Display and Color Part 3

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Goal For Last Week and This

- Understand display and perception
  - What the human visual system can perceive
    - In terms of color, patterns, etc.
    - Based on the structure of the eye and the processing within the brain
  - What is possible to display/see/understand
    - Can influence how we design visualizations
  - Today we will discuss applications based on color
- Much of the material drawn from Ware chapters 2-6.

Color Selection

- When a user needs to select a color (e.g. to label parts of a visualization), we want to provide an interface that allows straightforward selection of colors
- Separate lightness/brightness control from chromaticity control
- Lay out red-green and yellow-blue axes on a plane
  - Orthogonal axes provide good perceptual separation
- If possible, allow color selection to be displayed against different backgrounds

Color Selection Example

- https://color.adobe.com/create/color-wheel
- Note the color distribution is more similar to the CIELAB layout (red-green/yellow-blue), and intensity is separated

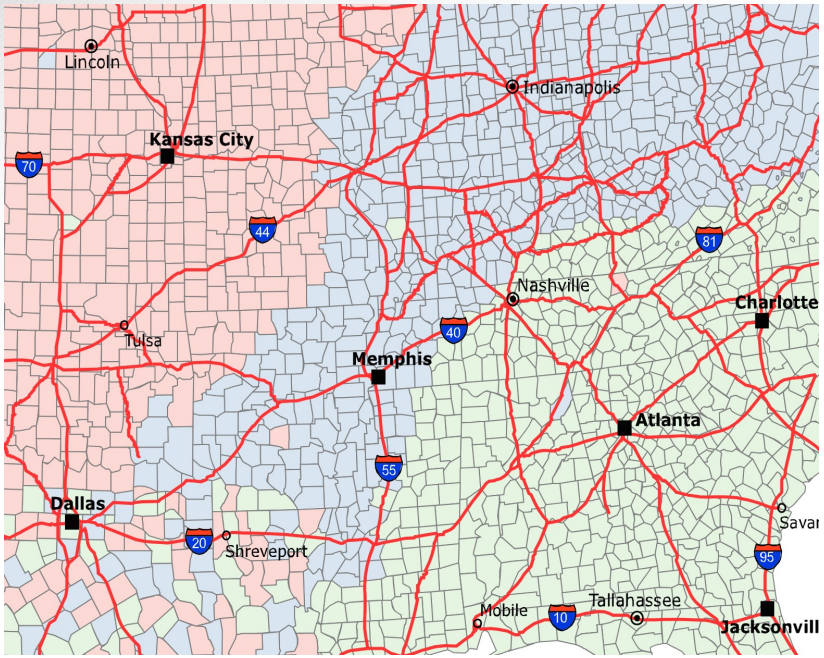
Color Labeling

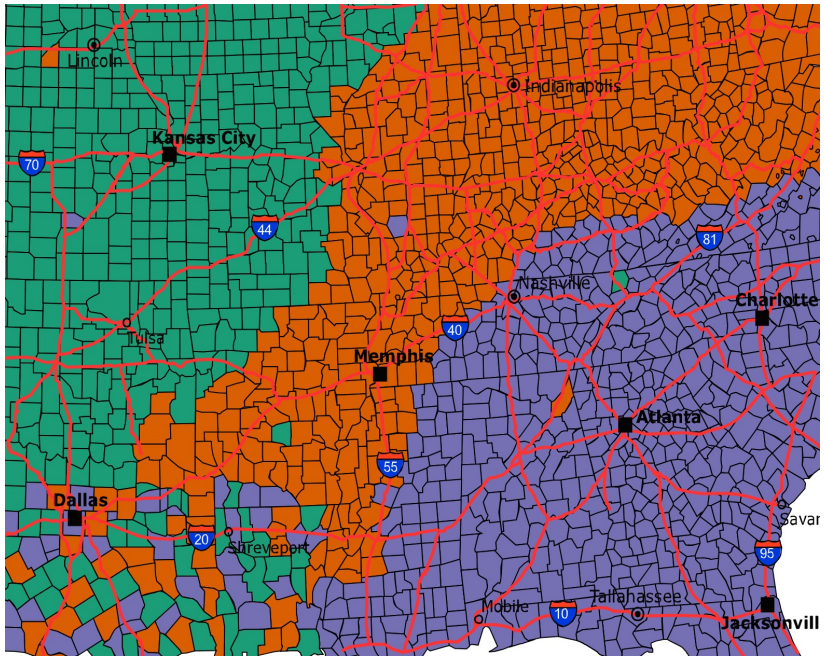
- When labeling nominal categories, need to choose a set of colors to use for labeing
  - Note: no ordering
- Key idea is that color can be remembered, recognized, and matched to the correct legend
- Colors should be distinct; spaced far apart in perceptual color space
  - Does not need to be maximally separate, just clearly distinct

