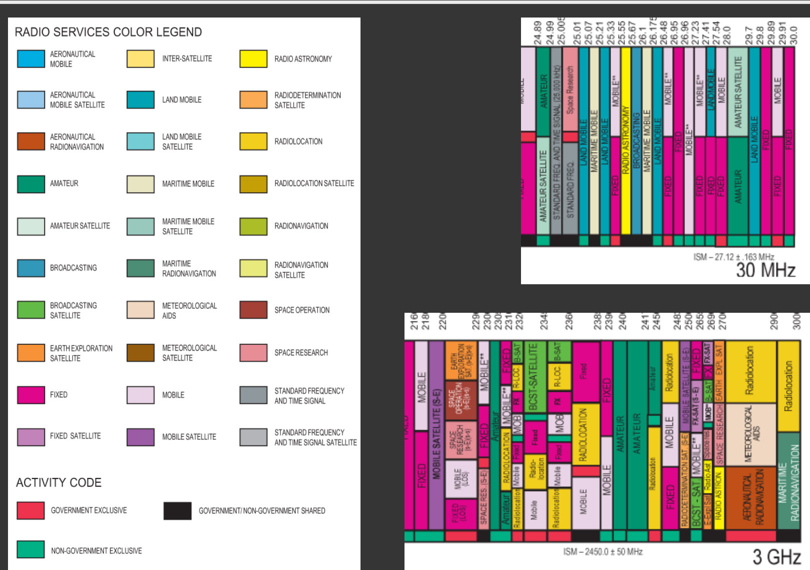
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
red	25.37	13.70	0.05	26.27	14.13	0.04	18.41	10.16	0.05	17.43	9.30	0.00
green	22.14	51.24	0.35	20.68	49.17	0.44	21.11	46.00	0.20	16.36	37.95	0.12
blue	13.17	3.71	74.89	15.38	5.20	86.83	11.55	3.37	65.53	9.96	3.44	56.14
gray	63.46	73.30	78.05	64.66	71.99	90.08	52.96	62.49	67.99	45.54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

Radio Spectrum Map (33 colors)



http://www.cybergeography.org/atlas/us_spectrum_map.pdf

Distinguishable on Inspection



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

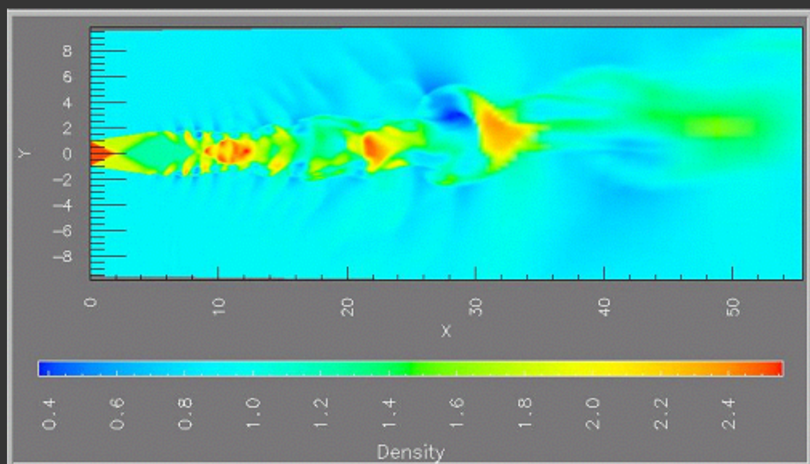
Minimize overlap and ambiguity of color names

