Foundation: Color

How?

Encode

- Arrange
  - Express
  - Separate
  - Order
  - Align
  - Use
- Map
  from categorical and ordered attributes
  - Color
    - Hue
    - Saturation
    - Luminance
  - Size, Angle, Curvature, ...
  - Shape
  - Motion
    Direction, Rate, Frequency, ...

Manipulate

- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

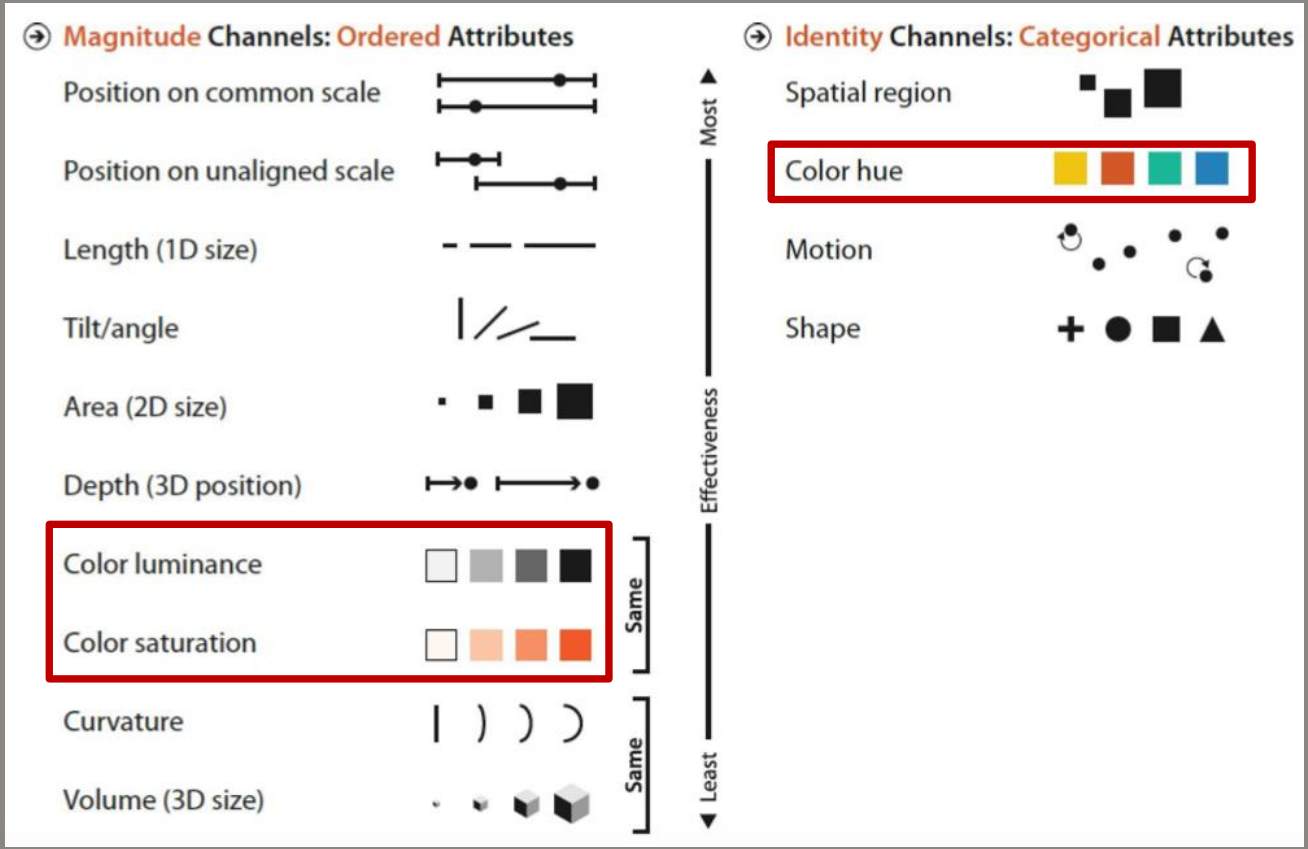
- Filter
- Aggregate
- Embed

What?

Why?

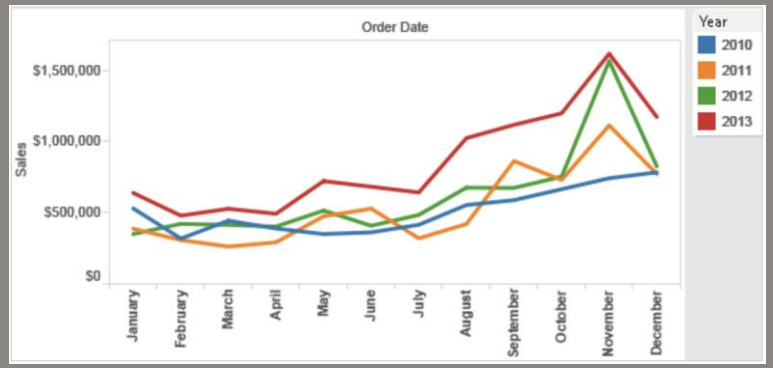
How?