Color Labeling (continued)

- For large areas of color, low saturation colors can be used
- For small marks, use higher saturation
- Should have luminance difference in foreground/background
  - Thin white/black borders around shapes will tend to reduce contrast effects

Example





- Notice that low saturation background with high saturation foreground is much easier to read, while still allowing comparison of background material
- Generated at https://colorbrewer2.org/

Color Labeling (continued)

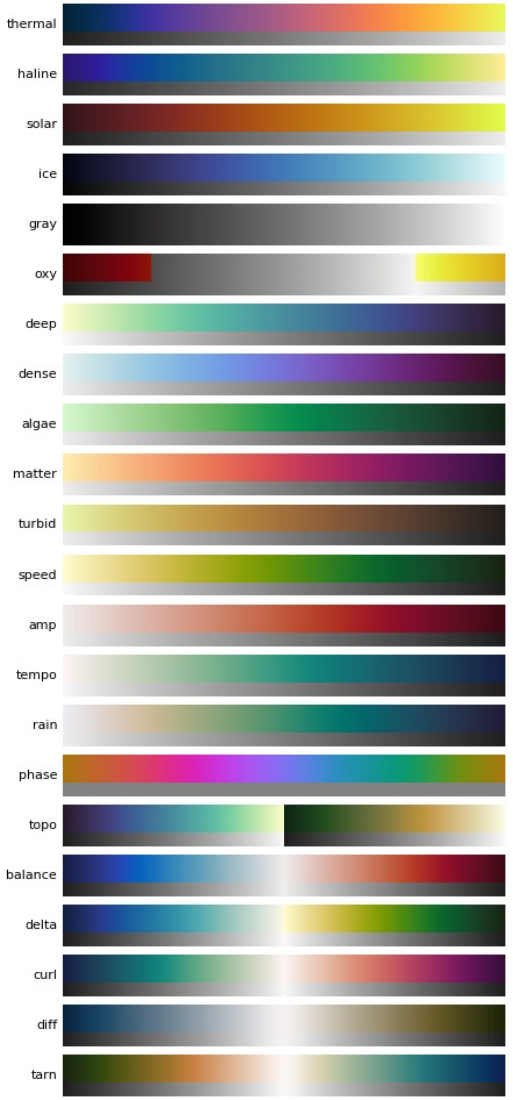
- For color blind viewers, ensure variation in the yellow-blue axis
  - For most common type of color blindness.
- No more than 10 different colors can be reliably used
  - Assumes same luminance value for each
  - Some estimates are lower than 10
- Color “families” (same hue, different saturation/lightness) can be used
  - Only about 3 levels of saturation/lightness are reliable

Pseudocolor Sequences

- We often want to have a pseudocolor scale
  - Also called Color map, Color sequence
- Map each value to some color along a scale
  - What scale is good?
  - Plot these on the map/diagram
- For many 2D images, this is called a **choropleth** diagram

Color Scales

- Many possible color scales have been used
- Can be of several types
  - Sequential
  - Divergent
  - Cyclic



