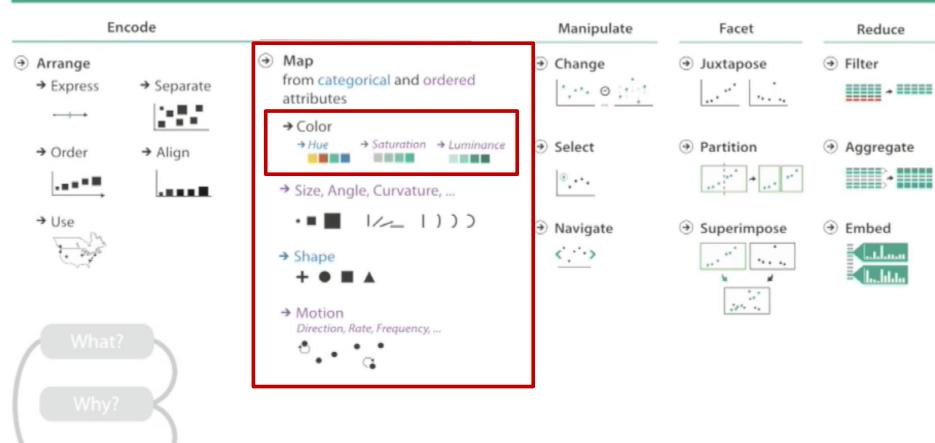
Foundation: Color

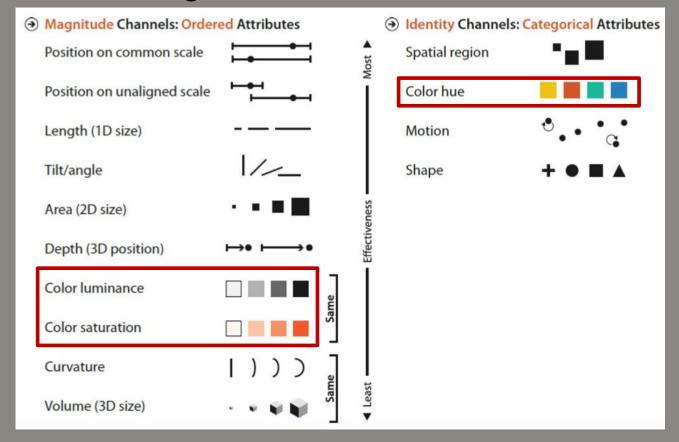


How?



How?

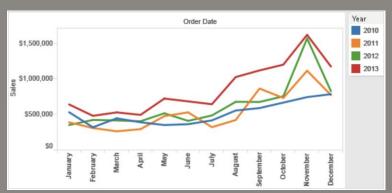
Channels: Big Picture

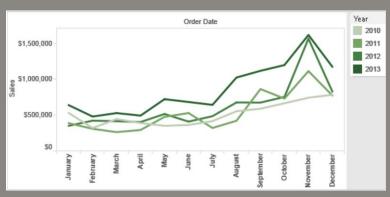


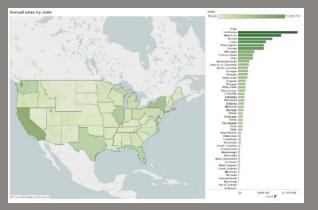


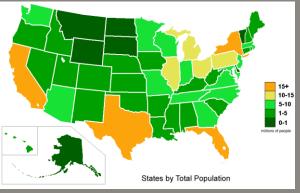


Categorical vs. Ordered Color











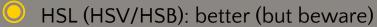
- Rule: do not directly talk about "color"
 - Color is confusing if treated it monolithic
- Decompose into three color channels
 - Ordered can show magnitude
 - Luminance
 - Saturation
 - Categorical can show identity
 - Hue
- Channel have different properties
 - What they convey directly to perceptual system
 - How much they can convey: how many discriminable bins can we use







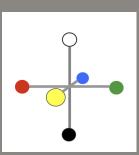
- RGB:
 - good for display hardware
 - poor for visual encoding
- CIE L*a*b*: good for visual design
 - L* intuitive: perceptually linear luminance
 - a*b* axes: perceptually linear but nonintuitive

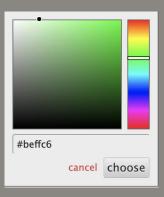


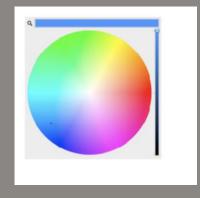
- HSL: (Hue/Saturation/Lightness)
- Lightness ≠ luminance

It is enough to somewhat understand these color space, know their properties. We rarely pick up colors for visualization by ourself.