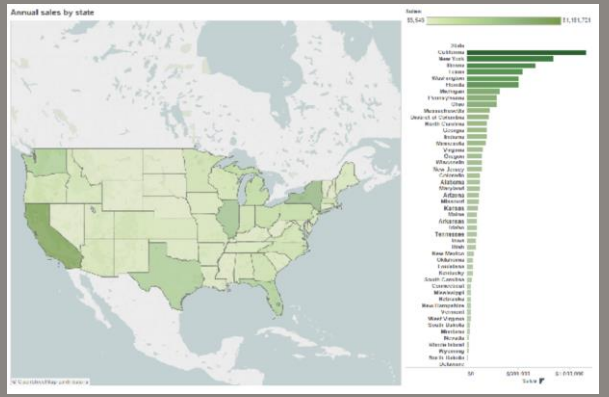
Channels: Big Picture

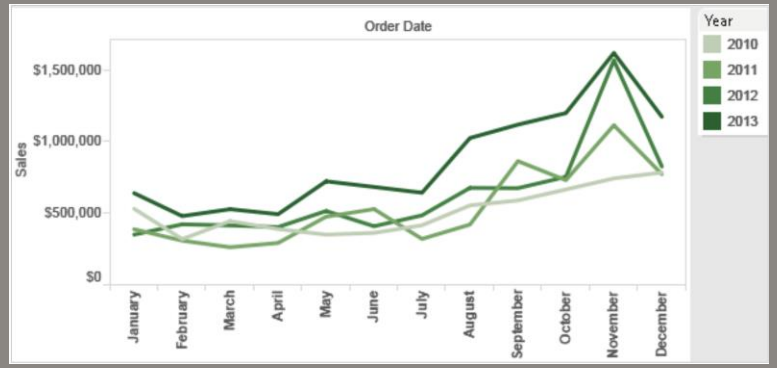


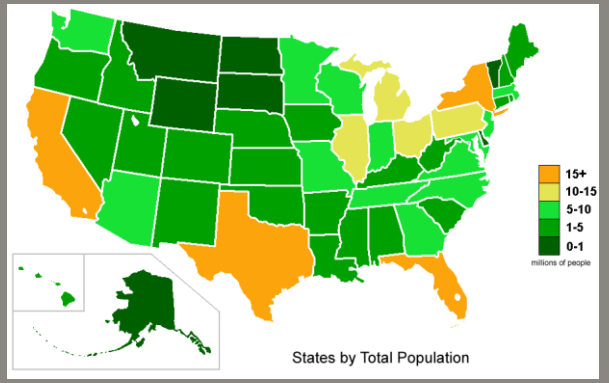
S04-01

Categorical vs. Ordered Color



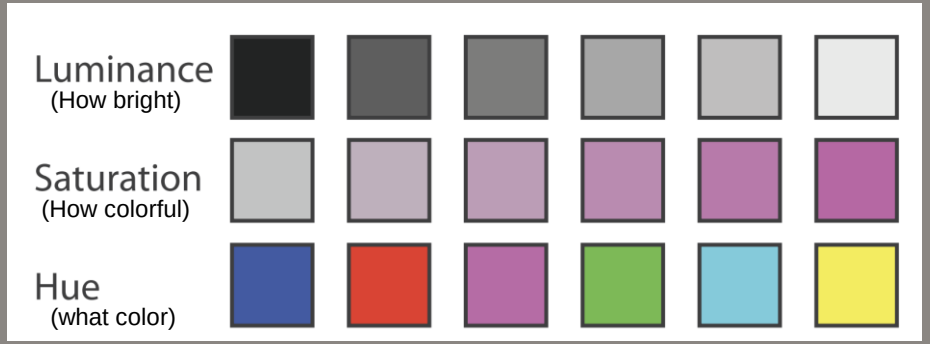






Decomposing Color

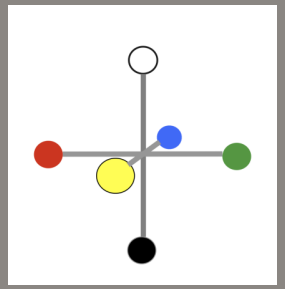
- Rule: do not directly talk about “color”
  - Color is confusing if treated it monolithic
- Decompose into three color channels
  - Ordered can show magnitude
    - Luminance
    - Saturation
  - Categorical can show identity
    - Hue
- Channel have different properties
  - What they convey directly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



S04-02

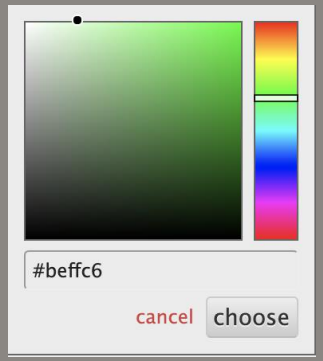
Color Space

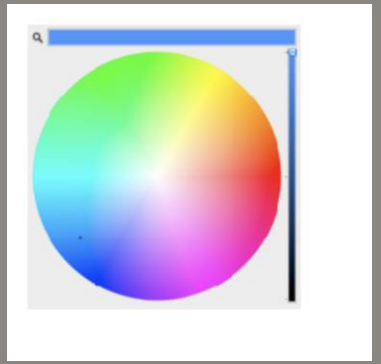
- RGB:
  - good for display hardware
  - poor for visual encoding



- CIE L*a*b*: good for visual design
  - L* intuitive: perceptually linear luminance
  - a*b* axes: perceptually linear but nonintuitive

- HSL (HSV/HSB): better (but beware)
  - HSL: (Hue/Saturation/Lightness)
  - Lightness ≠ luminance

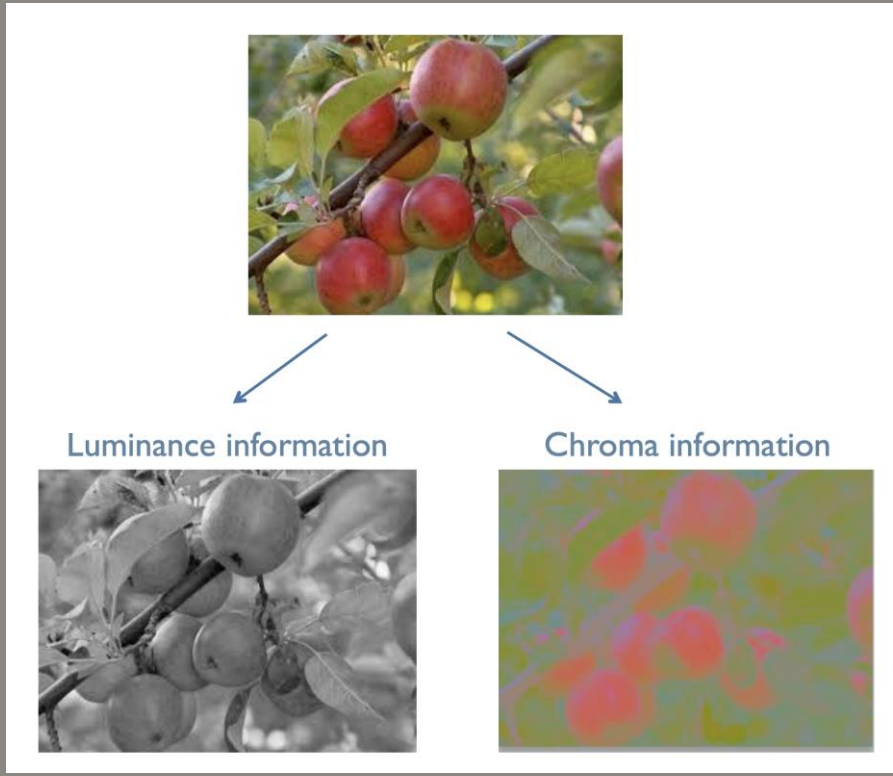




It is enough to somewhat understand these color space, know their properties.
We rarely pick up colors for visualization by ourself.
We might use tools or nice predefined color maps (introduce later)

Property of Luminance

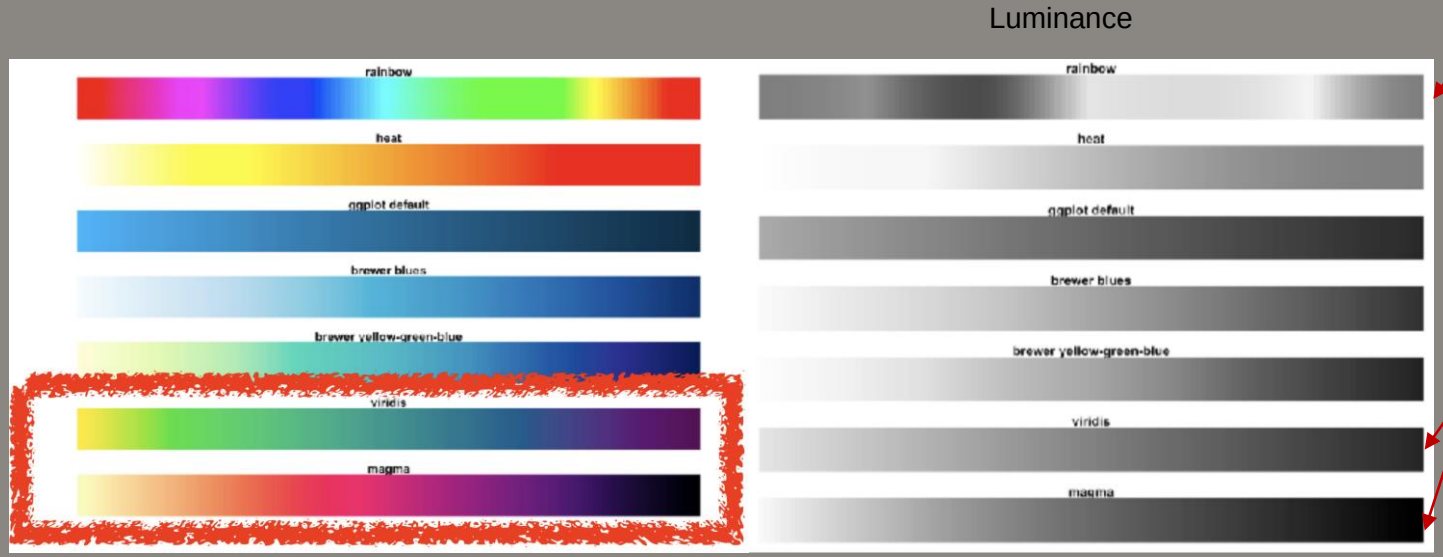
- Luminance for detecting edges
  - Fine-grained detail only visible through luminance contrast
  - Legible text requires luminance contrast
- Intrinsic perceptual ordering