https://matplotlib.org/cmocean/

Common color scales

https://sjmgarnier.github.io/viridis/articles/intro-to-viridis.html

Color Scales

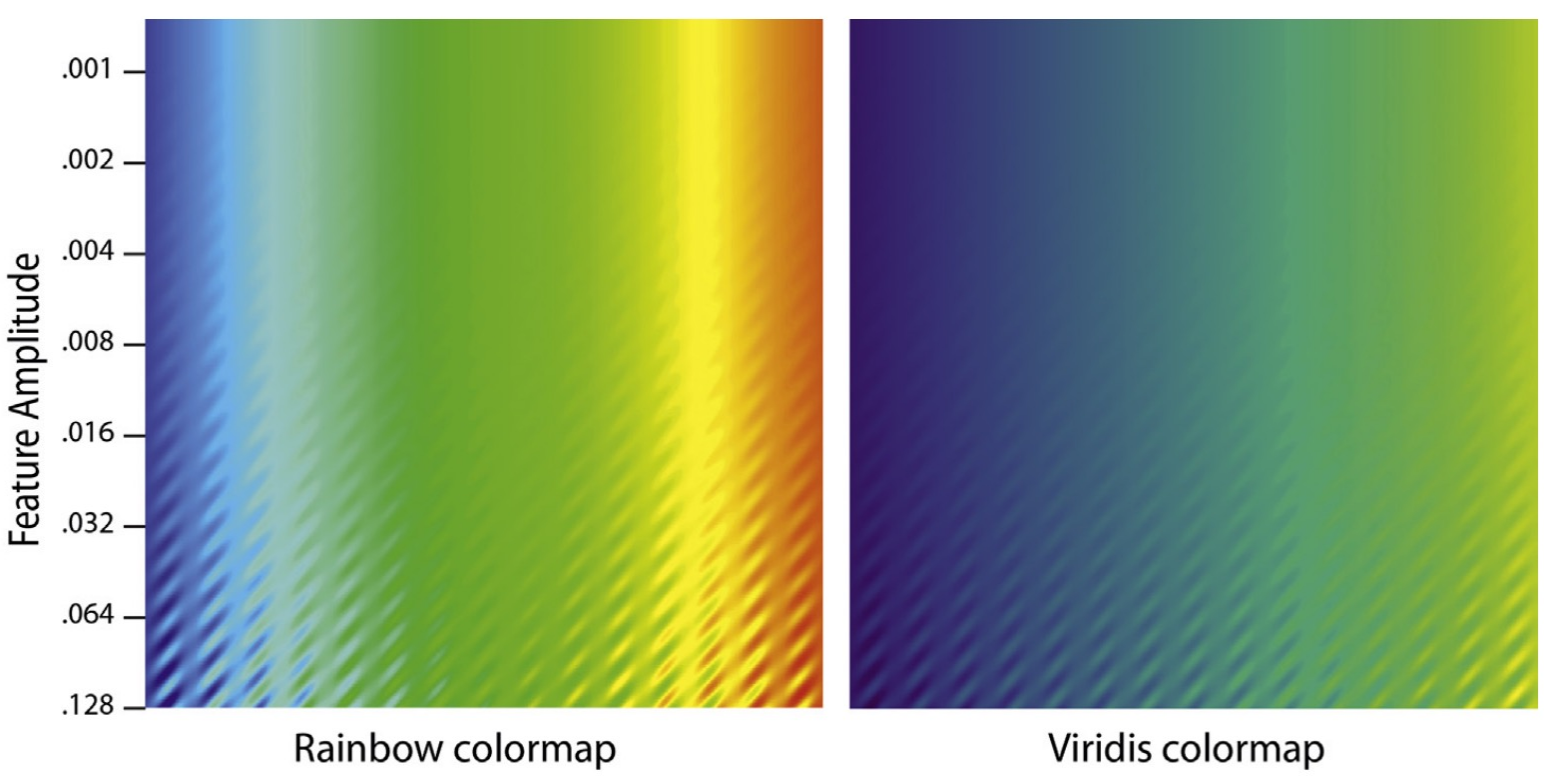
- What do we want to do with color scales?
  - Resolving features: can we perceive aspects in the map?
  - Identifying patterns: can we find highs/lows, positive/negative values, compare gradients, identify saddle points, elongated features, etc.?
  - Read values from key: can we determine what value a point has by comparing to some key?
  - Classify regions: can we determine what contiguous area meets some criteria?

Perceptual Properties of Colormaps

- Resolving power: How fine of features (variations in value) can be detected?
  - Uniformity: How uniform is this resolving power over the range of the scale?
- Perceptual monotonicity
- How readily are colors in the scale categorized?

