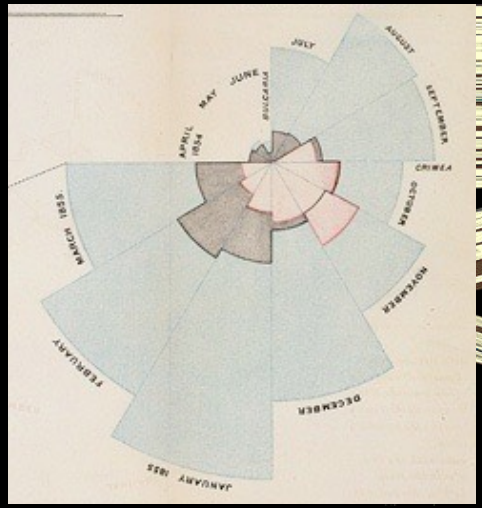
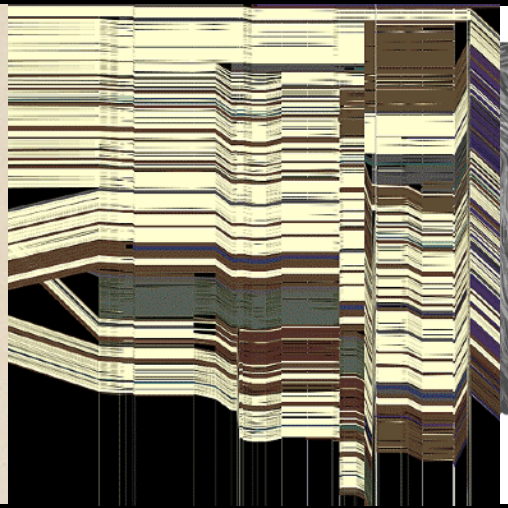
CSE 442 - Data Visualization

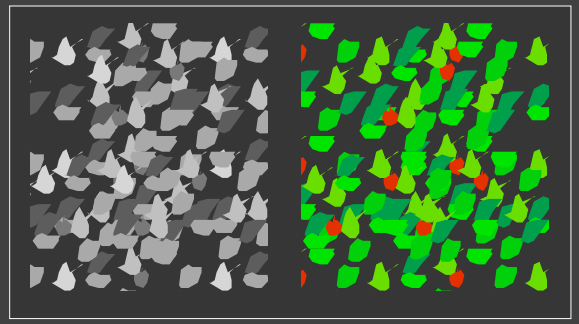
Color





Jeffrey Heer University of Washington

Purpose of Color



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

“Above all, do no harm.”
- Edward Tufte

Color Topics

Perception of Color
Light, Visual system, Mental models

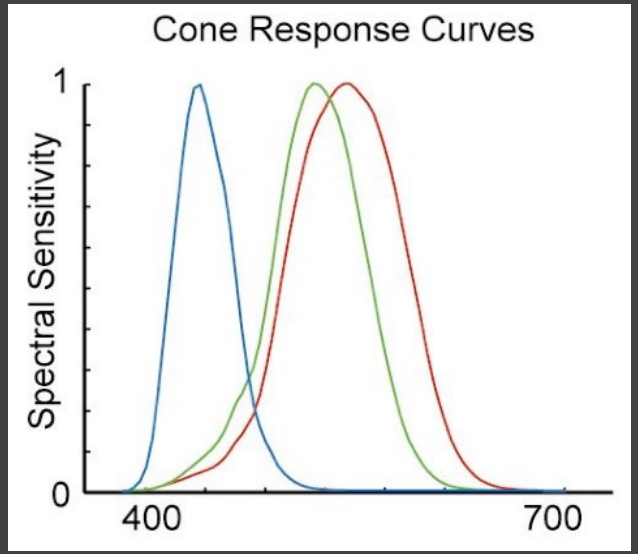
Color in Information Visualization
Categorical & Quantitative encoding
Guidelines for color palette design

Perception of Color

As light enters our retina…

LMS (Long, Middle, Short) Cones

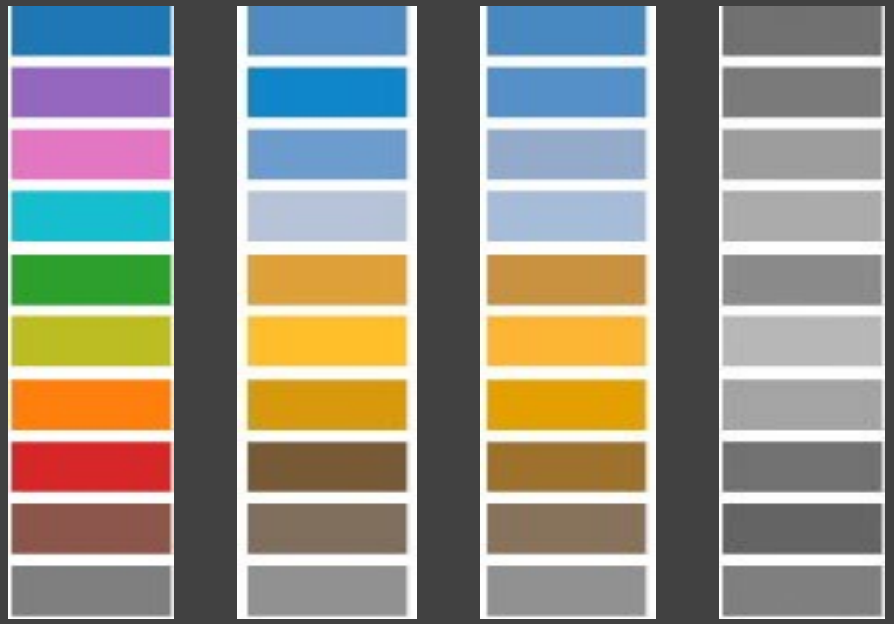
Sensitive to different wavelengths



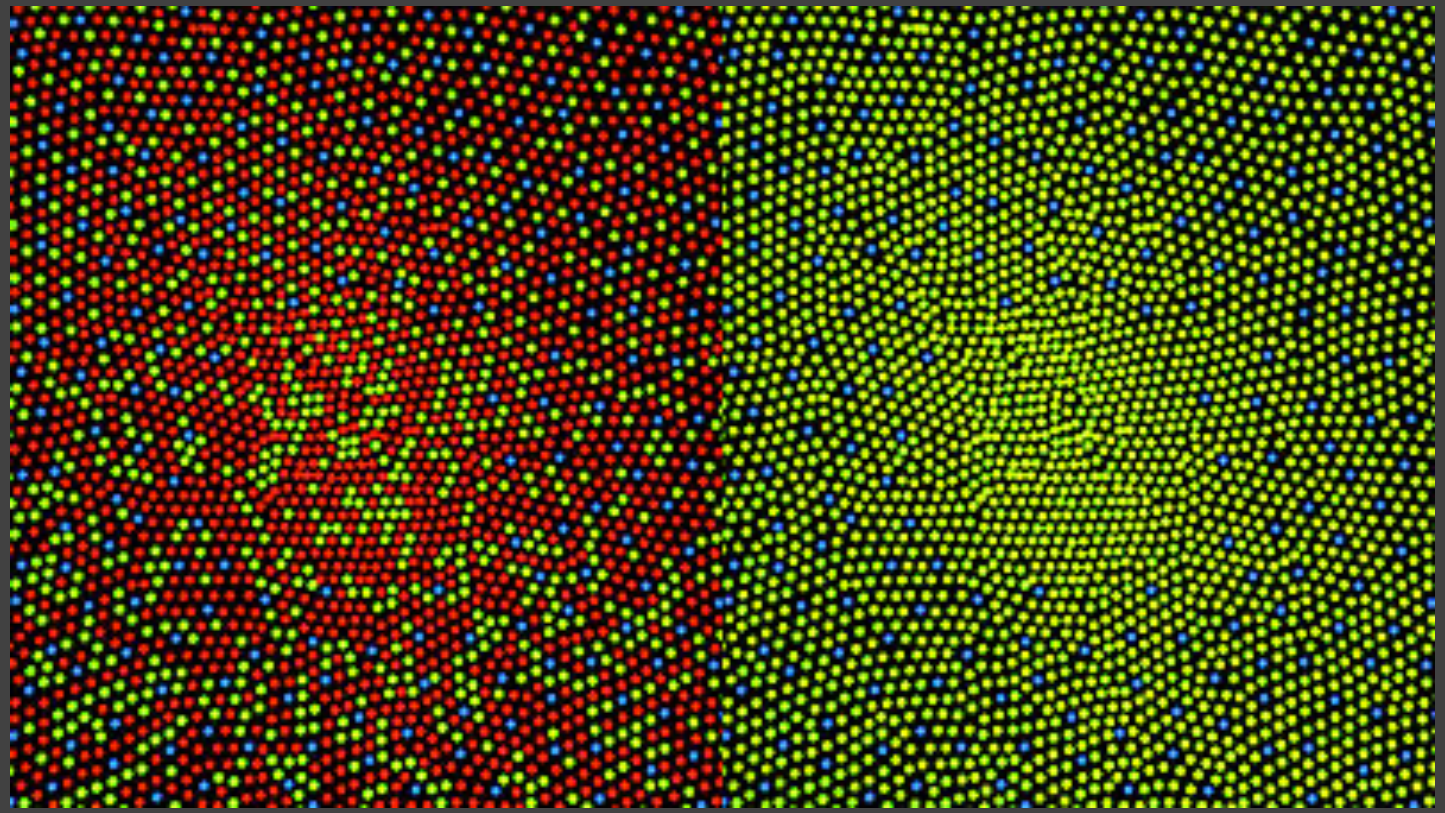
A Field Guide to Digital Color, M. Stone

Color Vision Deficiency (CVD)

Missing one or more cones or rods in retina.