S04-03

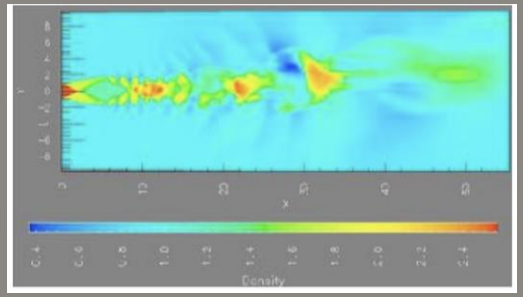
Virdis

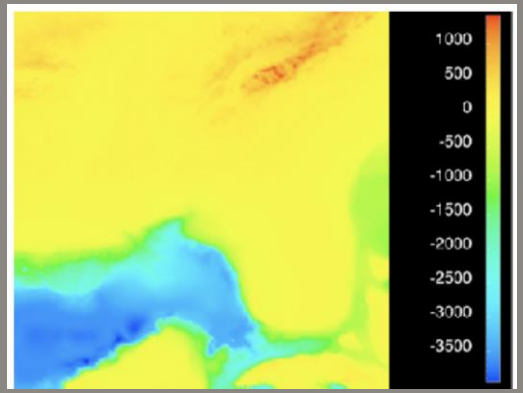
- Virdis color map: colorful, perceptually, uniform, colorblind-safe, monotonically increasing luminance



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





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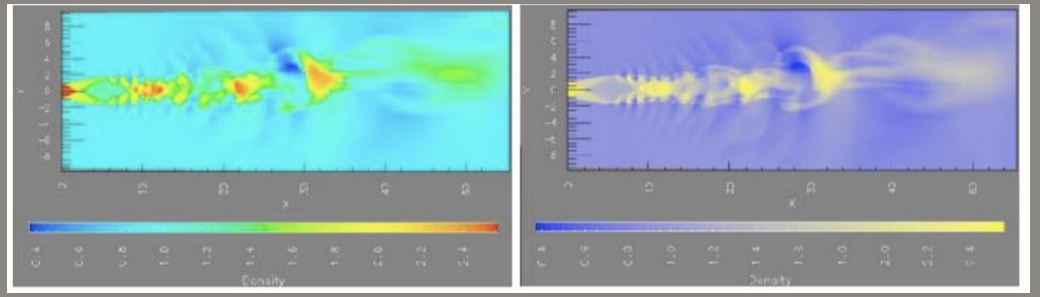

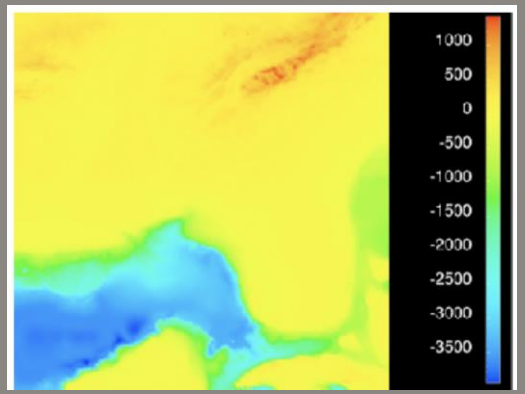

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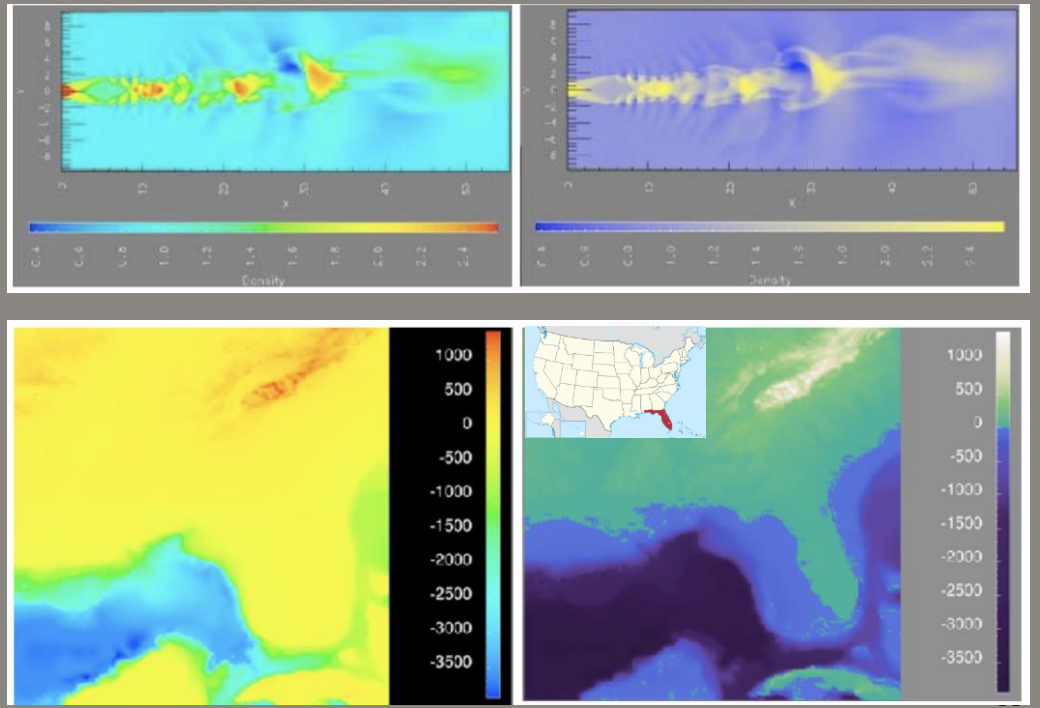
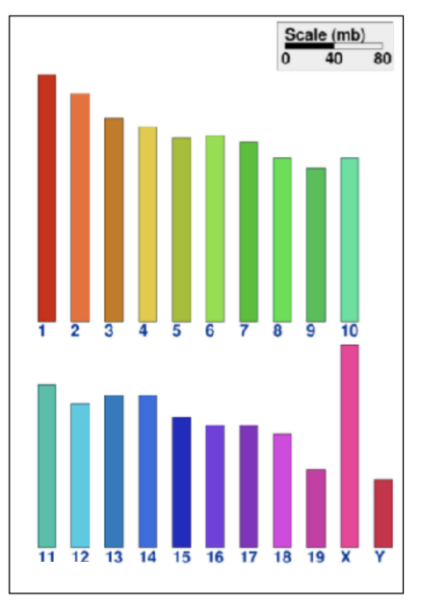


Limited Number of Discriminable Bins (Categorical Color)

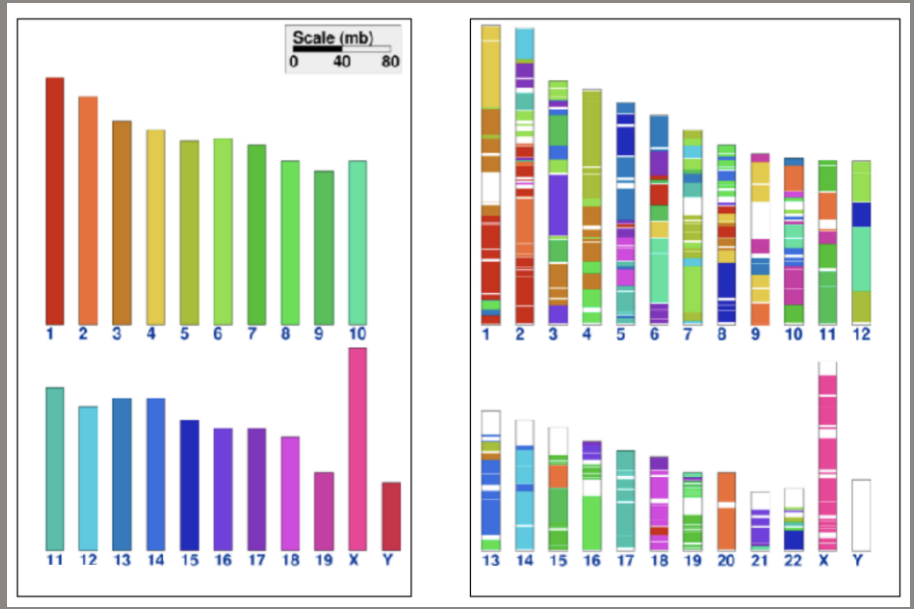
- Human perception built on relative comparisons
  - Great if colors next to each other



Limited Number of Discriminable Bins (Categorical Color)

- 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)