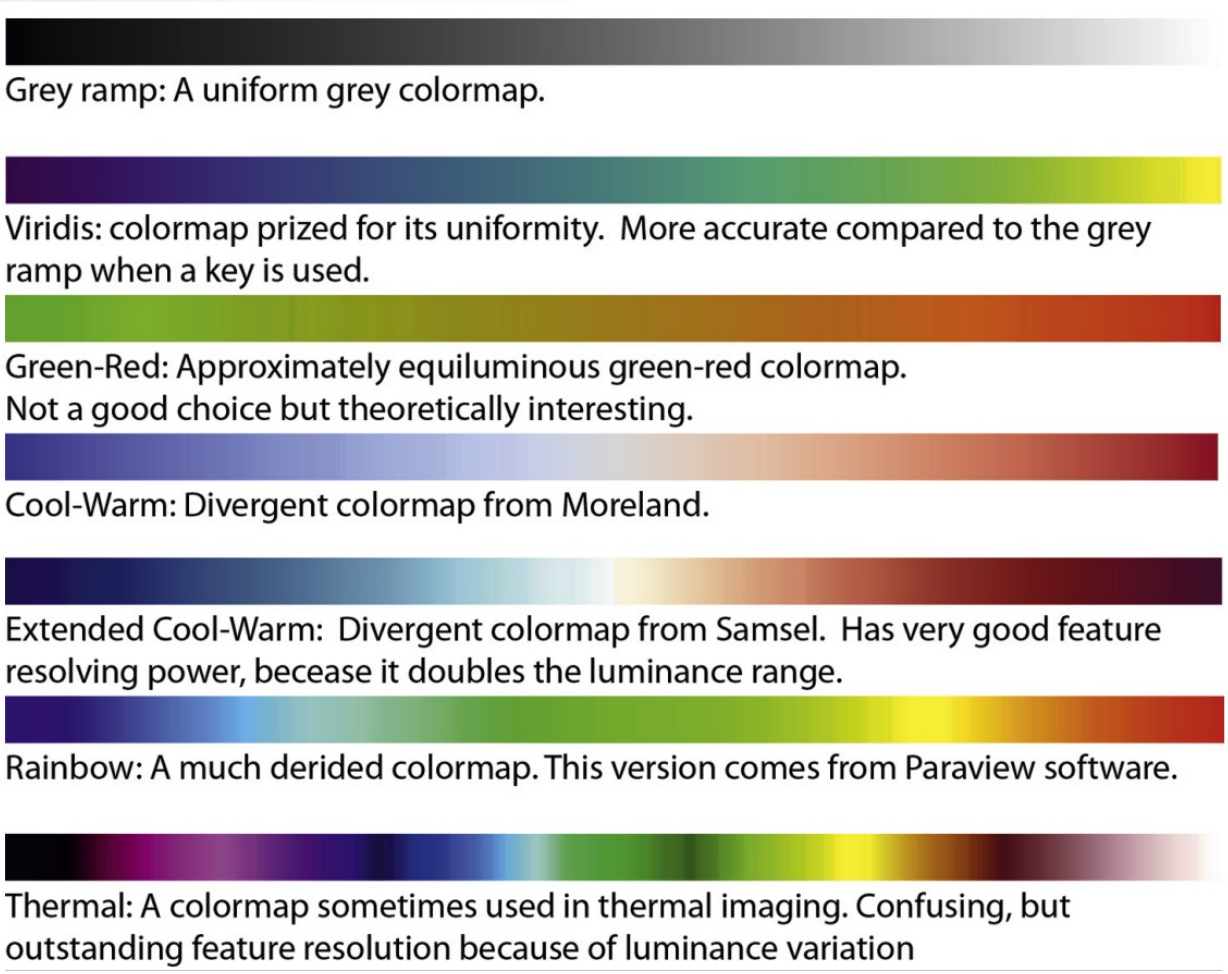
Uniformity and Resolving Power

- Different scales, have different ability to distinguish features across values



Ware, page 131, fig. 4.31

Some Scales for Comparison



Grey ramp: A uniform grey colormap.

Viridis: colormap prized for its uniformity. More accurate compared to the grey ramp when a key is used.

Green-Red: Approximately equiluminous green-red colormap.
Not a good choice but theoretically interesting.

Cool-Warm: Divergent colormap from Moreland.

Extended Cool-Warm: Divergent colormap from Samsel. Has very good feature resolving power, becease it doubles the luminance range.

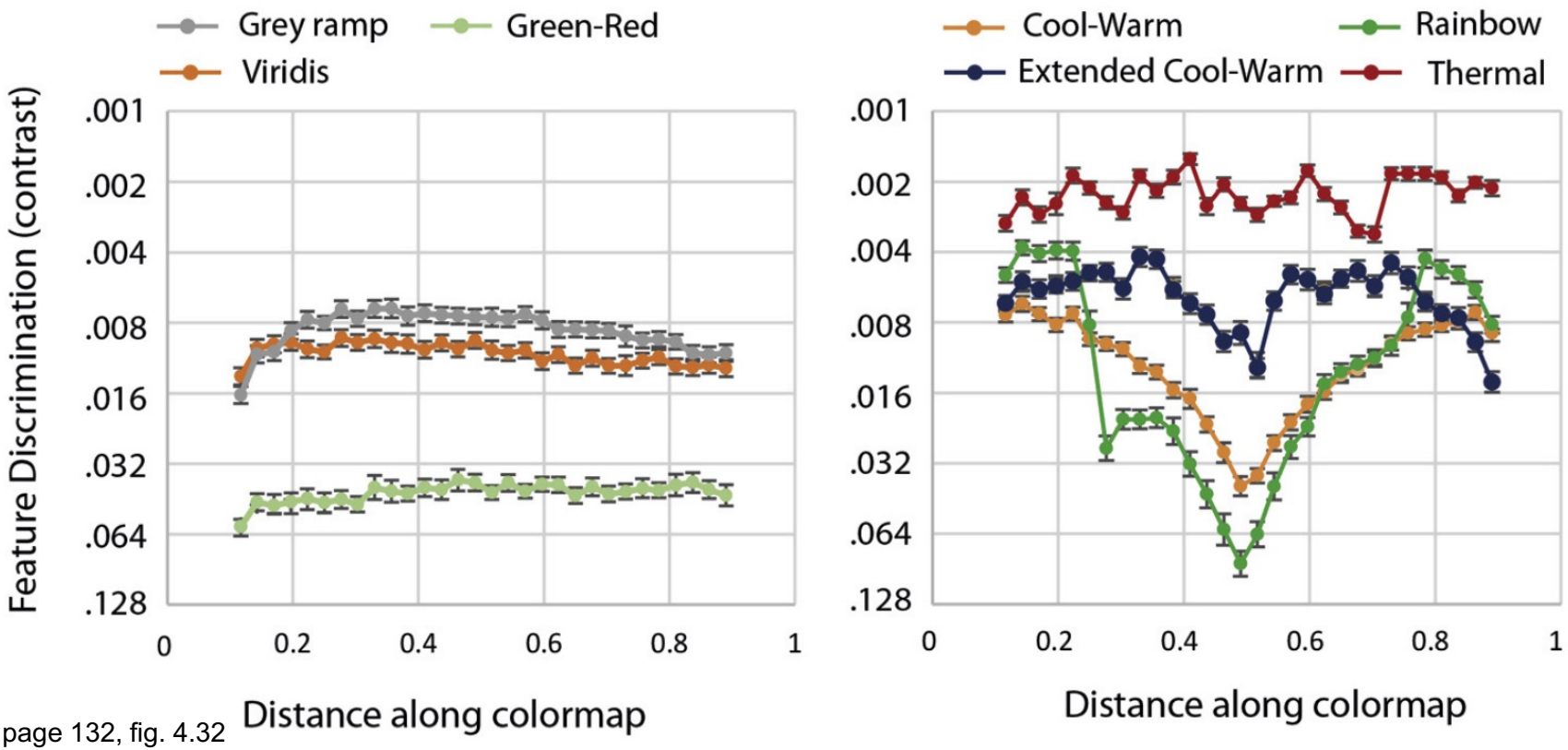
Rainbow: A much derided colormap. This version comes from Paraview software.