Protanope Deuteranope Luminance



Normal Retina

Protanopia

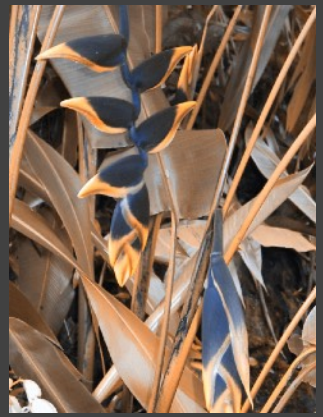
Color Vision Simulators

Simulate color vision deficiencies

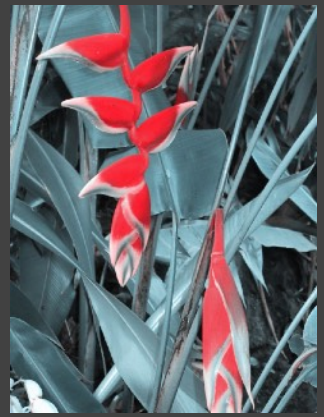
Browser plug-ins

Photoshop plug-ins, etc.

Deuteranope



Protanope



Tritanope

Primary Colors

To paint “all colors”:
Leonardo da Vinci, circa 1500 described in his notebooks a list of simple colors…

Yellow
Blue
Green
Red

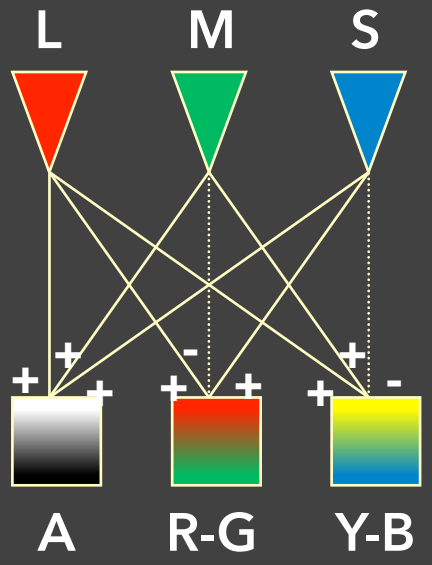
Opponent Processing

LMS are combined to create:

Lightness

Red-green contrast

Yellow-blue contrast



[Fairchild]

Opponent Processing

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Lightness

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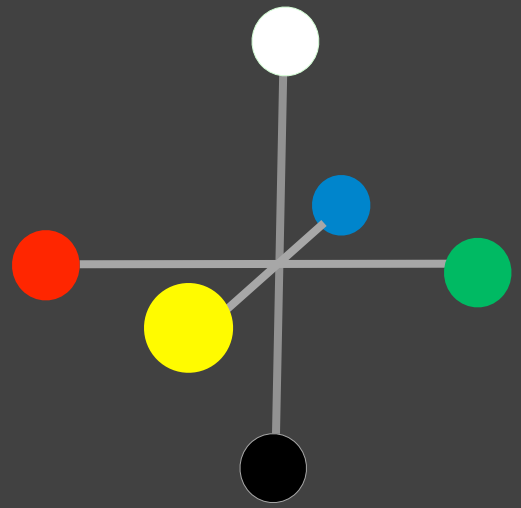
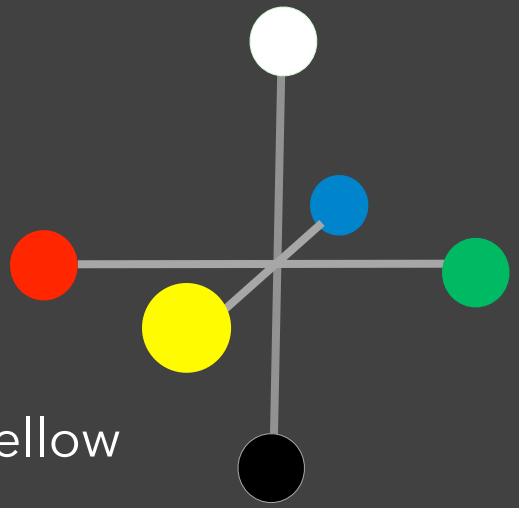
Yellow-blue contrast



Opponent Processing

LMS are combined to create:
Lightness
Red-green contrast
Yellow-blue contrast

Experiments:
No reddish-green, no blueish-yellow
Color after images



CIE LAB Color Space

Axes correspond to opponent signals

L* = Luminance

a* = Red-green contrast

b* = Yellow-blue contrast

Much more perceptually uniform than sRGB!

Scaling of axes to represent “color distance”

JND = Just noticeable difference (~2.3 units)

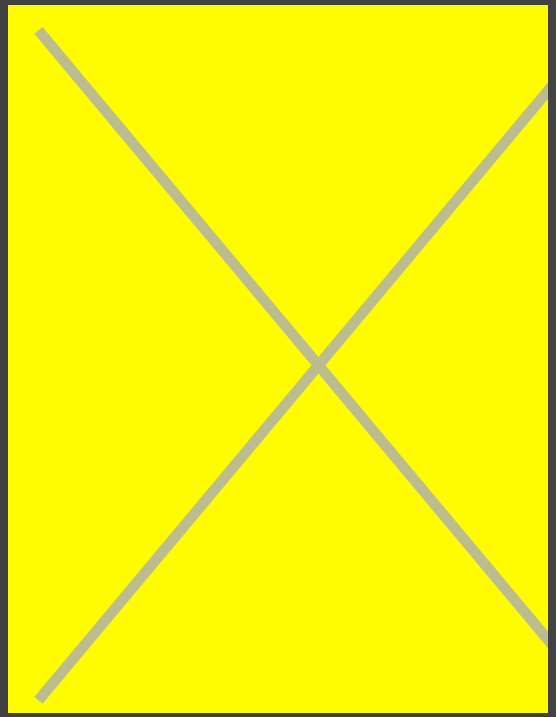
D3 + Vega include LAB color space support!

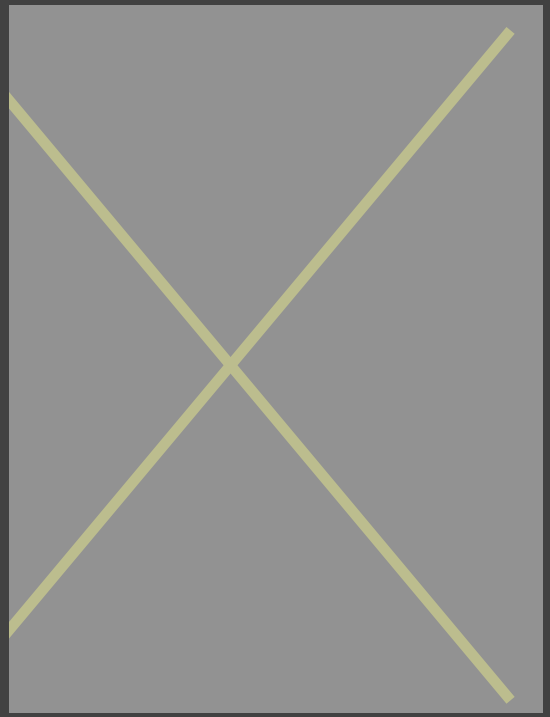
Color Appearance

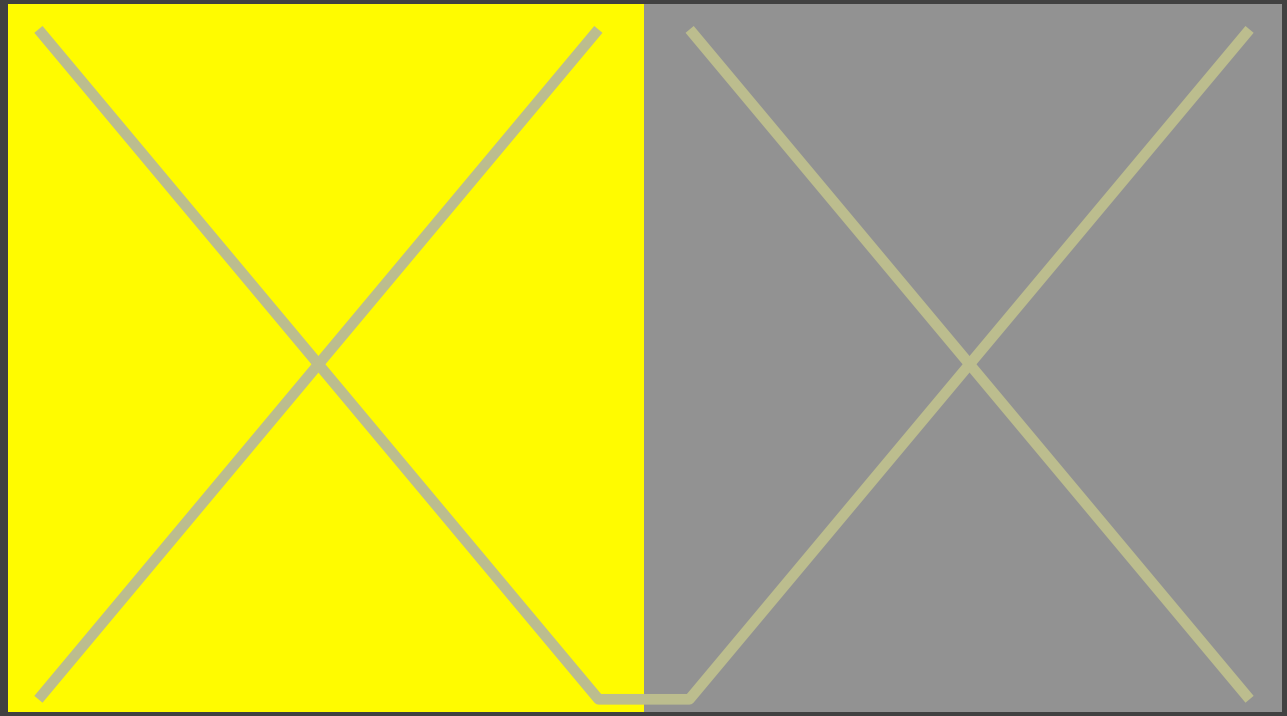
If we have a perceptually-uniform color space, can we predict how we perceive colors?