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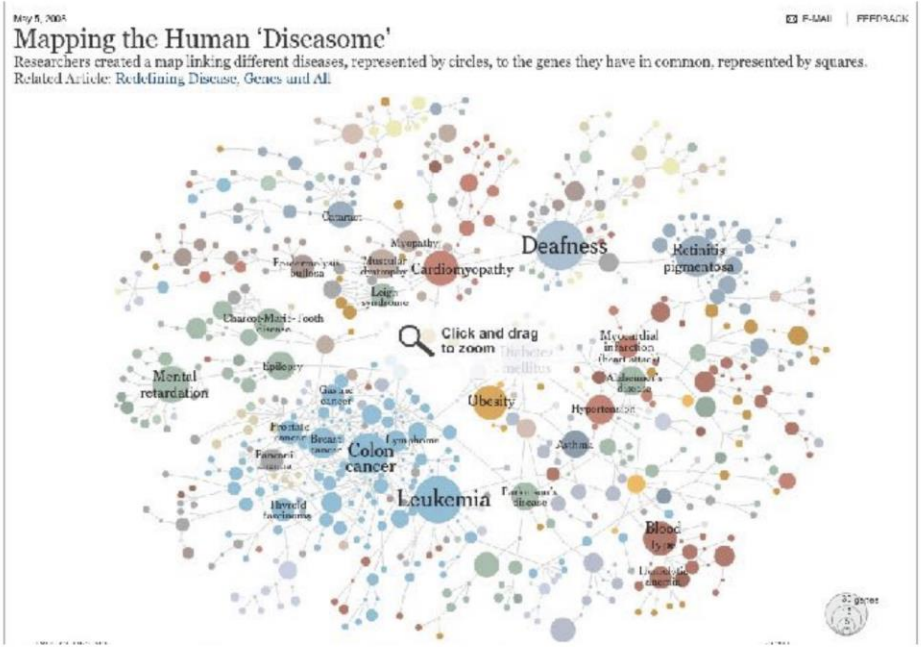
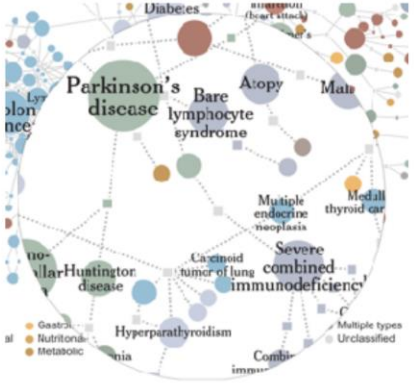


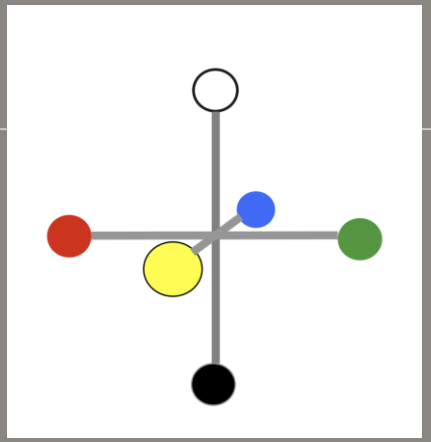


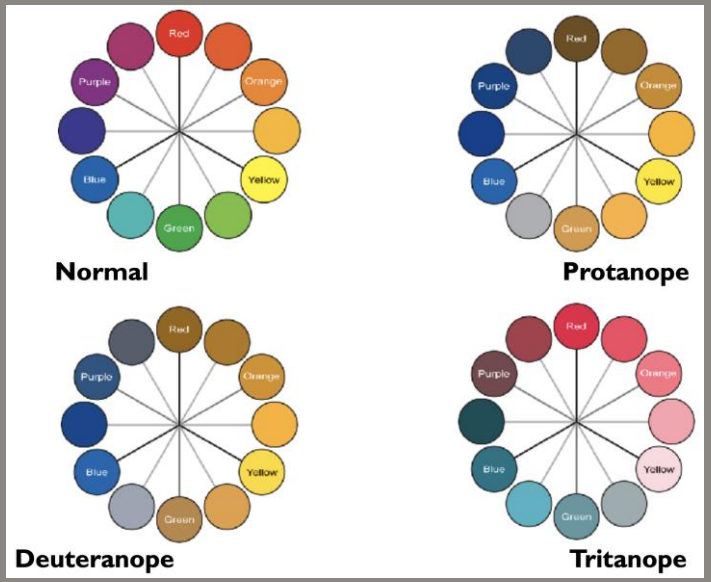
Cancer
Bone
Skeletal
Connective tissue
Muscular
Dermatological
Cardiovascular
Hematological
Renal
Endocrine
Immunological
Gastrointestinal
Nutritional
Metabolic
Ear, nose, throat
Ophthalmological
Respiratory
Developmental
Neurological
Psychiatric
Multiple types
Unclassified

Color Vision Deficiency (Color Blindness)

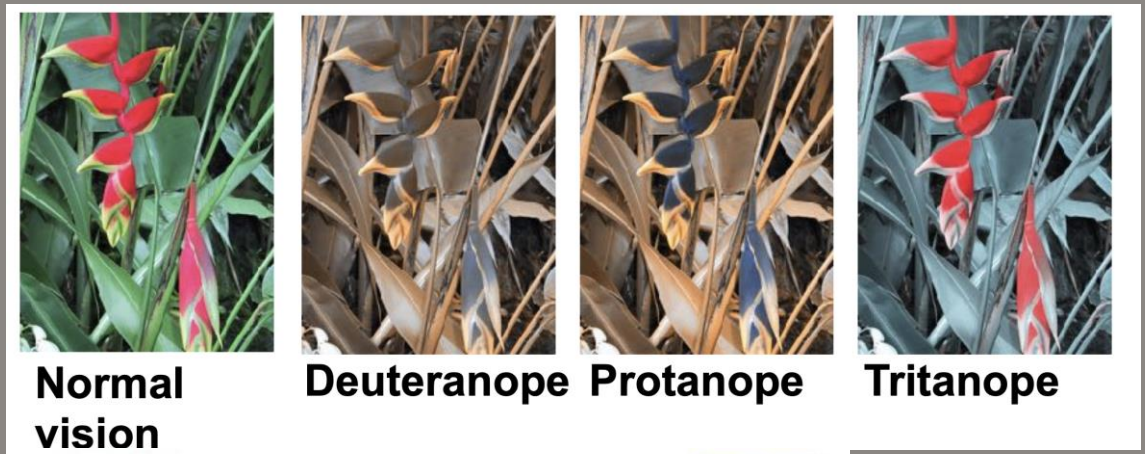
- Perceptual processing before optic nerve
  - One achromatic luminance channel L
    - Edge detection
  - Two chroma channel, R-G and Y-B