Thermal: A colormap sometimes used in thermal imaging. Confusing, but outstanding feature resolution because of luminance variation

Ware, page 129, fig. 4.29

Uniformity and Resolving Power

- Different color scales have different resolution and uniformity



Ware, page 132, fig. 4.32

Notes about Resolution

- Rainbow scale is very nonuniform
- Grayscale, Viridis, Green-red are very uniform
- Thermal has some of the best resolving power

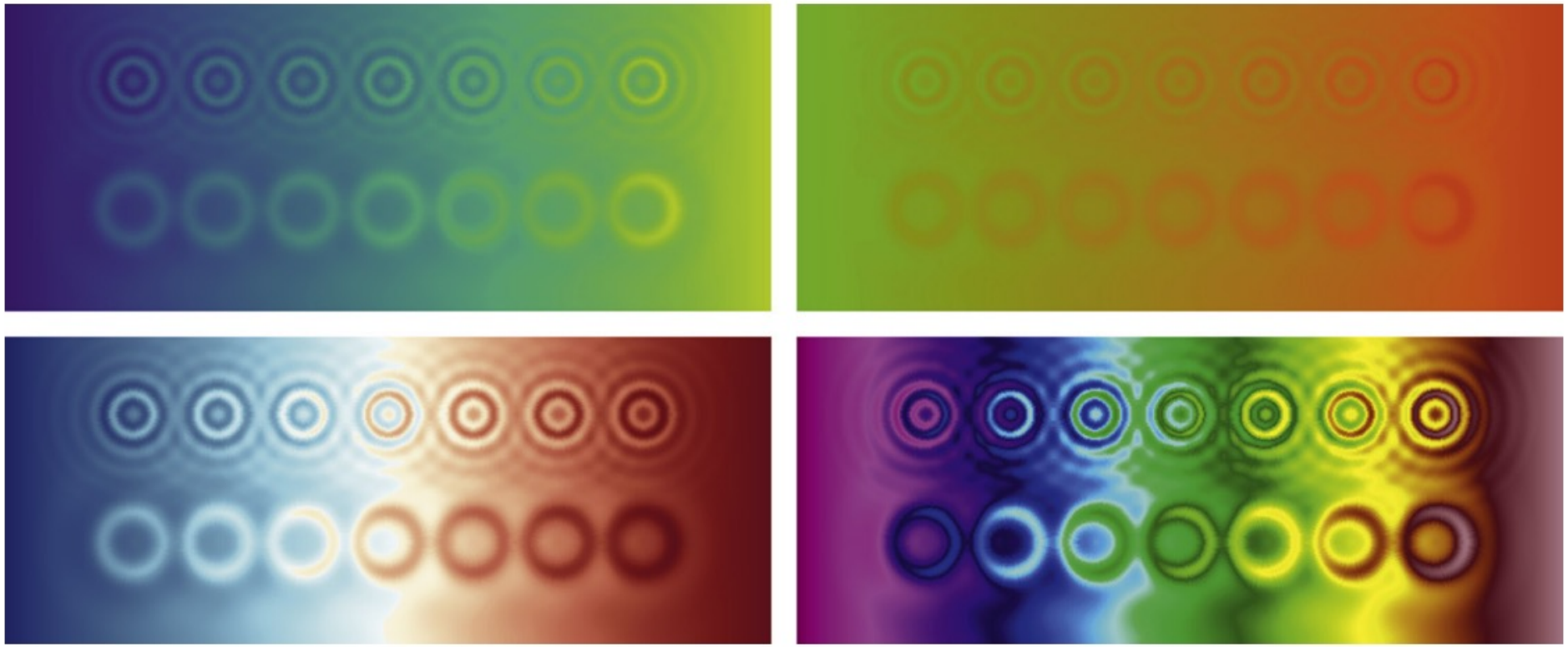
- Generally, luminance variation is good for helping improve resolving power