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*	

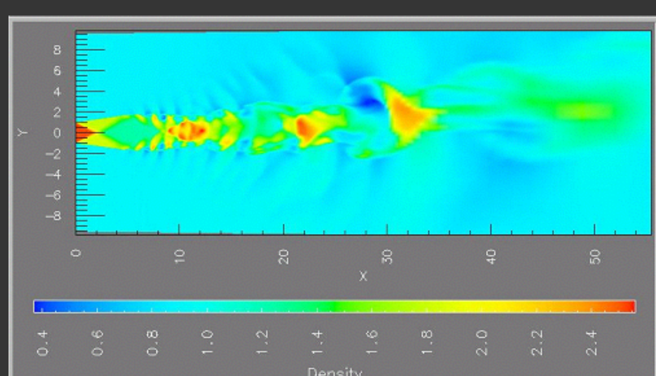
http://vis.stanford.edu/color-names

Mapping Data to Color Scale

Default rainbow maps



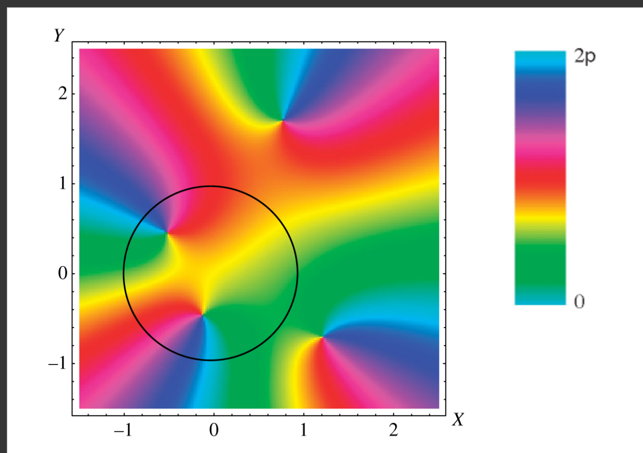
Avoid rainbow color maps!



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

Phase Diagrams (hue scale)

Singularities occur where all colors meet



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

Phases of the Tides

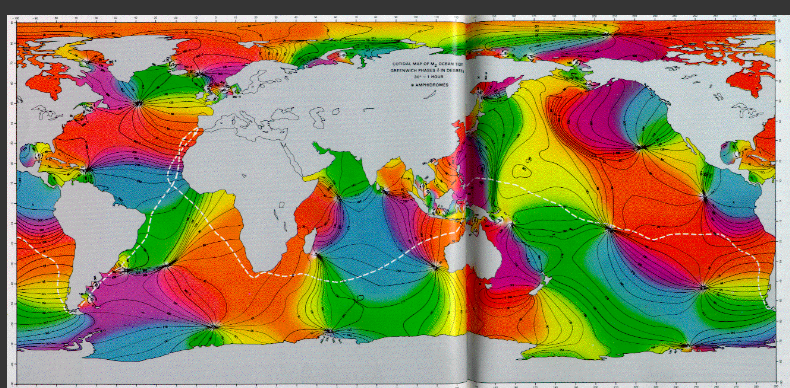
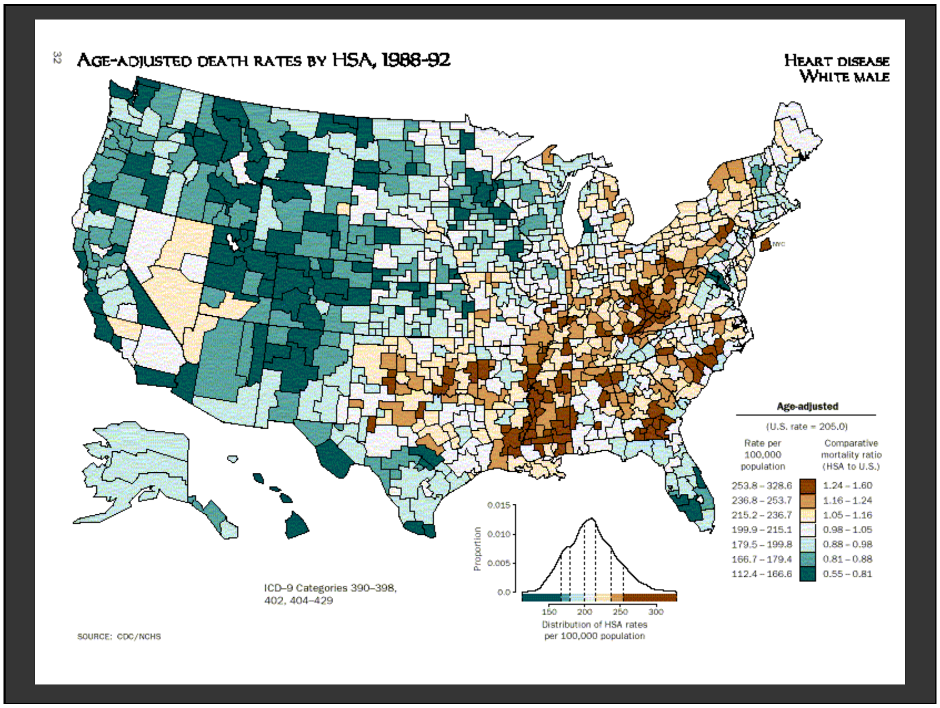
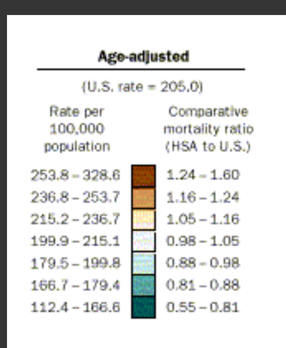
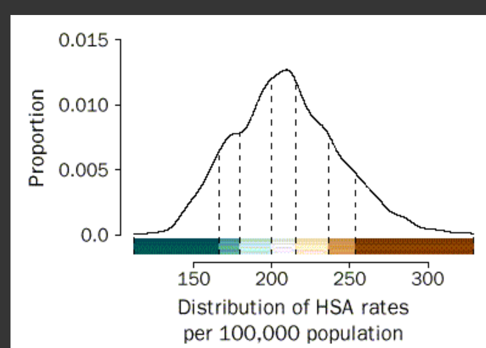