We might use tools or nice predefined color maps (introduce later)

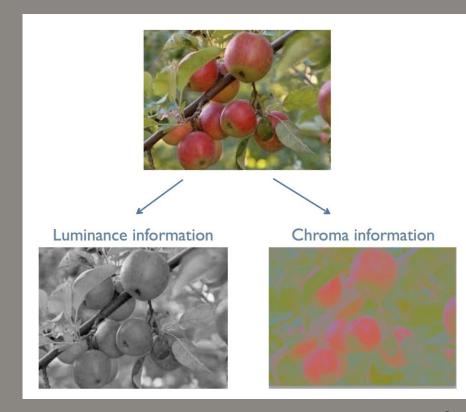






Property of Luminance

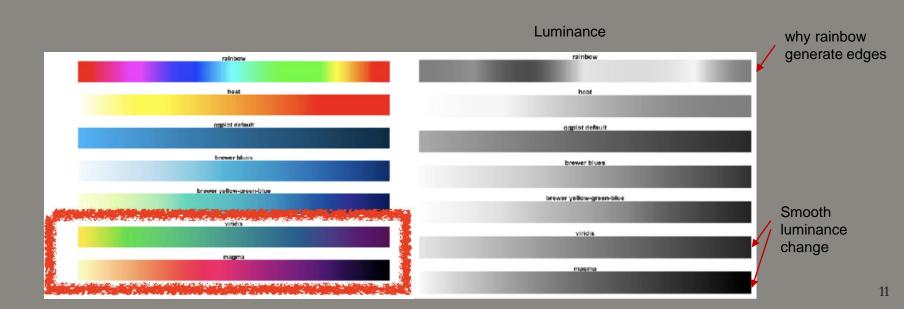
- Luminance for detecting edges
 - Fine-grained detail only visible through luminance contrast
 - Legible text requires luminance contrast
- Intrinsic perceptual ordering





Virdis

 Virdis color map: colorful, perceptually, uniform, colorblindsafe, monotonically increasing luminance

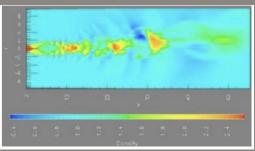


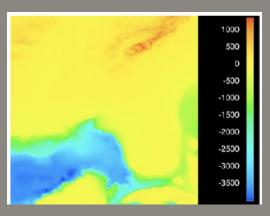


Rainbow is Poor Default

- For continuous/ordered data
- Problems
 - Perceptually unordered
 - Perceptually nonlinear
 - Human may perceive edges because of rainbow color map instead of data
- Benefits
 - Fine-grained structure visible and namable





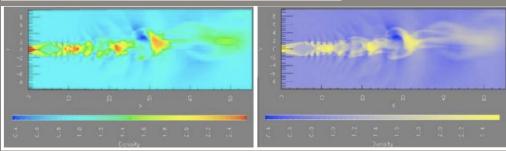


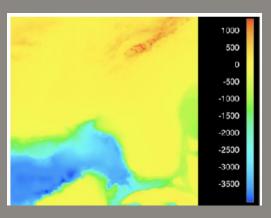


Rainbow is **Poor** Default

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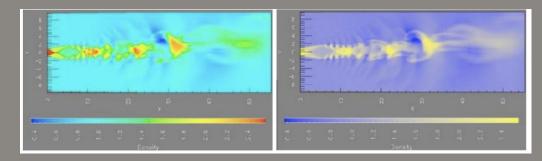