- “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

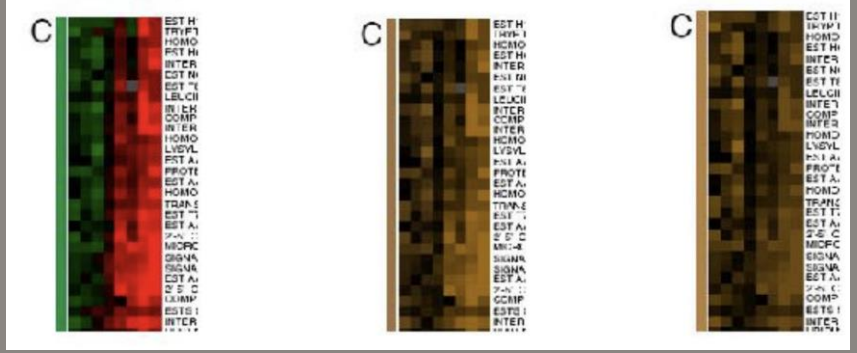




Designing for Color Deficiency: Check with Simulator

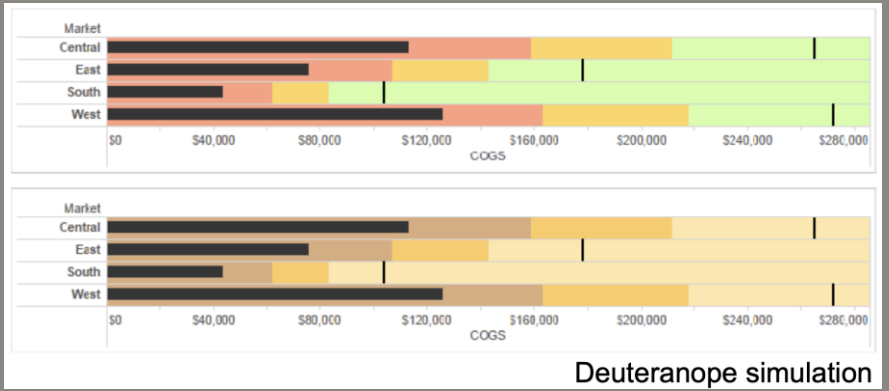


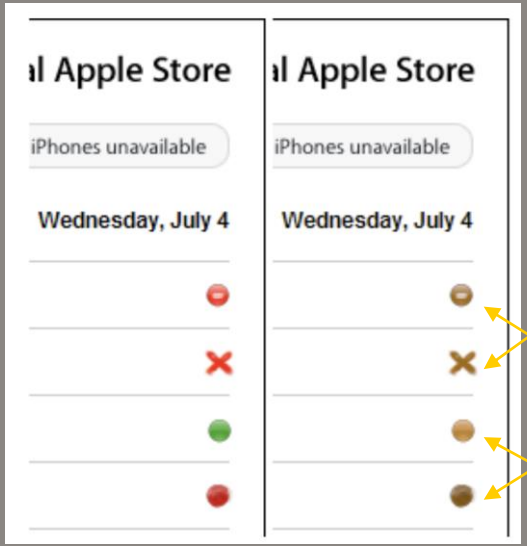
https://www.color-blindness.com/coblis-color-blindness-simulator/



Design for Color Deficiency: Avoid Encoding by Hue Only

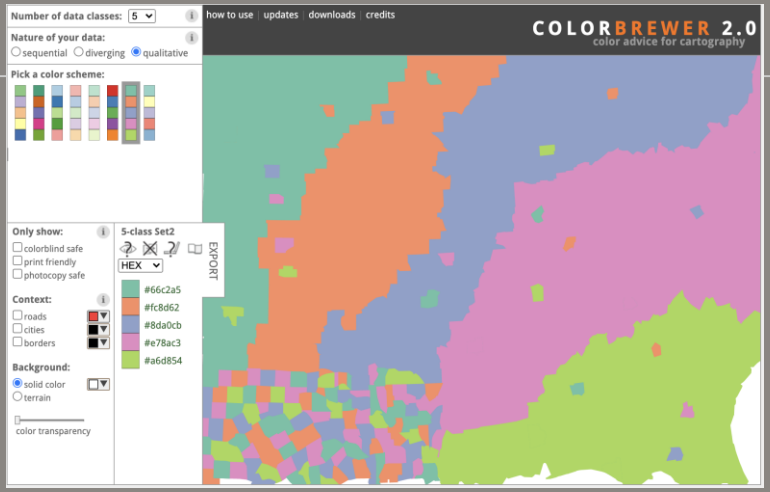
- Redundantly encode
  - Vary luminance
  - Change shape

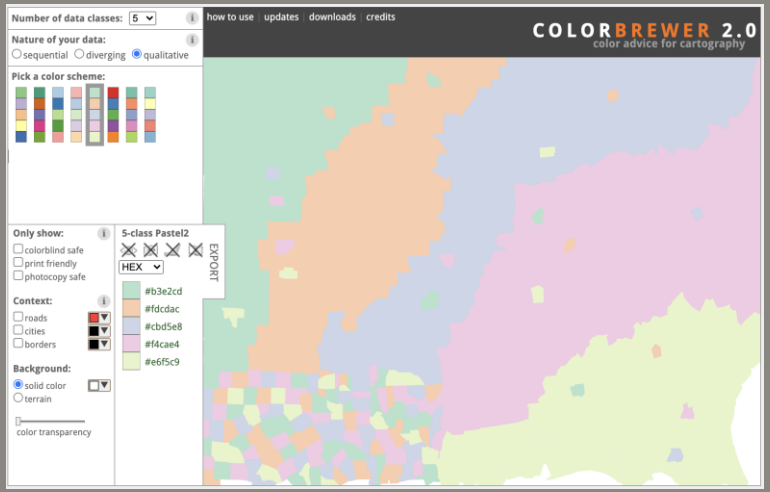




Interaction with Other Channel

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

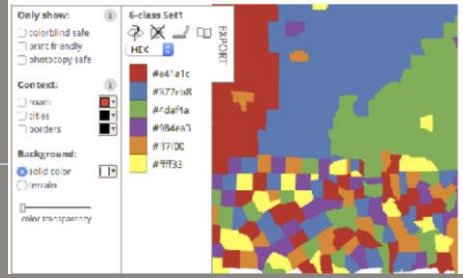


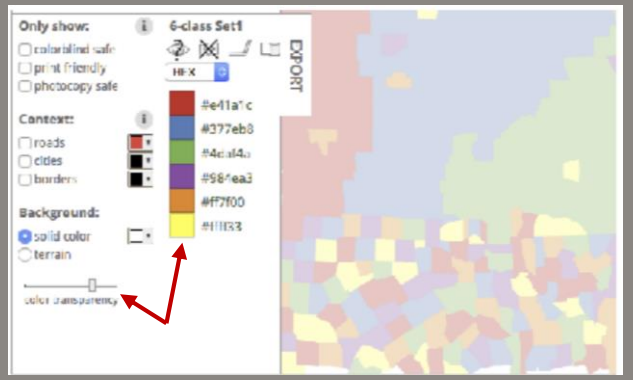


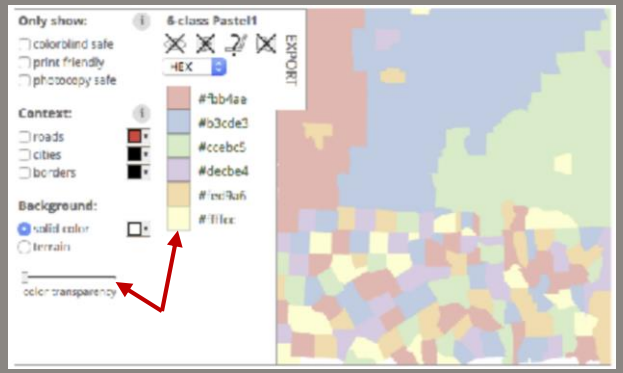
S04-04

Interaction with Other Channel

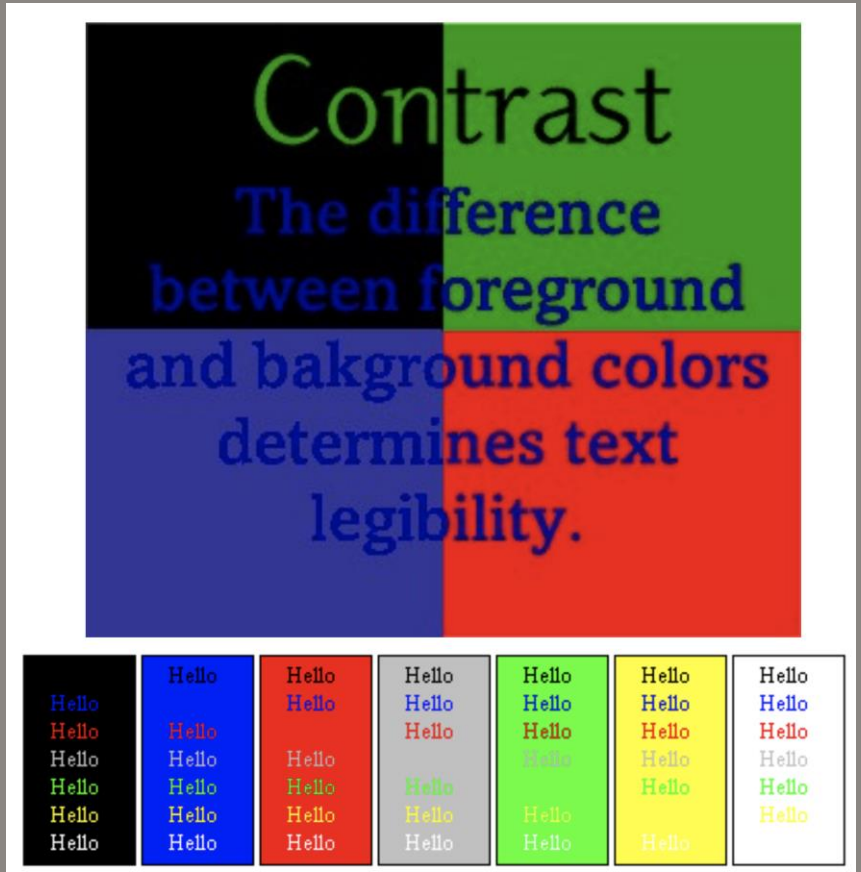
- Color channel interactions
  - Size heavily affect salience
  - Small regions need high saturation
- Saturation & luminance
  - Not very separable from each other
  - Also, not separable from transparency
  - 3-4 bins max (small and separated region)
  - Many bins (contiguous regions)