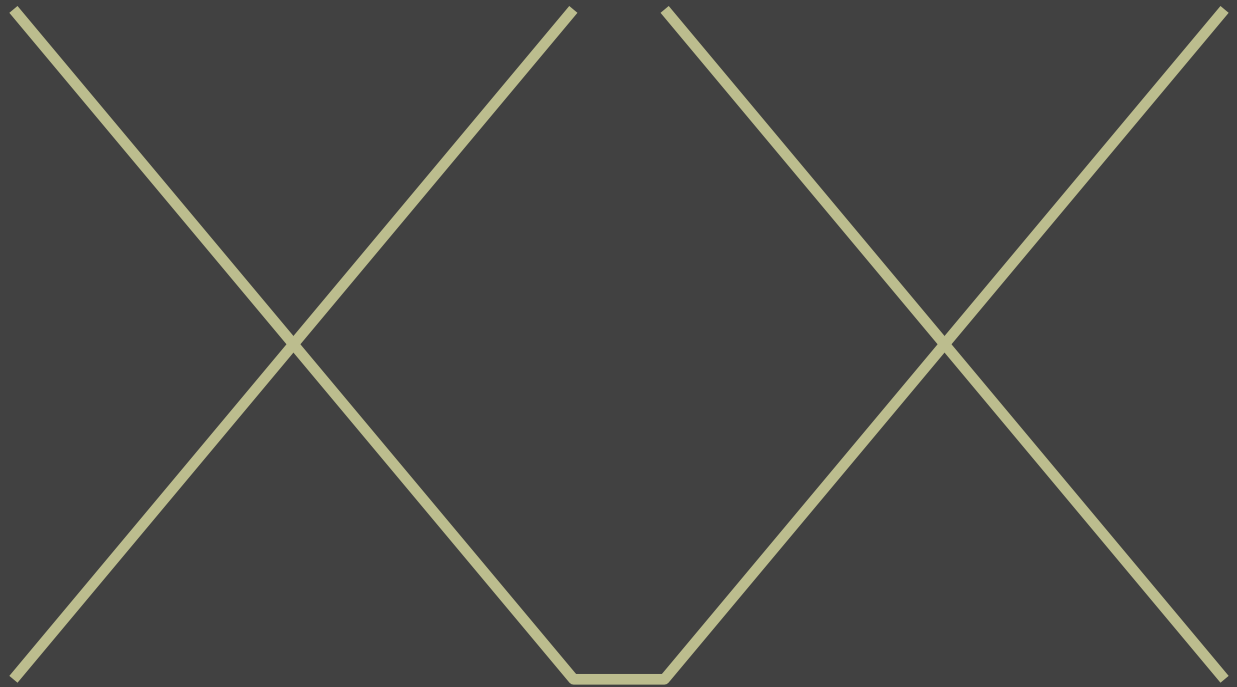
“In order to use color effectively it is necessary to recognize that it deceives continually.”

- Josef Albers, *Interaction of Color*

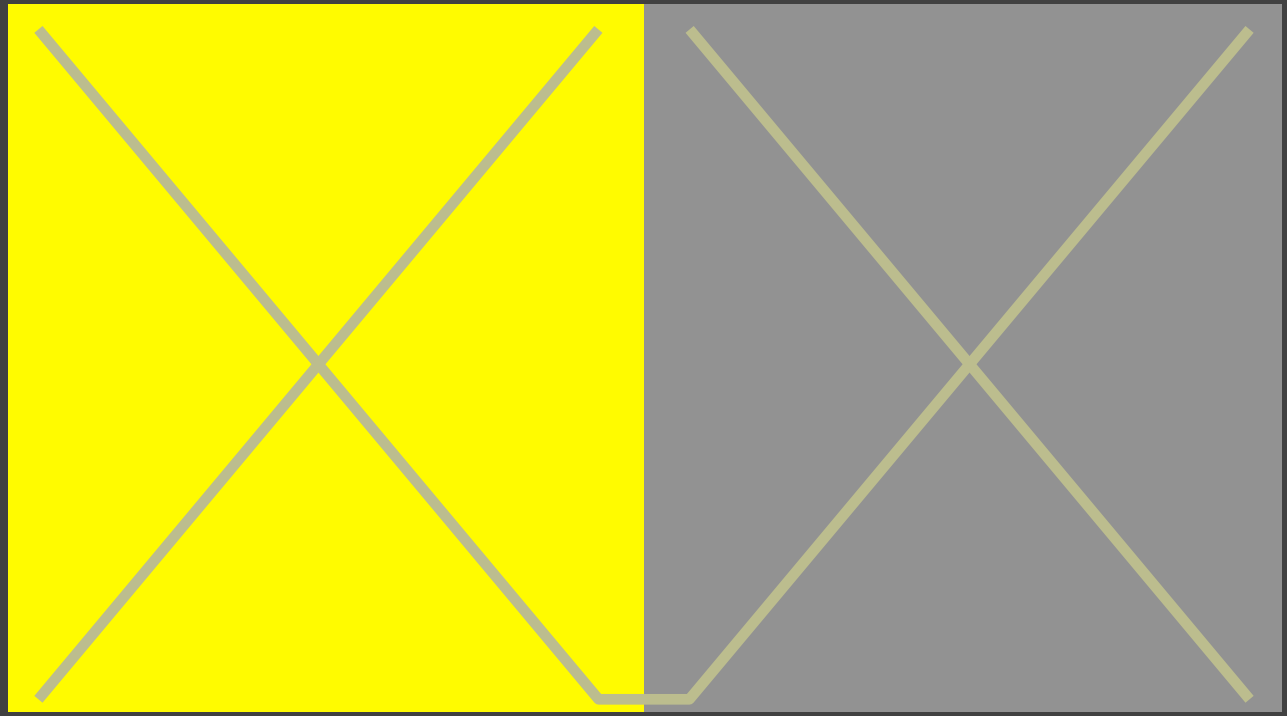








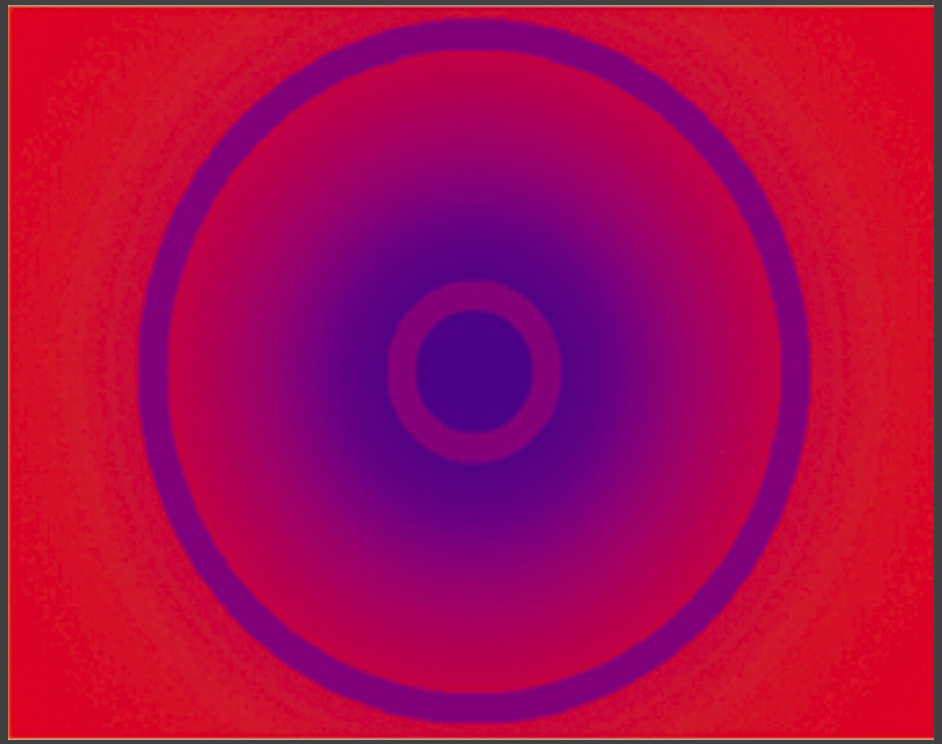
Simultaneous Contrast



Josef Albers

Simultaneous Contrast

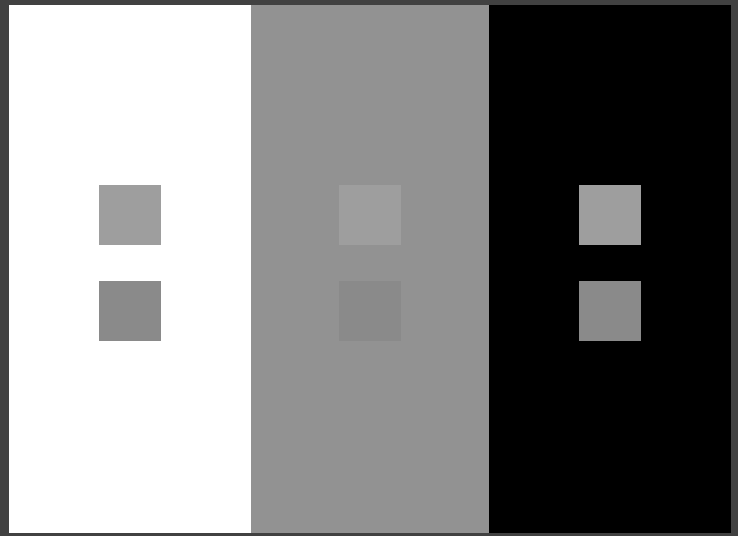
Inner & outer rings are the same physical purple.