Figure 1.9. Cotidal chart. Tide phases relative to Greenwich are plotted for all the world's oceans. Phase progresses from red to orange to yellow to green to blue to purple. The lines converge on anphidromic points, singularities on the earth's surface where there is no defined tide. [Winfree, 1987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



Classing quantitative data

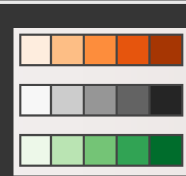




Age-adjusted mortality rates for the United States

Quantitative color encoding

Sequential color scale



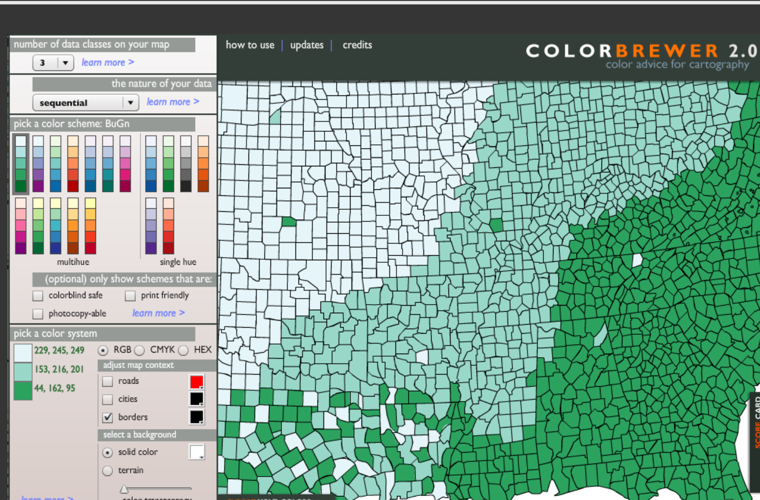
- Constrain hue, vary luminance/saturation
- Map higher values to darker colors