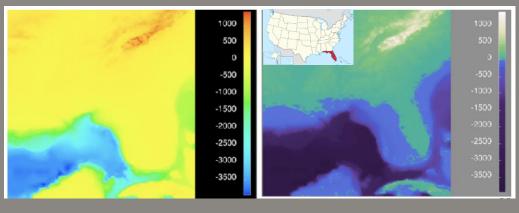


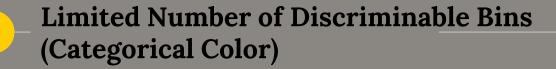


Rainbow is Poor Default

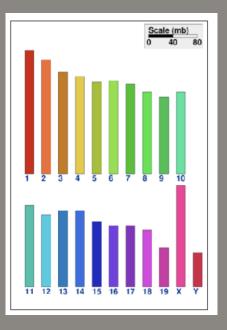
- For continuous/ordered data
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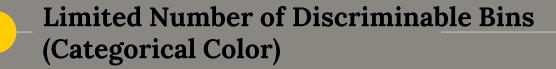




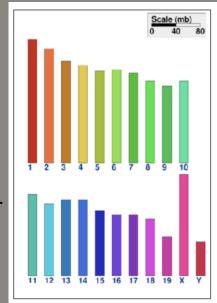


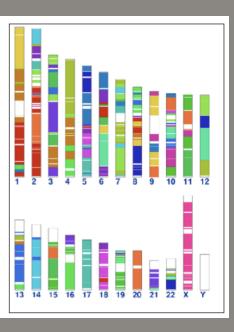
- Human perception built on relative comparisons
 - Great if colors next to each other



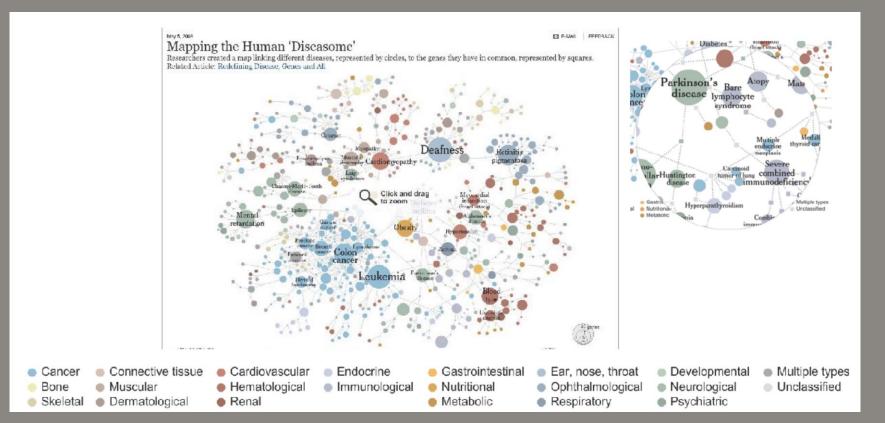


- Human perception built on relative comparisons
 - Great if colors next to each other
 - Surprisingly bad for absolute comparisons
- Noncontiguous small region of color
 - Fewer bins than you want
 - Rule of thumb: 6-12 bins (including background and highlights)



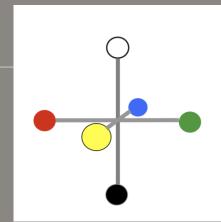


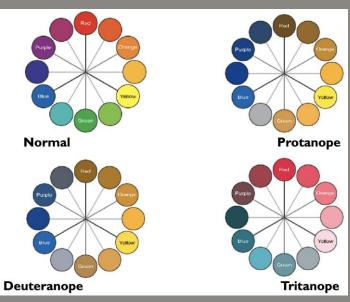
Limited Number of Discriminable Bins (Categorical Color)



Color Vision Deficiency (Color Blindness)

- Perceptual processing before optic nerve
 - One achromatic luminance channel L
 - Edge detection
 - Two chroma channel, R-G and Y-B
- "color blind" if one axis has degraded acuity
 - Red-green color blindness affects up to 8% of males and 0.5% of females of Northern European descent. (wiki)
 - Blue/yellow color blindness is rare