Interaction with Background



D3: https://github.com/d3/d3-scale-chromatic

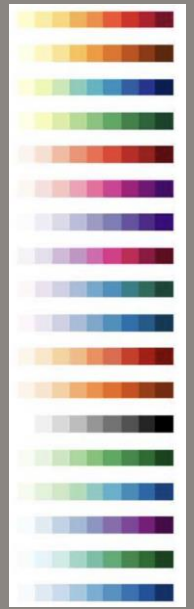
Color Map

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

Segmented (discreet)

diverging

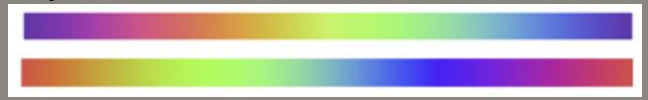
sequential



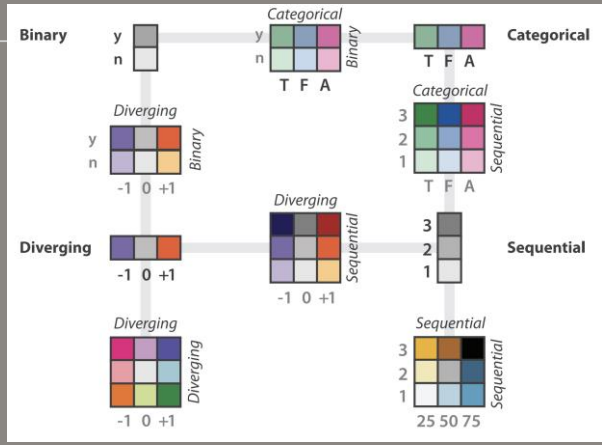
categorical

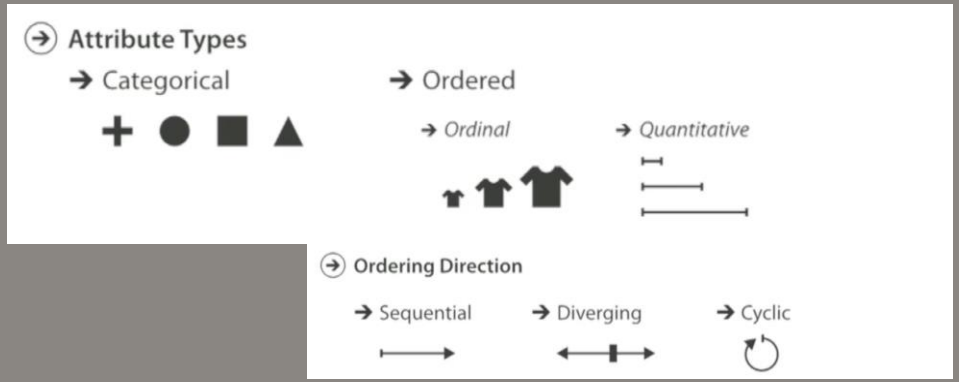
Continuous

Cyclic multi-hue



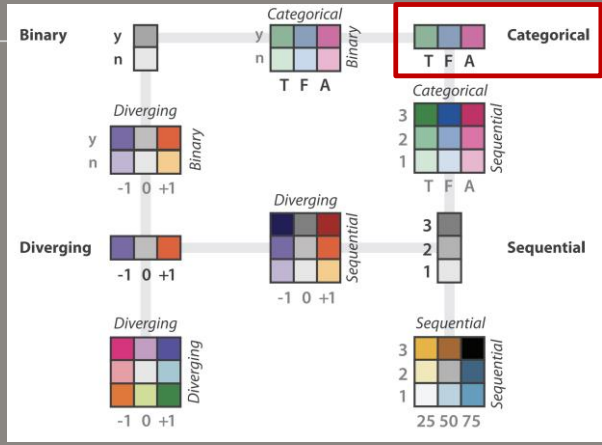
Color Map: Univariate

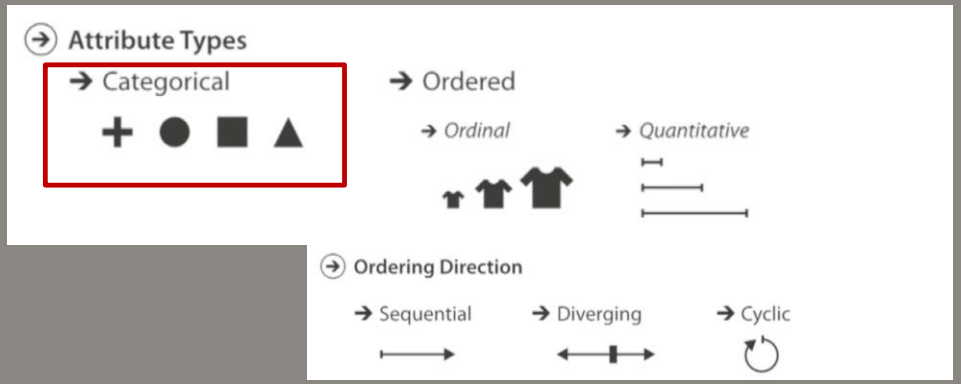




Color Map: Univariate

- Categorical
  - Aim for maximum distinguishability
    - Qualitative, nominal

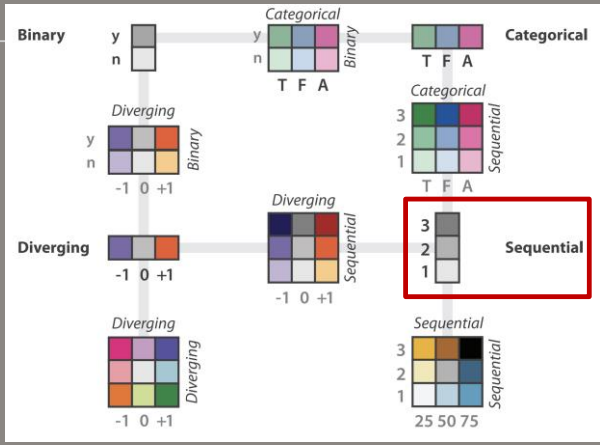


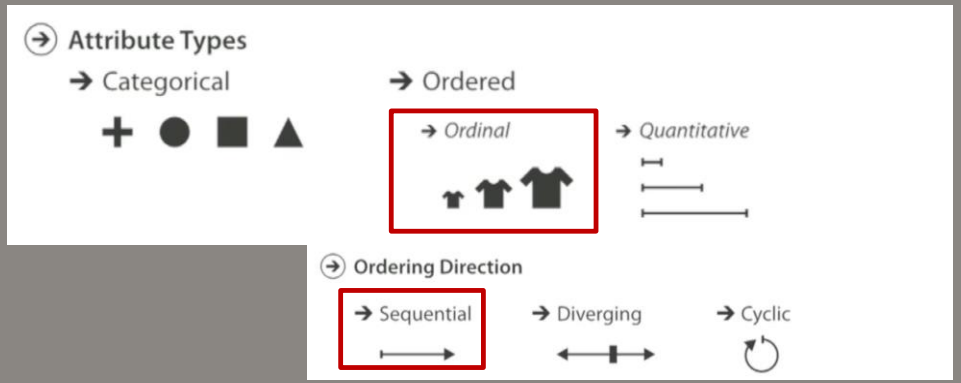


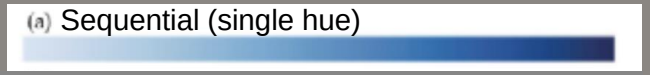