Diverging color scale

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

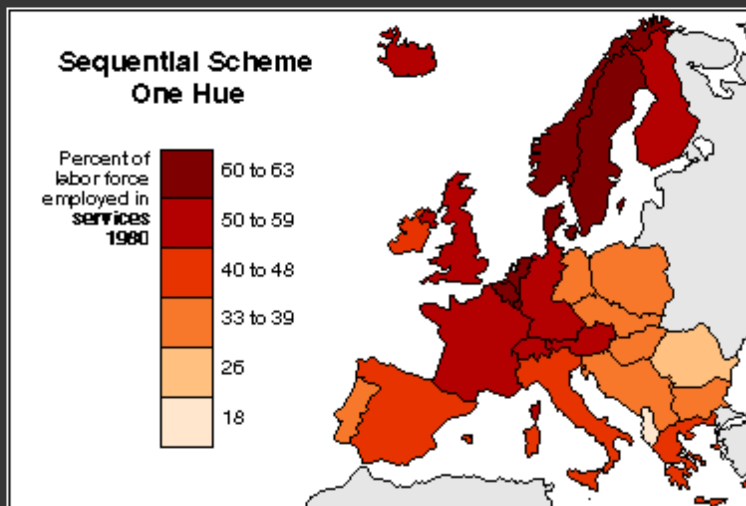
Limit number of steps in color to 3-9

Color Brewer

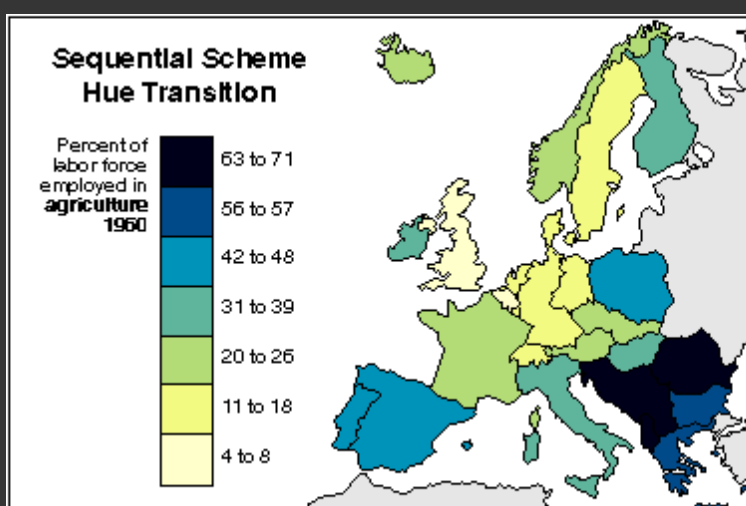


www.colorbrewer.org

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

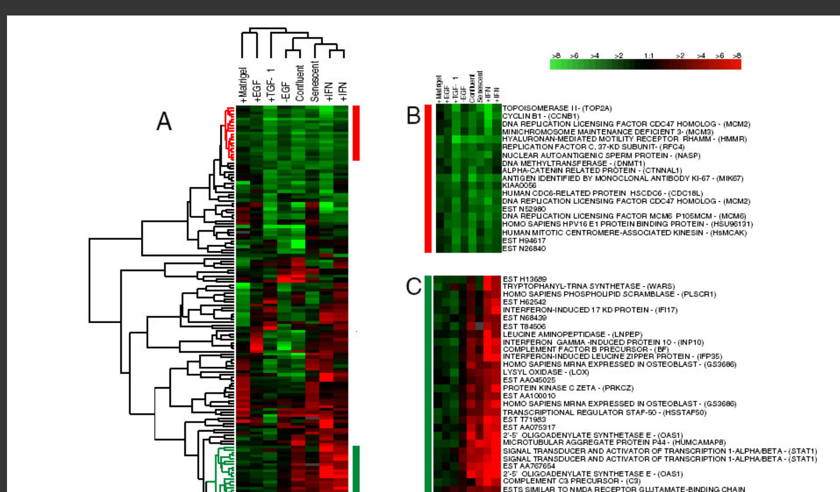
Hue Transition

Two hues

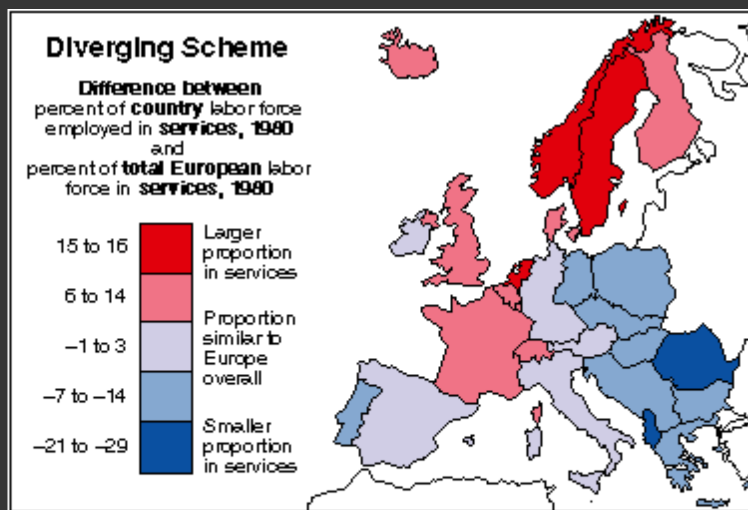
Neighboring hues interpolate better

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

Hints for the colorist

Use only a few colors (~6 ideal)
Colors should be distinctive and named
Strive for color harmony (natural colors?)
Use cultural conventions; appreciate symbolism
Beware of bad interactions (red/blue etc.)
Get it right in black and white
Respect the color blind