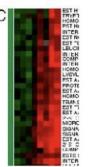




Designing for Color Deficiency: Check with Simulator



Normal vision





Deuteranope Protanope





Tritanope

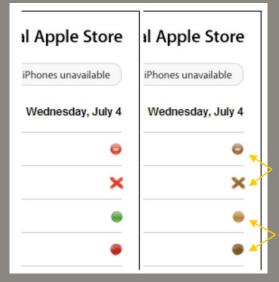


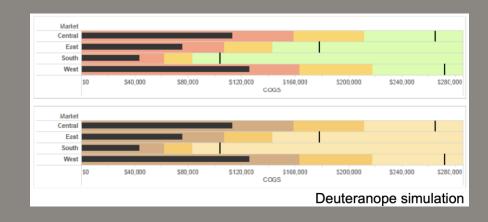


https://www.colorblindness.com/coblis-colorblindness-simulator/

Design for Color Deficiency: Avoid Encoding by Hue Only

- Redundantly encode
 - Vary luminance
 - Change shape



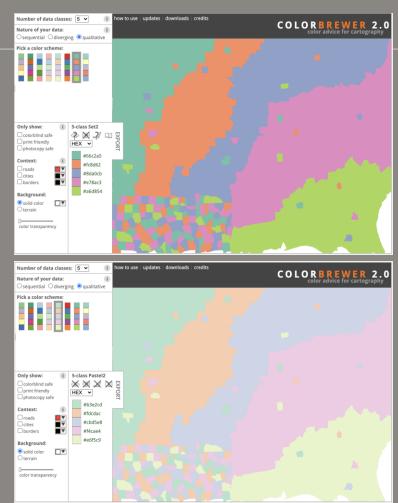


Change the shape

Change the luminance

Interaction with Other Channel

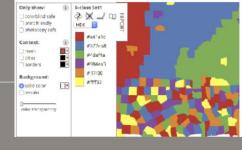
- Color channel interactions
 - Size heavily affect salience
 - Small regions need high saturation

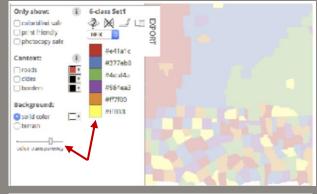


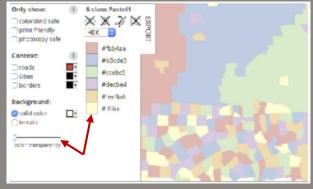


Interaction with Other Channel

- Color channel interactions
 - Size heavily affect salience
 - Small regions need high saturation
- Saturation & luminance
 - Not very separable from each other
 - Also, not separable from transparency
 - 3-4 bins max (small and separated region)
 - Many bins (contiguous regions)







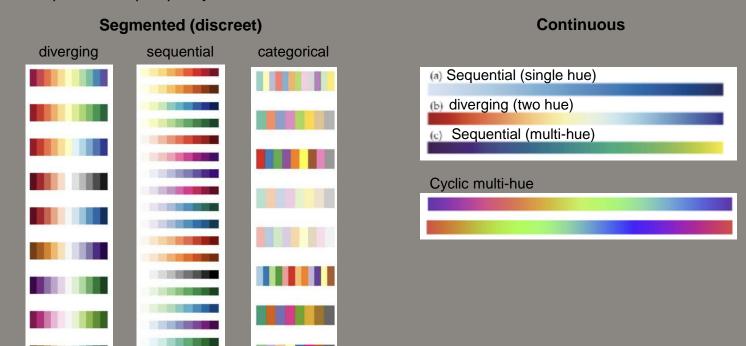
Interaction with Background



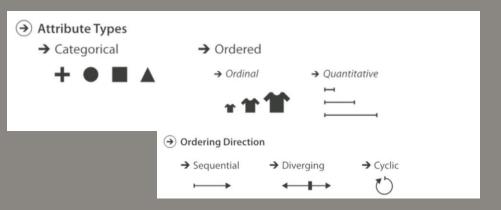
Hello Hello	Hello Hello	Hello Hello	Hello Hello Hello	Hello Hello Hello	Hello Hello Hello	Hello Hello Hello
Hello Hello	Hello Hello	Hello Hello	Hello	25/220	Hello Hello	Hello Hello
Hello Hello	Hello Hello	Hello Hello	Hello Hello	Hello Hello	Helio	Hello

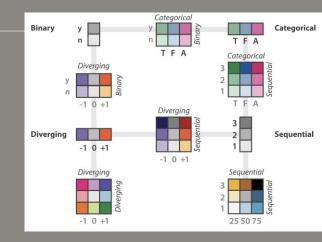
Color Map

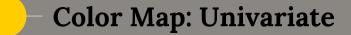
You can get many predefined color maps (D3/Mapplotlib). How to interpret and properly use them?