Perceptual Monotonicity

- We want the scale to be clearly ordered (monotonic) from low to high
- Grayscale (pure luminance) is the best at allowing this, and can be adjusted for perception very precisely
  - But, recall that it is *not* good for maps of data due to contrast effects; hue is needed to allow accurate reading
- Color scales that have smooth luminance ramps will produce better results

Form Perception

- Consistency and clarity of patterns varies by scale



Ware, page 134, fig. 4.33

Categorization

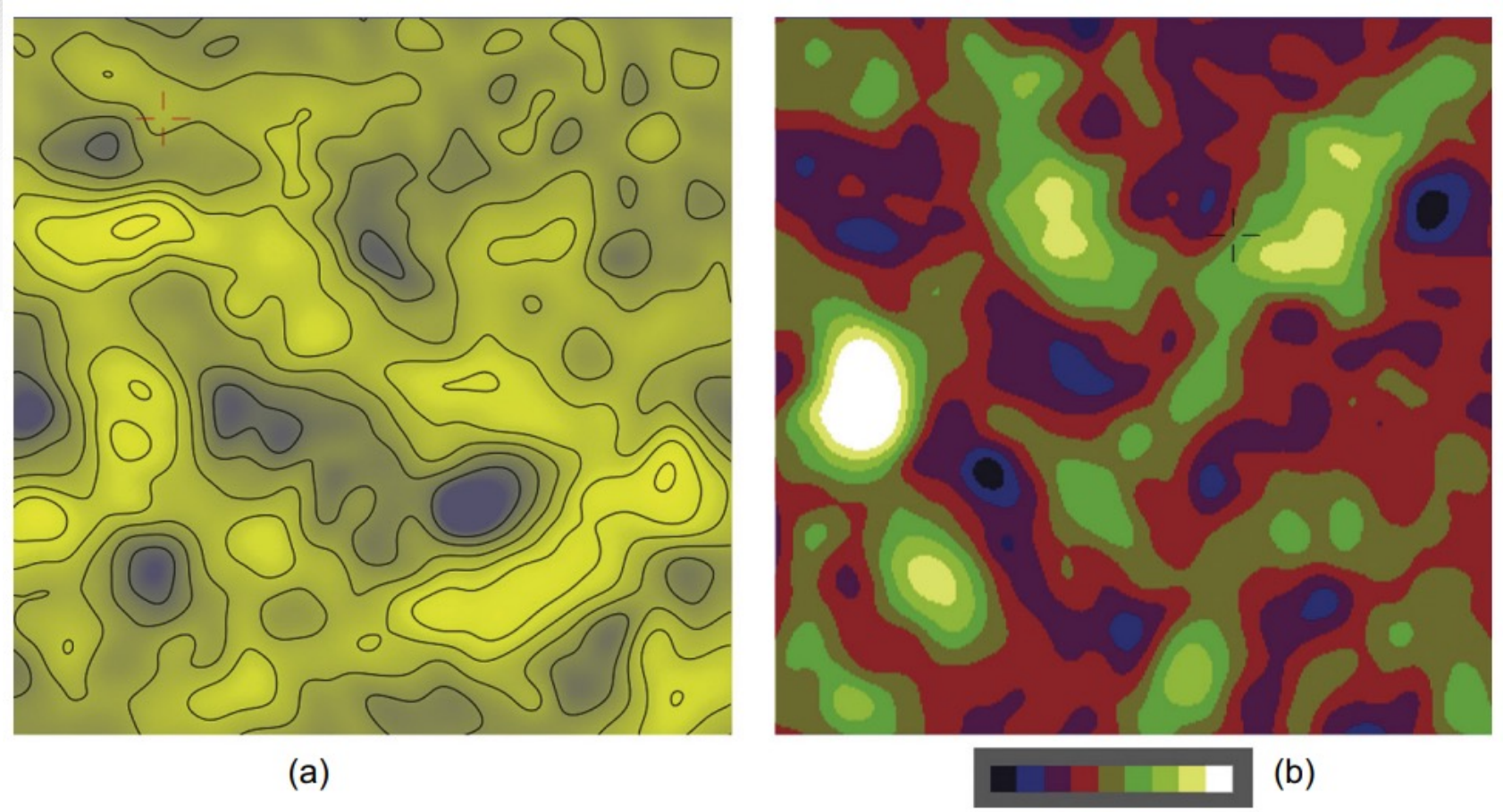
- If a scale is used to categorize (i.e. to identify one region vs. another), perceptual smoothness an uniformity is not needed.
- Want distinctive regions to appear distinctive
  - Rainbow scale sometimes actually works well for this
- Especially true around zero (to identify positive/negative); diverging scales work well here
  - Neutral color in middle; opposing at edges