Donald
MacLeod

Crispening

Perceived difference depends on background



Color Appearance Models, Fairchild

Designing Colormaps

Colormap Design Considerations

Perceptually distinguishable colors

Value distance matches perceptual distance

Colors and concepts properly align

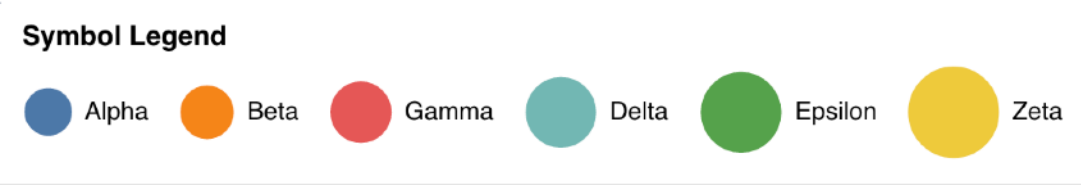
Aesthetically pleasing, intriguing

Respect color vision deficiencies

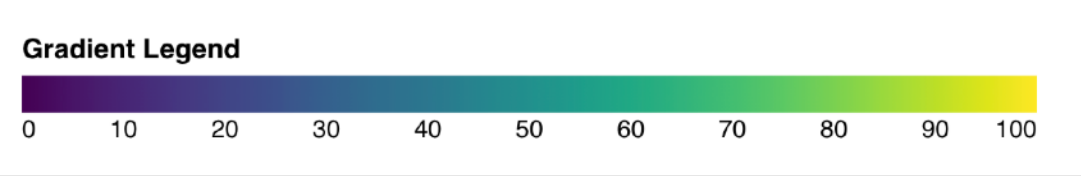
Should survive printing to black & white

Don’t overwhelm people’s capability!

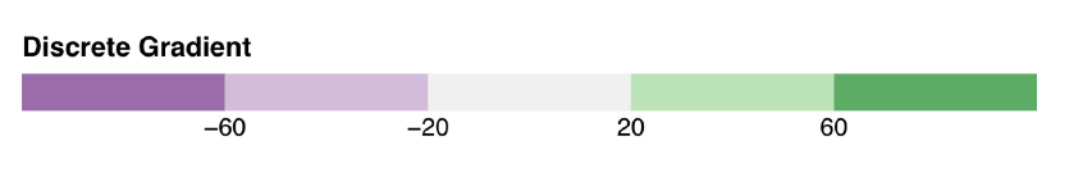
Discrete (Binary, Categorical)



Continuous (Sequential, Diverging, Cyclic)

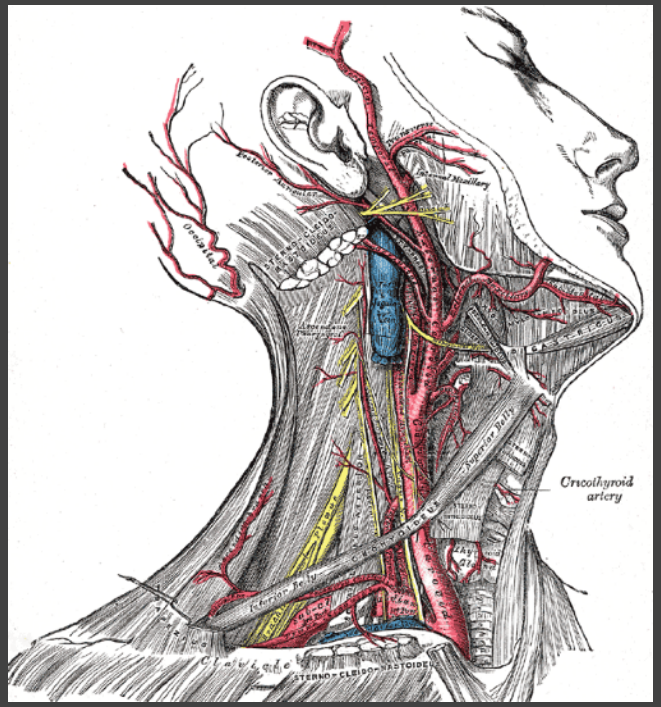


Discretized Continuous



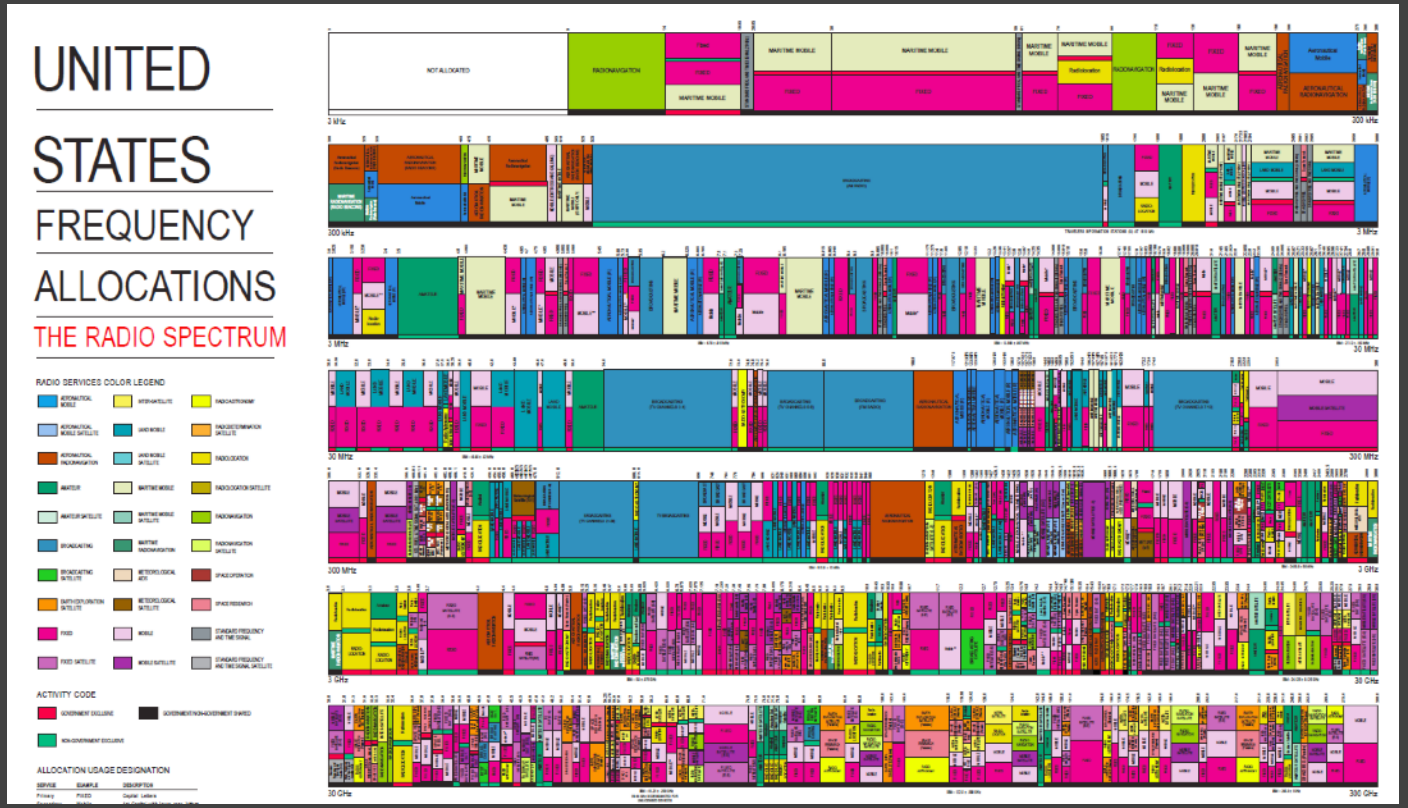
Categorical Color

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)