categorical

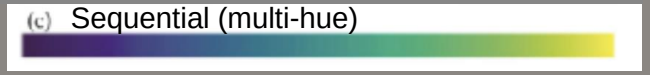
Color Map: Univariate

- Sequential
  - Ramp luminance or saturation









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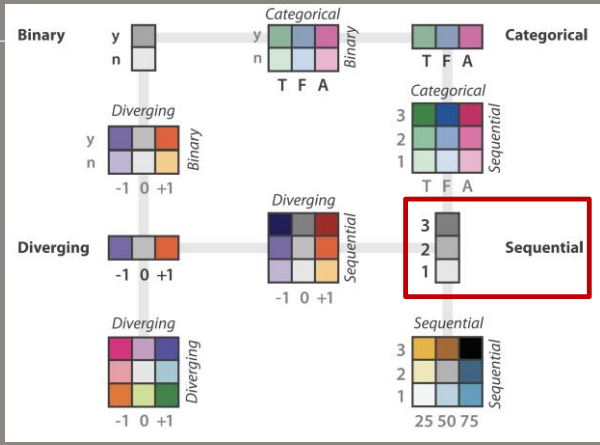
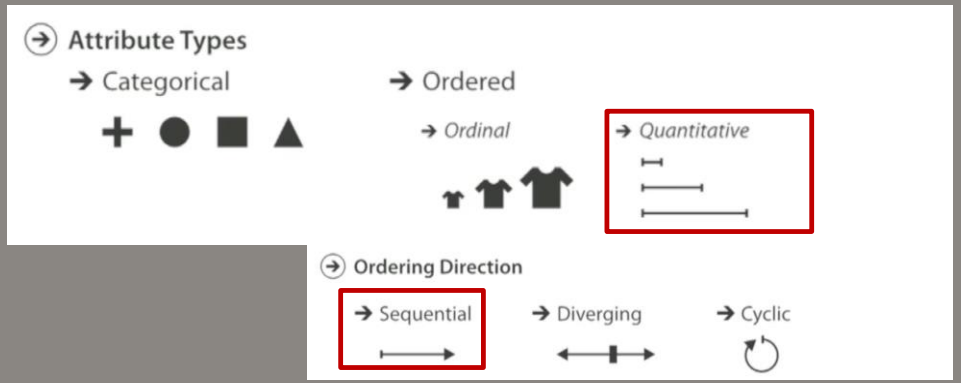
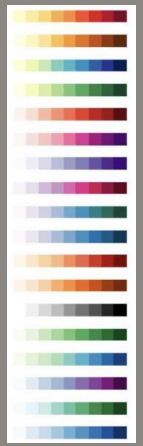
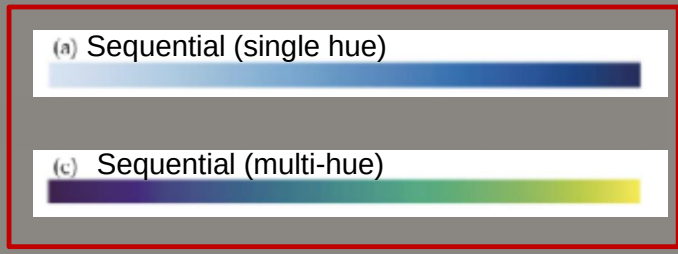




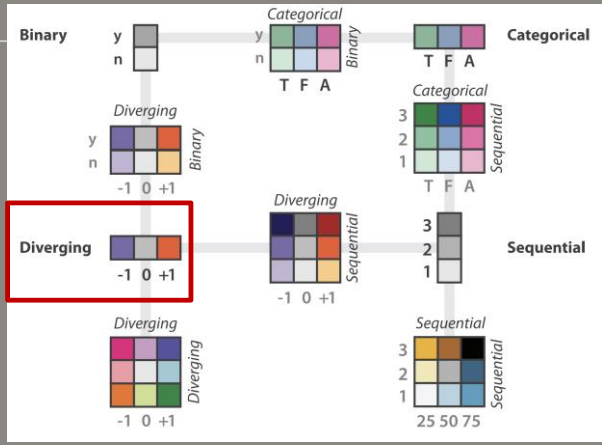
sequential

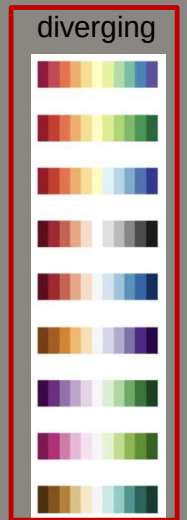




Color Map: Univariate

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





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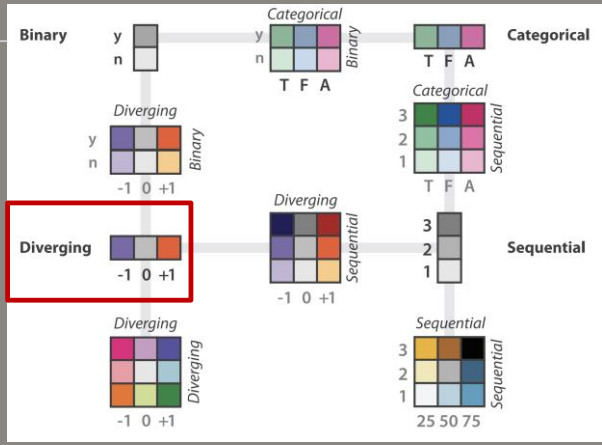
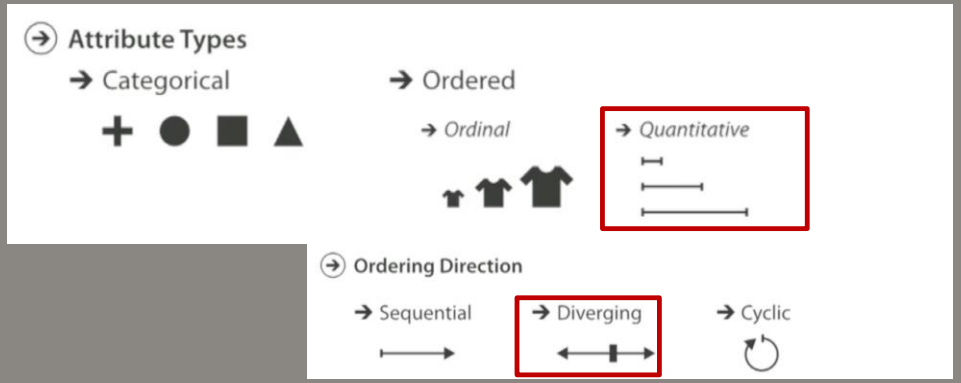
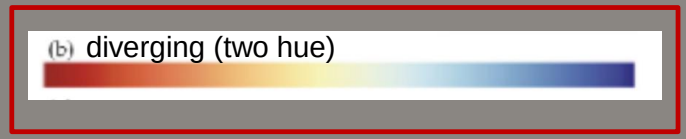