Contours and Discrete Color Sequence

- Contours can help categorize regions
  - Help group regions that “belong” togehter
- A discrete color sequence (rather than a color scale) can make it even easier to detect discrete regions

Ware, page 135, fig. 4.34

Contours and Discrete Color Sequence



Ware, page 135, fig. 4.34

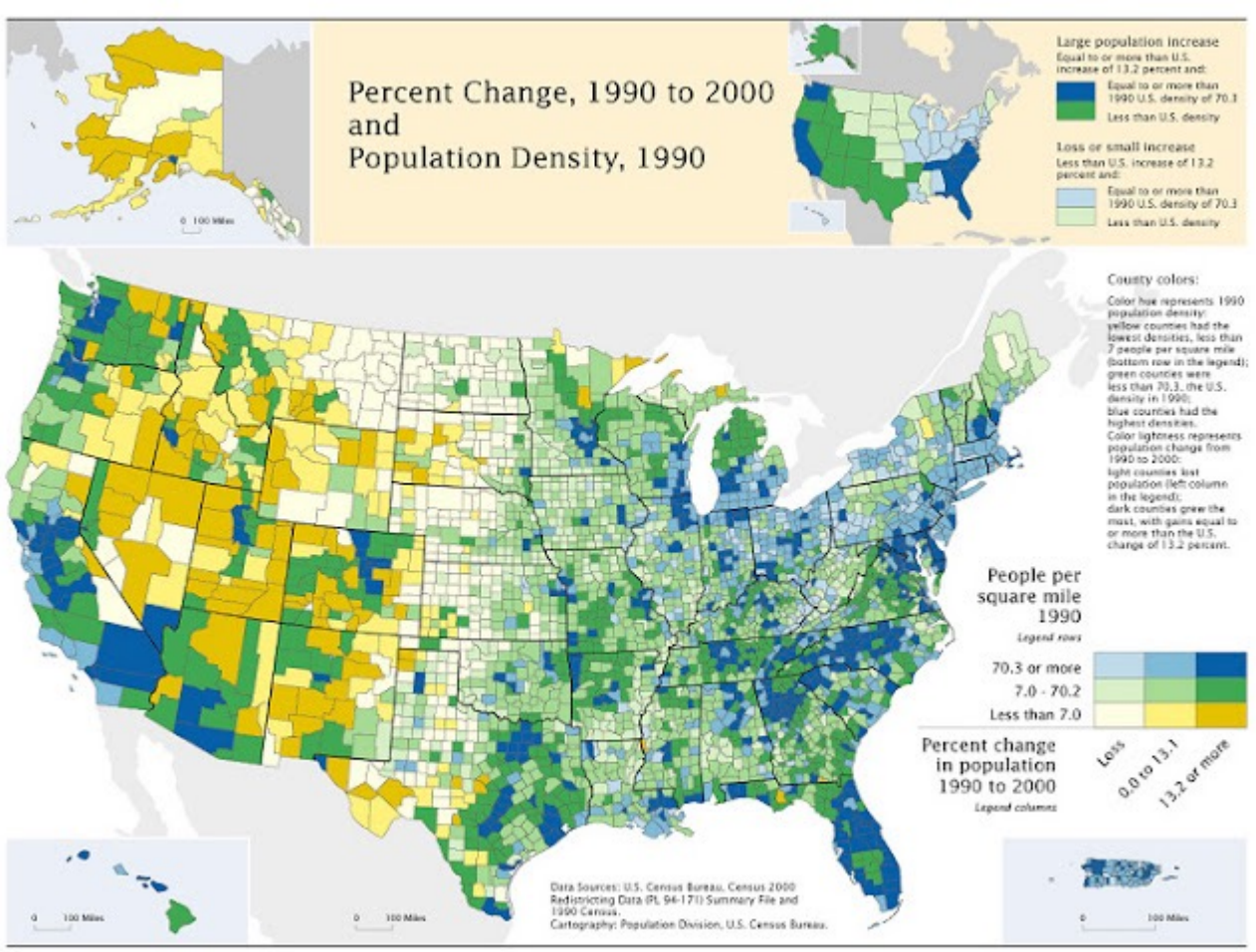
Bivariate Scales

- Since color is 3 dimensional, we could potentially map any 3 variables into color space
  - e.g. one to Red, one to Green, one to Blue
- However, this is not perceptually uniform
  - It is very difficult to distinguish across 3 channels
- But, bivariate has worked
  - Hue for one channel, lightness or saturation for the other
  - Still, can be VERY difficult to read