Allocation of the Radio Spectrum



http://www.ntia.doc.gov/osmhome/allochrt.html

Alloc rum

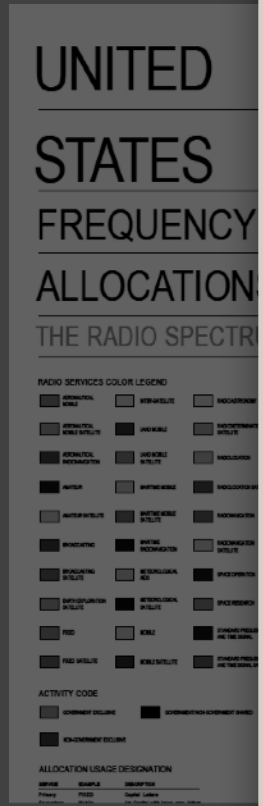
UNITED

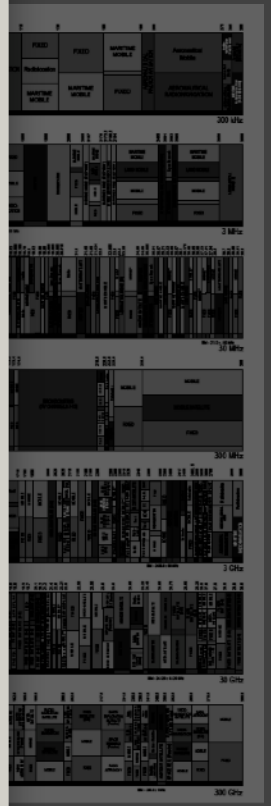
STATES

FREQUENCY

ALLOCATION

THE RADIO SPECTR



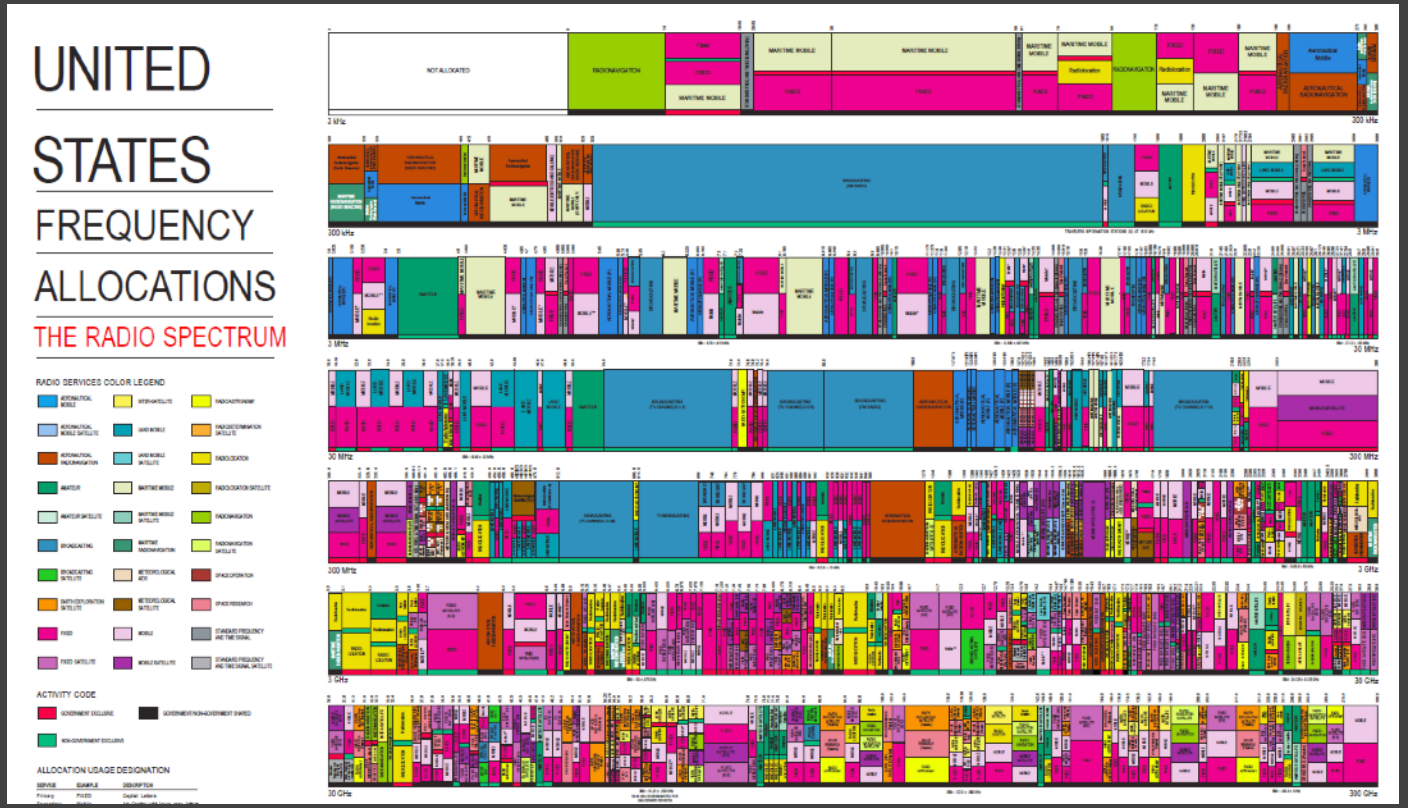


RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE SATELLITE
- MARITIME RADIONAVIGATION
- METEOROLOGICAL AIDS
- METEOROLOGICAL SATELLITE
- MOBILE
- MOBILE SATELLITE
- RADIO ASTRONOMY
- RADIODETERMINATION SATELLITE
- RADIOLOCATION
- RADIOLOCATION SATELLITE
- RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- SPACE OPERATION
- SPACE RESEARCH
- STANDARD FREQUENCY AND TIME SIGNAL
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

Allocation of the Radio Spectrum



http://www.ntia.doc.gov/osmhome/allochrt.html

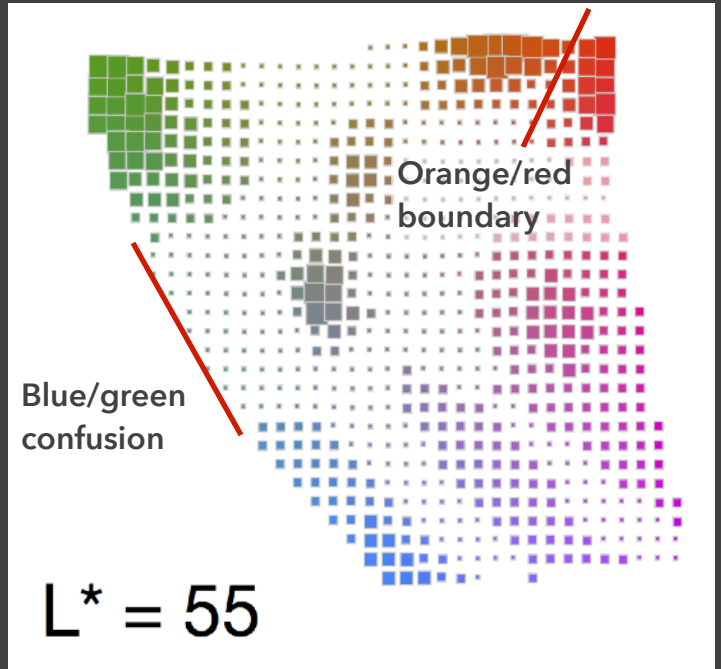
Color Naming Models [Heer & Stone '12]

Model 3 million responses from XKCD survey

Bins in LAB space sized by *saliency*:

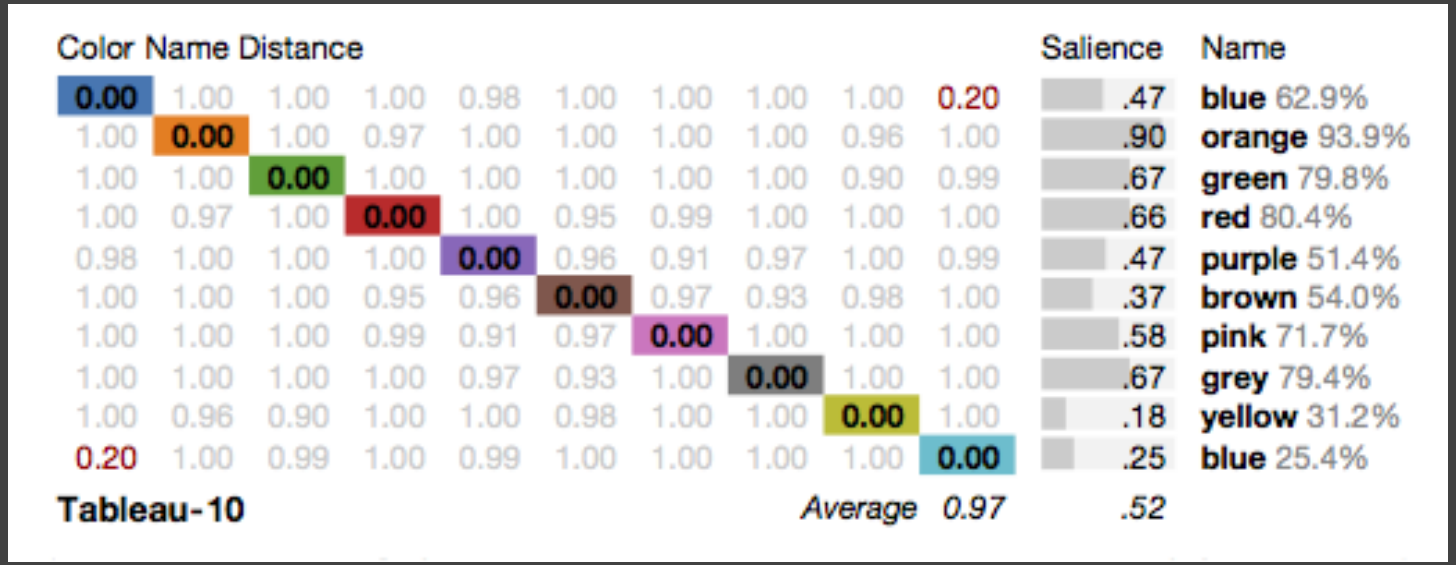
How much do people agree on color name?

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



Palette Design & Color Names

Minimize overlap and ambiguity of colors.