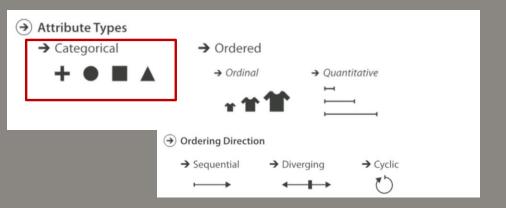
Color Map: Univariate

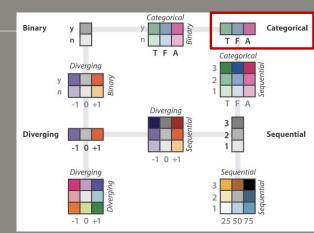






- Categorical
 - Aim for maximum distinguishability
 - Qualitative, nominal

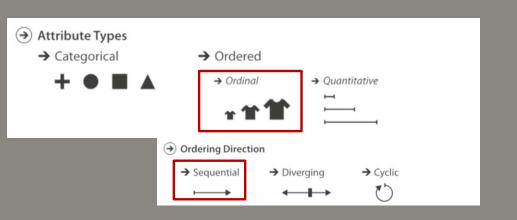


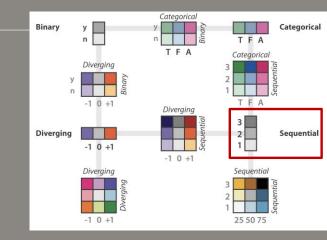




Color Map: Univariate

- Sequential
 - Ramp luminance or saturation



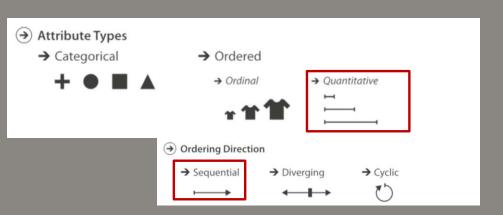


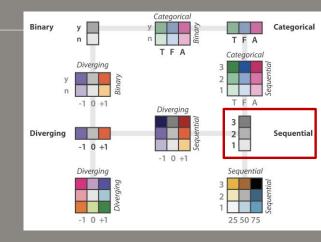


- (a) Sequential (single hue)
- (c) Sequential (multi-hue)

Color Map: Univariate

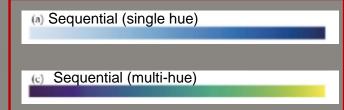
- Sequential
 - Ramp luminance or saturation

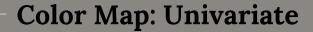




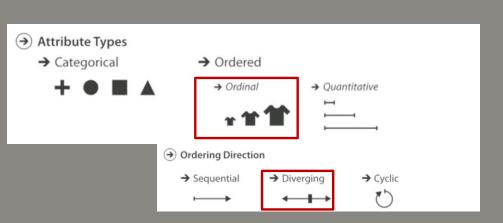


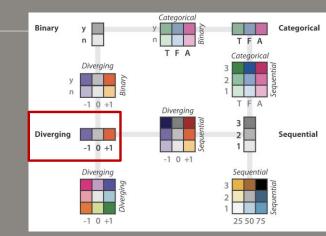






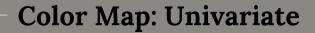
- Diverging
 - Useful when data has meaningful "midpoint"
 - Use neutral color for midpoint
 - White, yellow, grey
 - Use saturated color for end points



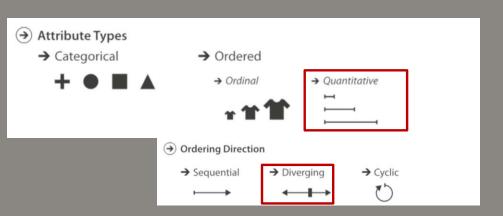


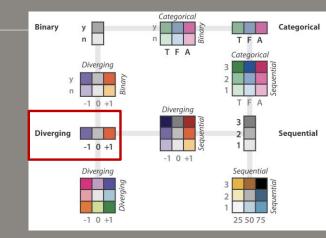


diverging (two hue)