Bivariate Scales

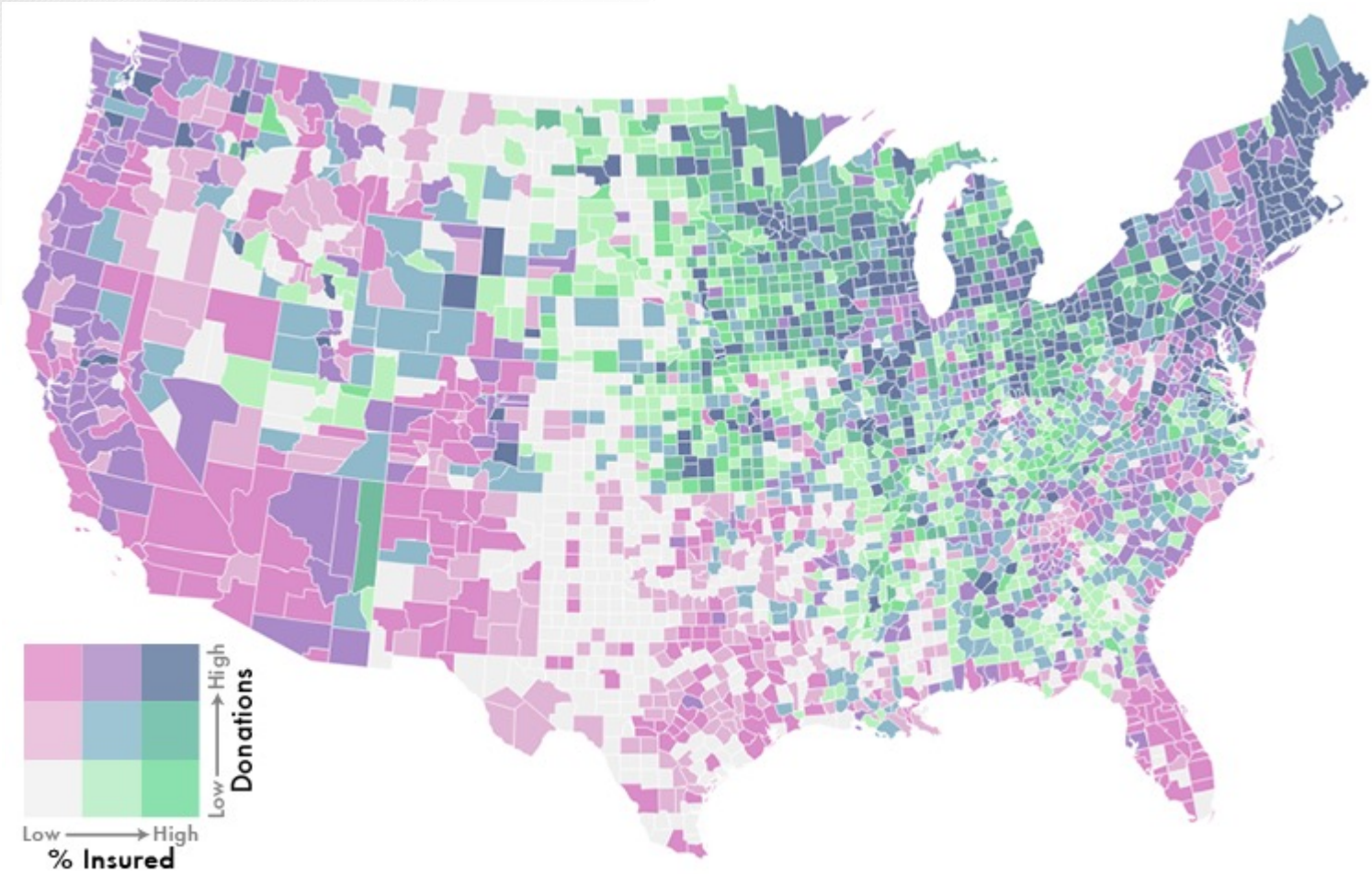
- Good scale:
  - Hue for one channel, usually discrete
  - Lightness or Saturation for the other
- Sometimes have a “mixed” hue grid
  - Often just a 3x3 grid of values along 2 scales
  - Much more than this is too difficult to read
  - Might get better with experience

Saturation for One Axis



https://mapsbykels.blogspot.com/2013/04/choropleth-map-bivariate.html

Two Hue Scales



https://www.joshuastevens.net/cartography/make-a-bivariate-choropleth-map/

Overall Takeaways for Color Scale

- The rainbow (spectral) scale is really not good for use as a color scale
  - Unless identifying discrete colors is the main task
- Viridis is a pretty good/safe choice for a color map, but is not the only one