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

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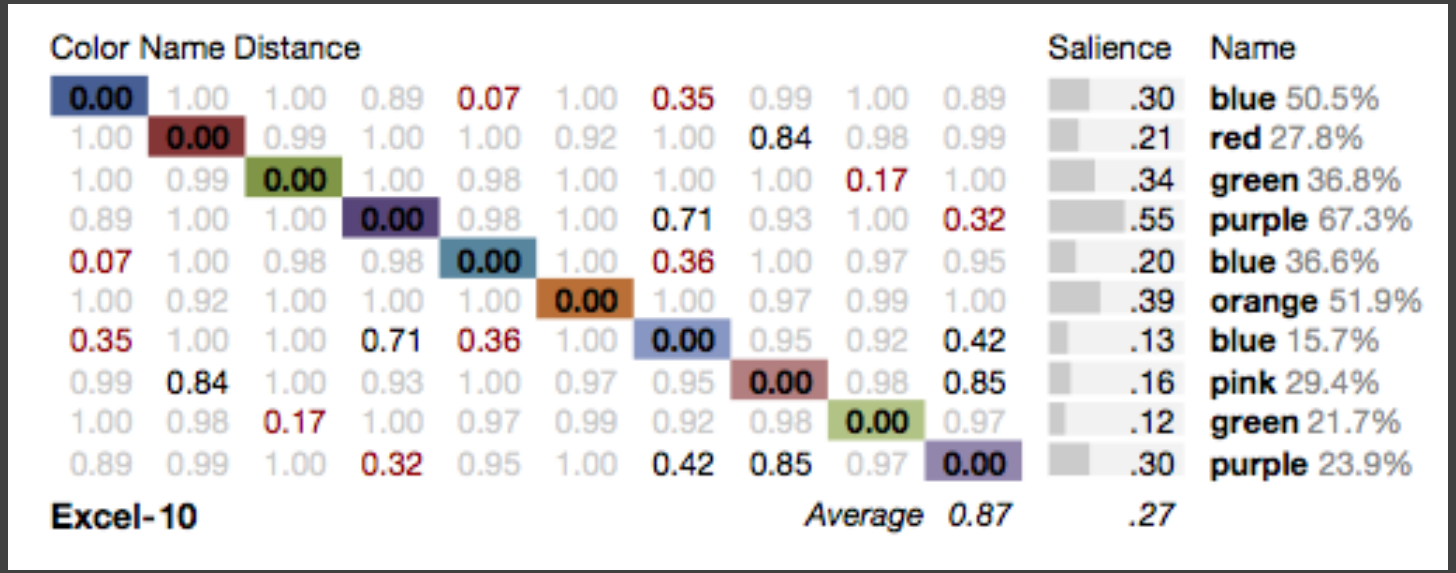
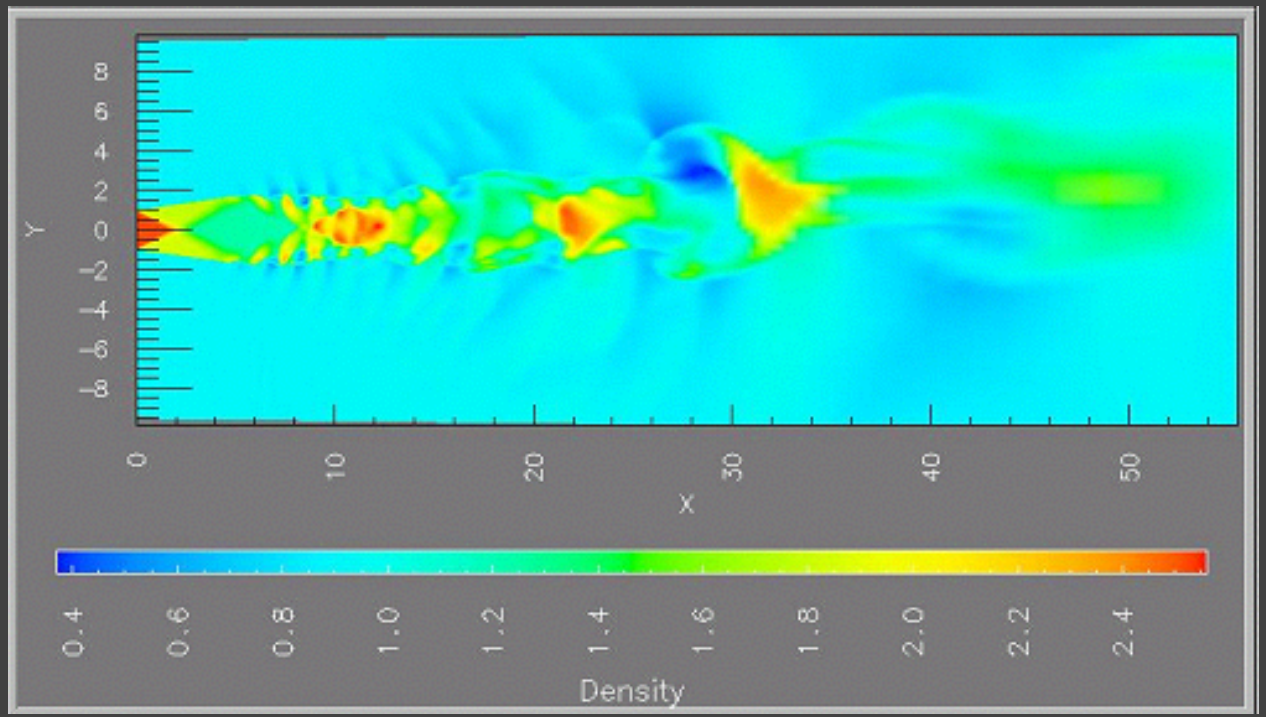


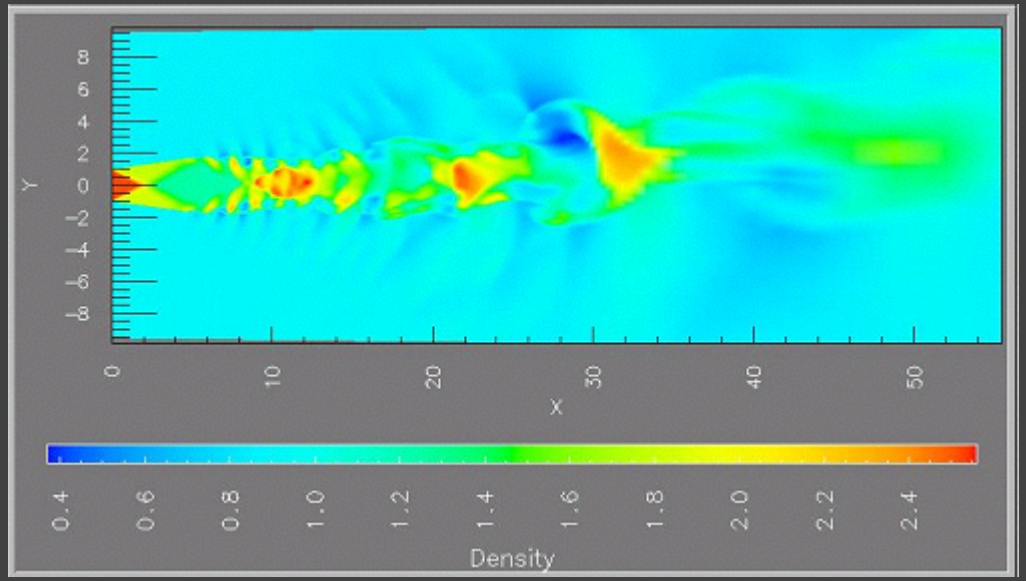
http://vis.stanford.edu/color-names

Quantitative Color

Rainbow Color Maps

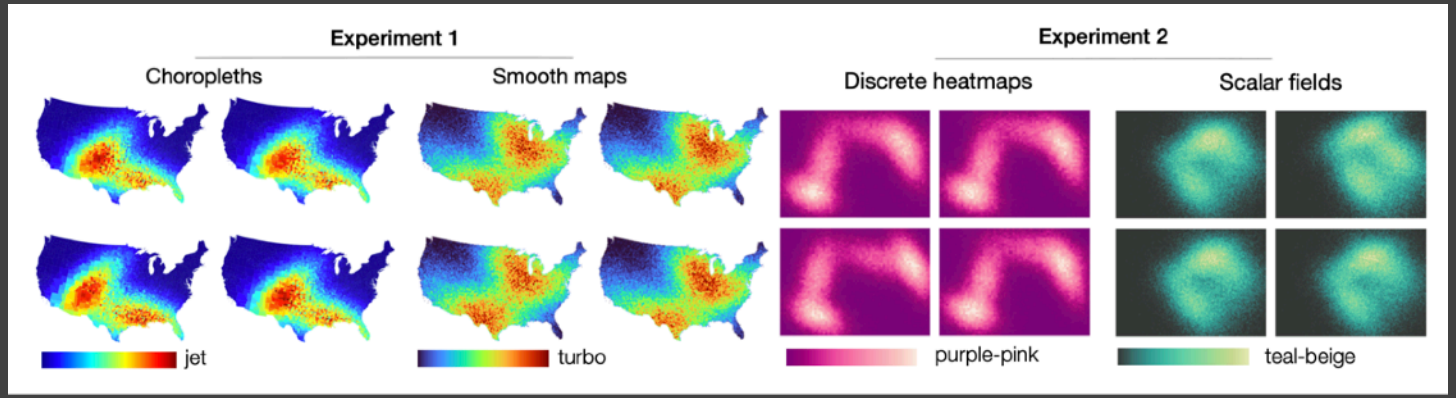


Be wary of naïve rainbows?



1. Naive rainbows are unfriendly to color blind viewers
2. Hues are not naturally ordered
3. Some colors are less effective at high spatial frequencies
4. People segment colors into classes -> perceptual banding

But rainbow helpful for inference?