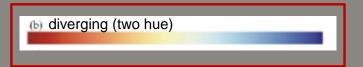


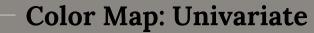
- Diverging
 - Useful when data has meaningful "midpoint"
 - Use neutral color for midpoint
 - White, yellow, grey
 - Use saturated color for end points





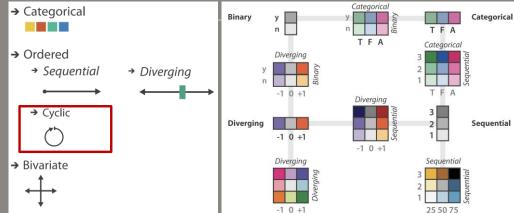


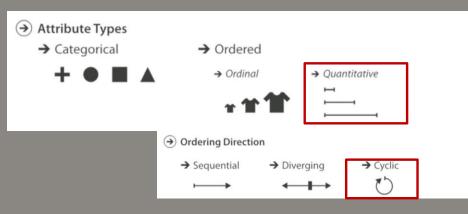


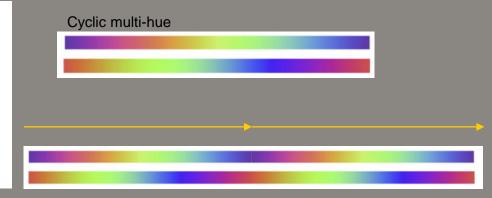


O Cyclic

Date, time, month...

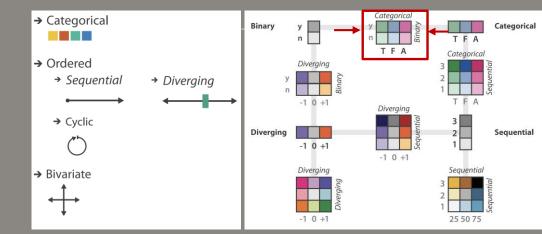


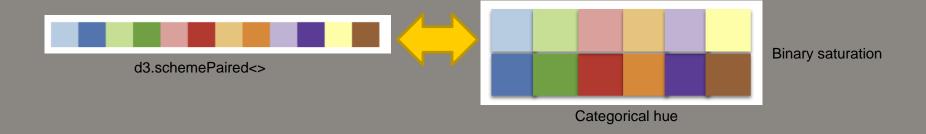




Color Map: Bivariate

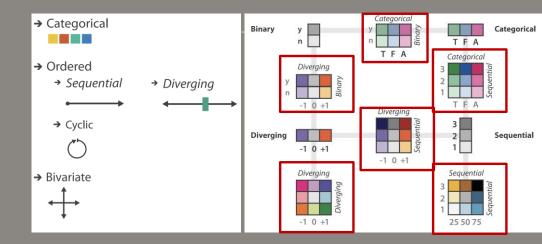
- Encode two attributes by color
- Best and simple bivariate case
 - Binary in one of the direction





Color Map: Bivariate

- Encode two attributes by color
- Best and simple bivariate case
 - Binary in one of the direction
- Use with care!!!
 - Bivariate can be very hard to interpret when multiple levels in each direction



Color Map

You can get many predefined color maps (D3/Mapplotlib). How to interpret and properly use them?

Continuous Segmented (discreet) diverging sequential categorical (a) Sequential (single hue) diverging (two hue) (c) Sequential (multi-hue) Cyclic multi-hue Questions to ask before select a color map: Segmented or continuous? Diverging or sequential or cyclic? Single hue or two hue or multiple hue? Perceptually linear? Ordered by luminance? Colorblind safe?

Tool and Library for Color

- ColorBrewer:
 - https://colorbrewer2.org/#type=sequential&scheme=BuGn&n=3
 - Generate reasonable combination with conditions
 - Segmented color map
- Adobe color picker
 - https://color.adobe.com/zh/create/color-wheel
 - General purpose
- Colorgorical
 - http://vrl.cs.brown.edu/color
 - Only targeted at categorical data
- D3 color map
 - https://github.com/d3/d3-scale-chromatic
- Matplotlib color map
 - https://matplotlib.org/stable/tutorials/colors/colormaps.html