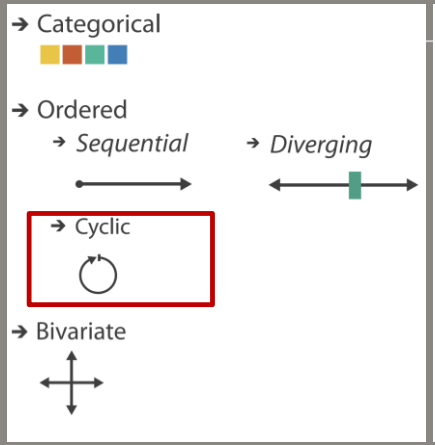


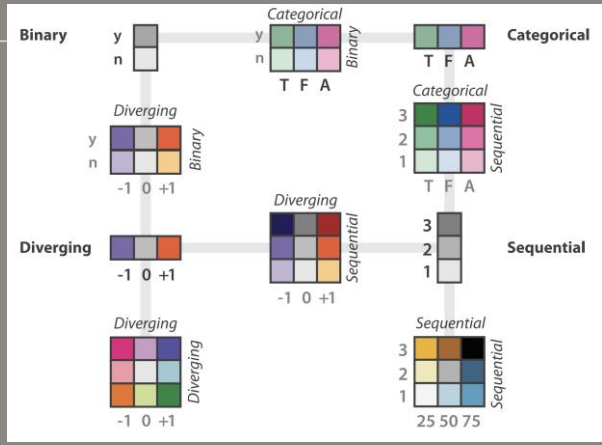
diverging

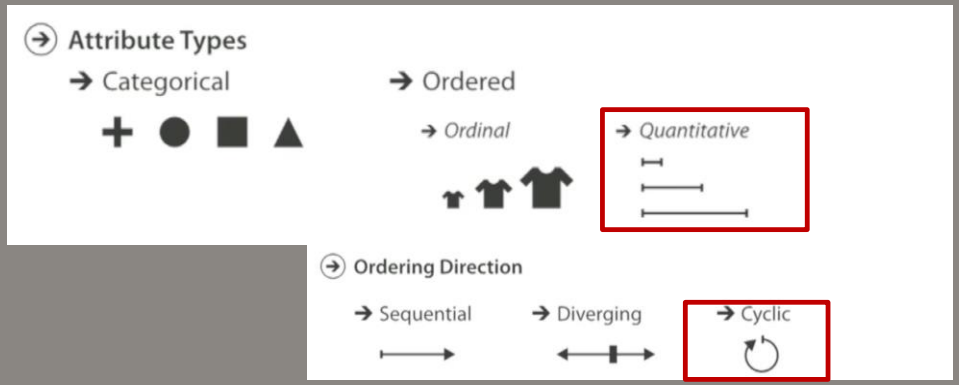


Color Map: Univariate

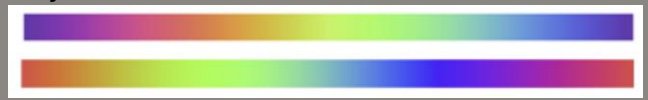
- Cyclic
  - Date, time, month...

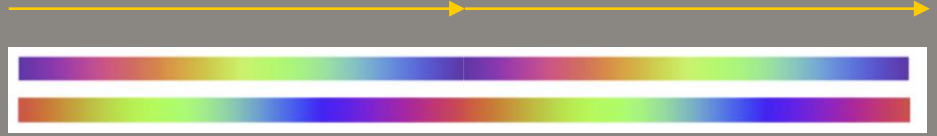






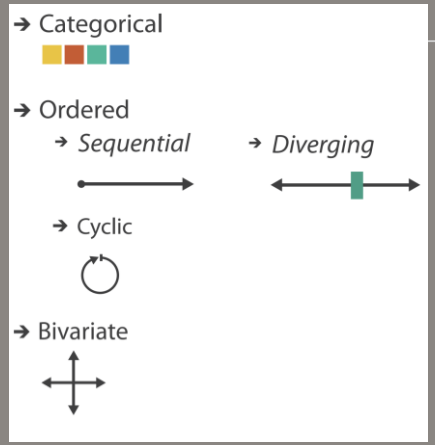
Cyclic multi-hue

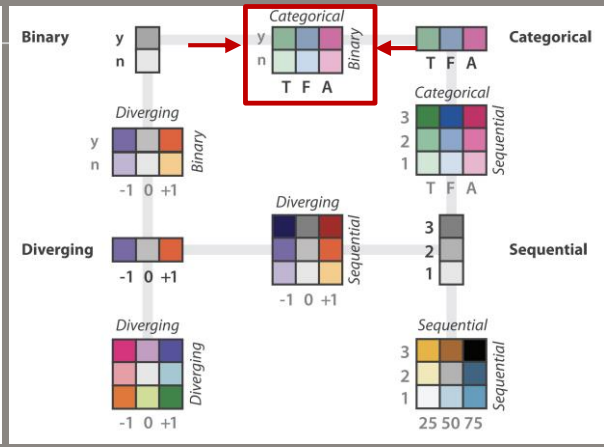




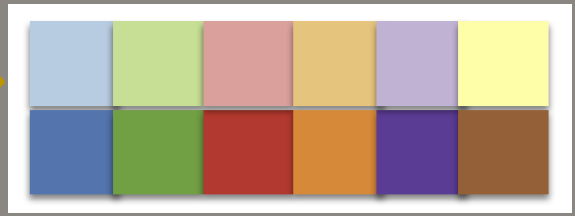
Color Map: Bivariate

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





d3.schemePaired<>

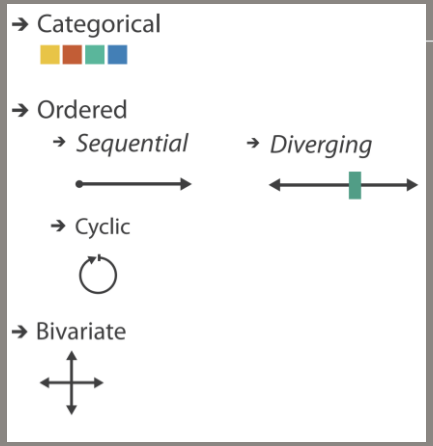


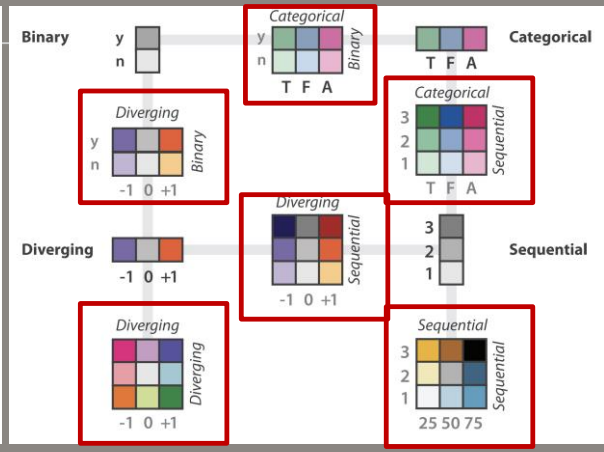
Binary saturation

Categorical hue

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





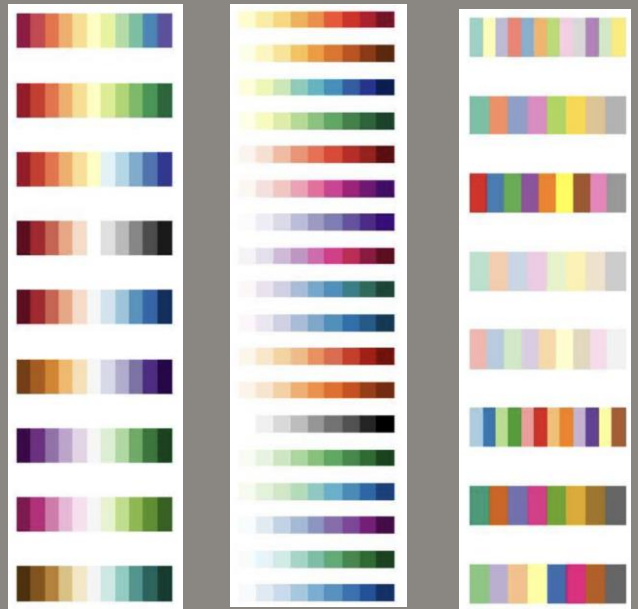
D3: https://github.com/d3/d3-scale-chromatic

Color Map

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

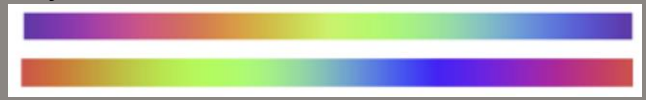
Segmented (discreet)

diverging | sequential | categorical



Continuous

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

S04-05