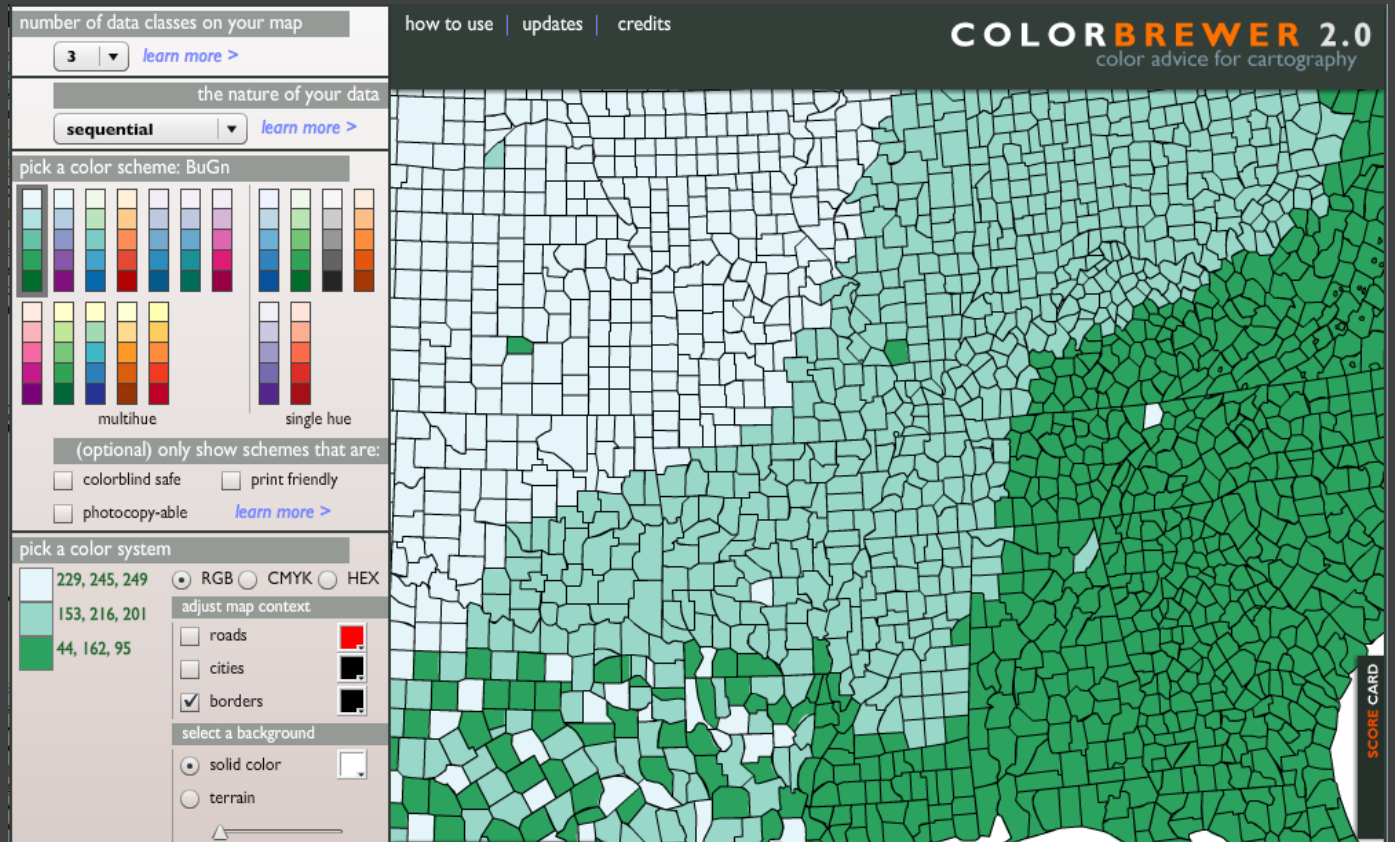
Reda et al. '21: Color Nameability Predicts Inference Accuracy in Spatial Visualizations

Rainbow found ineffective for *value comparison* [Liu '18]…

…but color name salience found to improve performance on *inference task* of distinguishing distributions [Reda '21]

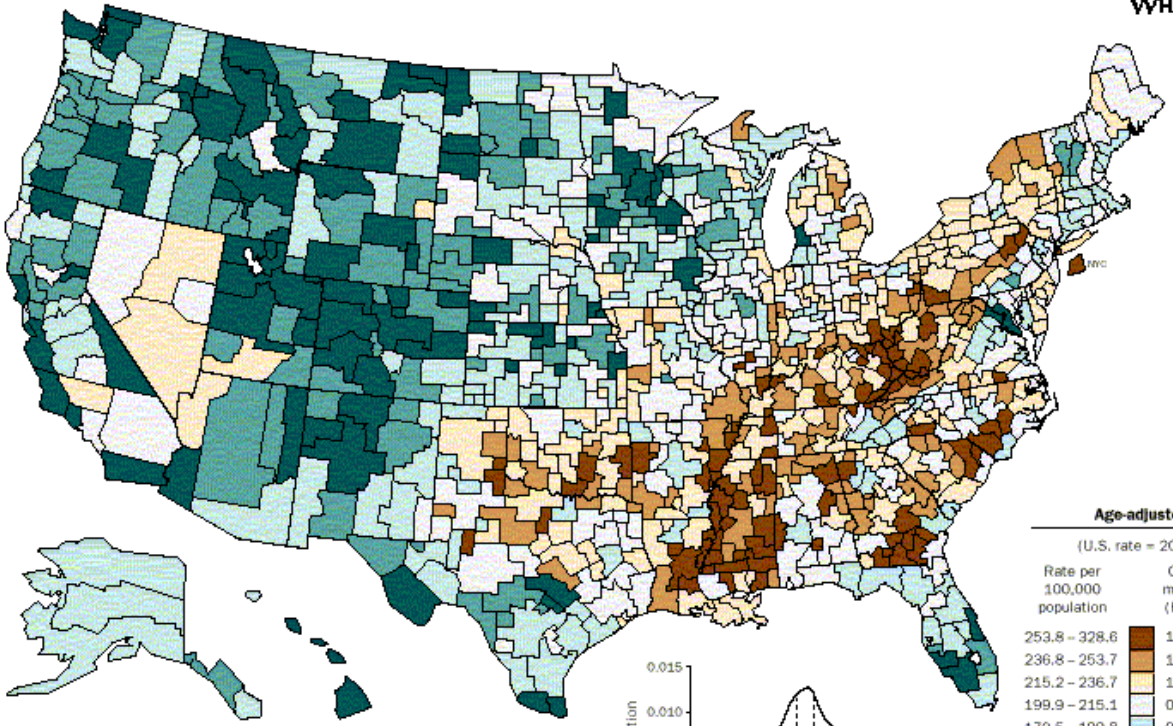
Task matters!

Steps, rather than Gradients?



Age-adjusted death rates by HSA, 1988-92

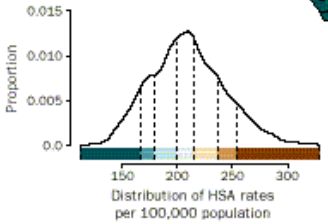
Heart disease
White male



Age-adjusted

(U.S. rate = 205.0)

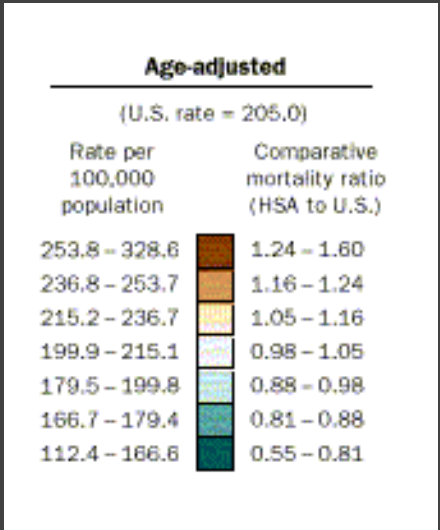
Rate per 100,000 population	Comparative mortality ratio (HSA to U.S.)
253.8 – 328.6	1.24 – 1.60
236.8 – 253.7	1.16 – 1.24
215.2 – 236.7	1.05 – 1.16
199.9 – 215.1	0.98 – 1.05
179.5 – 199.8	0.88 – 0.98
166.7 – 179.4	0.81 – 0.88
112.4 – 166.6	0.55 – 0.81

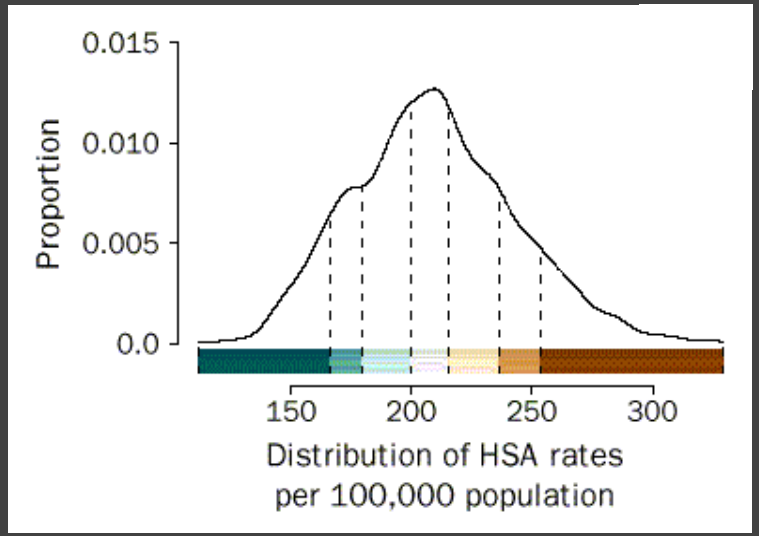


ICD–9 Categories 390–398, 402, 404–429

SOURCE: CDC/NCHS

Classing Quantitative Data





Age-adjusted mortality rates for the United States.
Common option: break into 5 or 7 quantiles.

Classing Quantitative Data

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

   Minimize within group variance

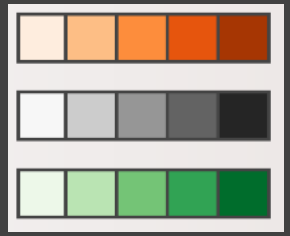
   Maximize between group variance

Quantitative Color Encoding

Sequential color scale

Ramp in luminance, possibly also hue

Higher value -> darker color (or vice versa)



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Ramp in luminance, possibly also hue

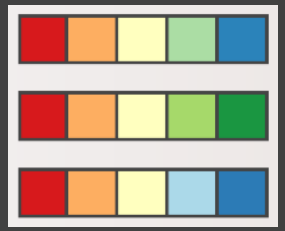
Higher value -> darker color (or vice versa)

Diverging color scale

Useful when data has meaningful “midpoint”

Use neutral color (e.g., grey) for midpoint

Use saturated colors for endpoints



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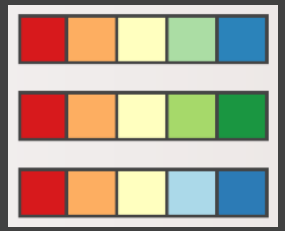

Limit number of steps in color to 3-9

Why?

Quantitative Color Encoding

Sequential color scale

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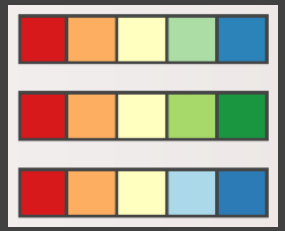
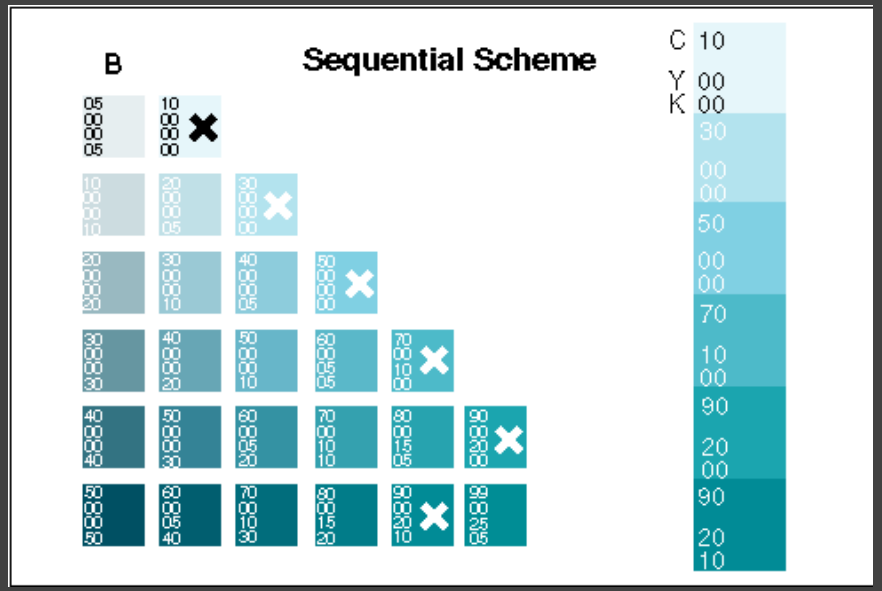


Limit number of steps in color to 3-9

Avoid simultaneous contrast, hold mappings in memory

Sequential Scales: Single-Hue

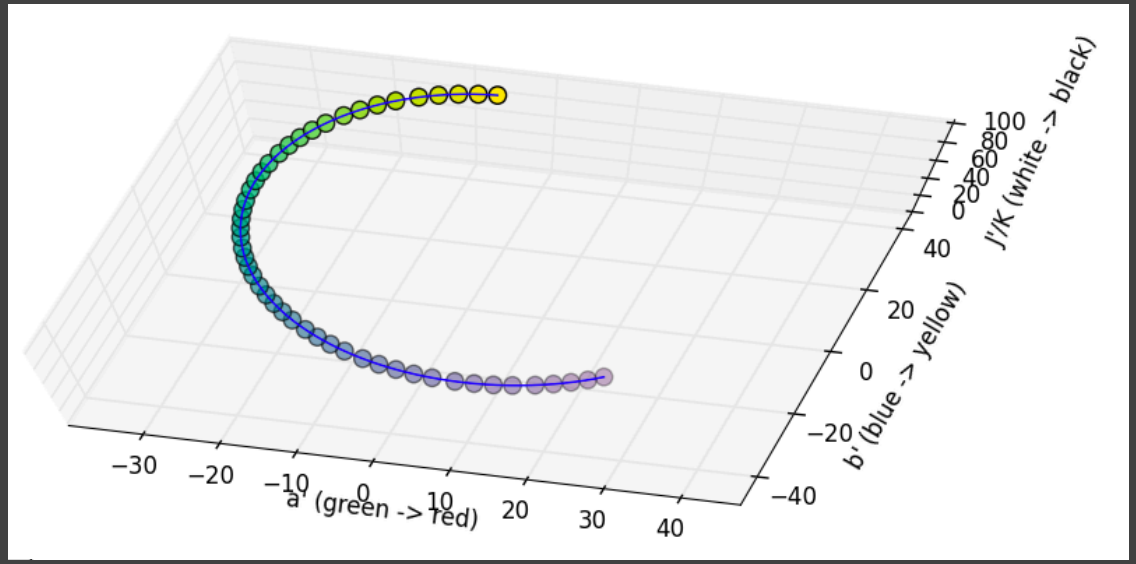
Ramp primarily in luminance, subtle hue difference



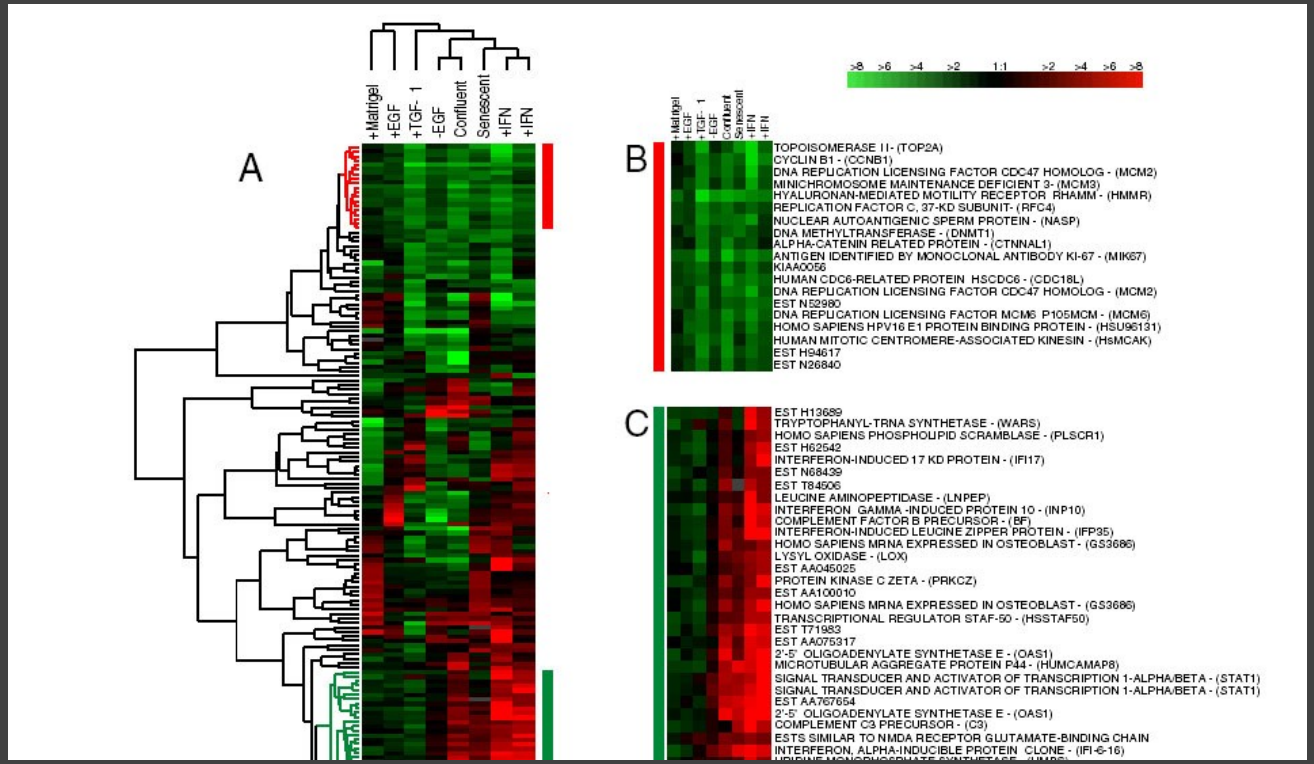
http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html

Sequential Scales: Multi-Hue

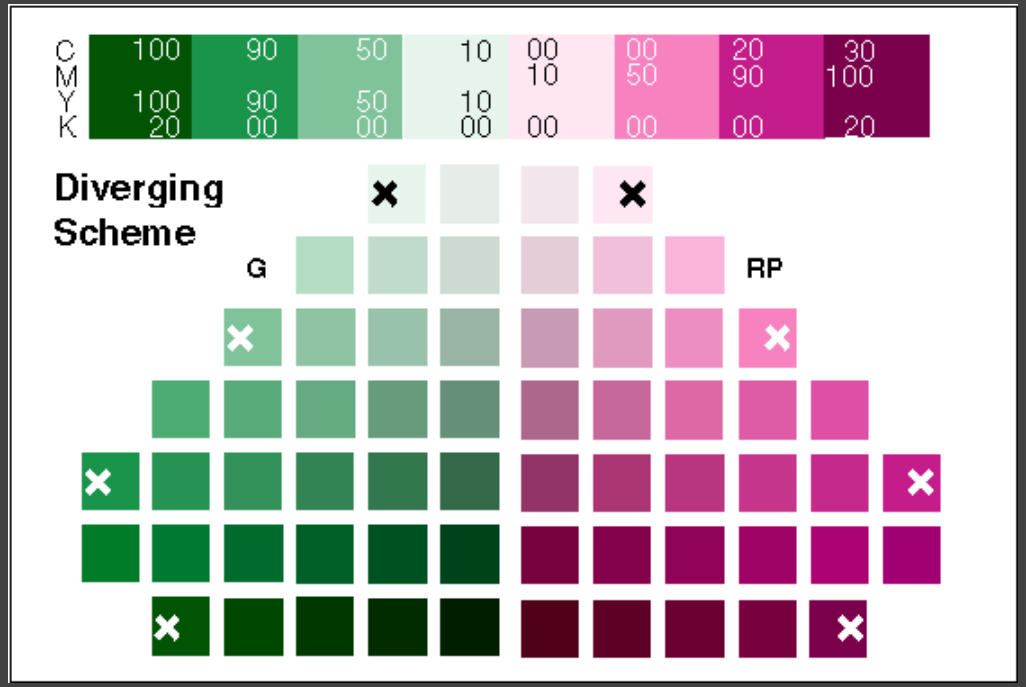
Ramp luminance & hue in perceptual color space
Avoid contrasts subject to color blindness!



Diverging Color Scheme



Designing Diverging Scales



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Designing Diverging Scales

Hue Transition

Carefully Handle Midpoint
Choose classes of values
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

Get it right in **black and white**

Respect the **color blind**

Take advantage of **perceptual color spaces**

Color is cultural and a matter of taste!