Chapter 11

Map Colors and Other Channels

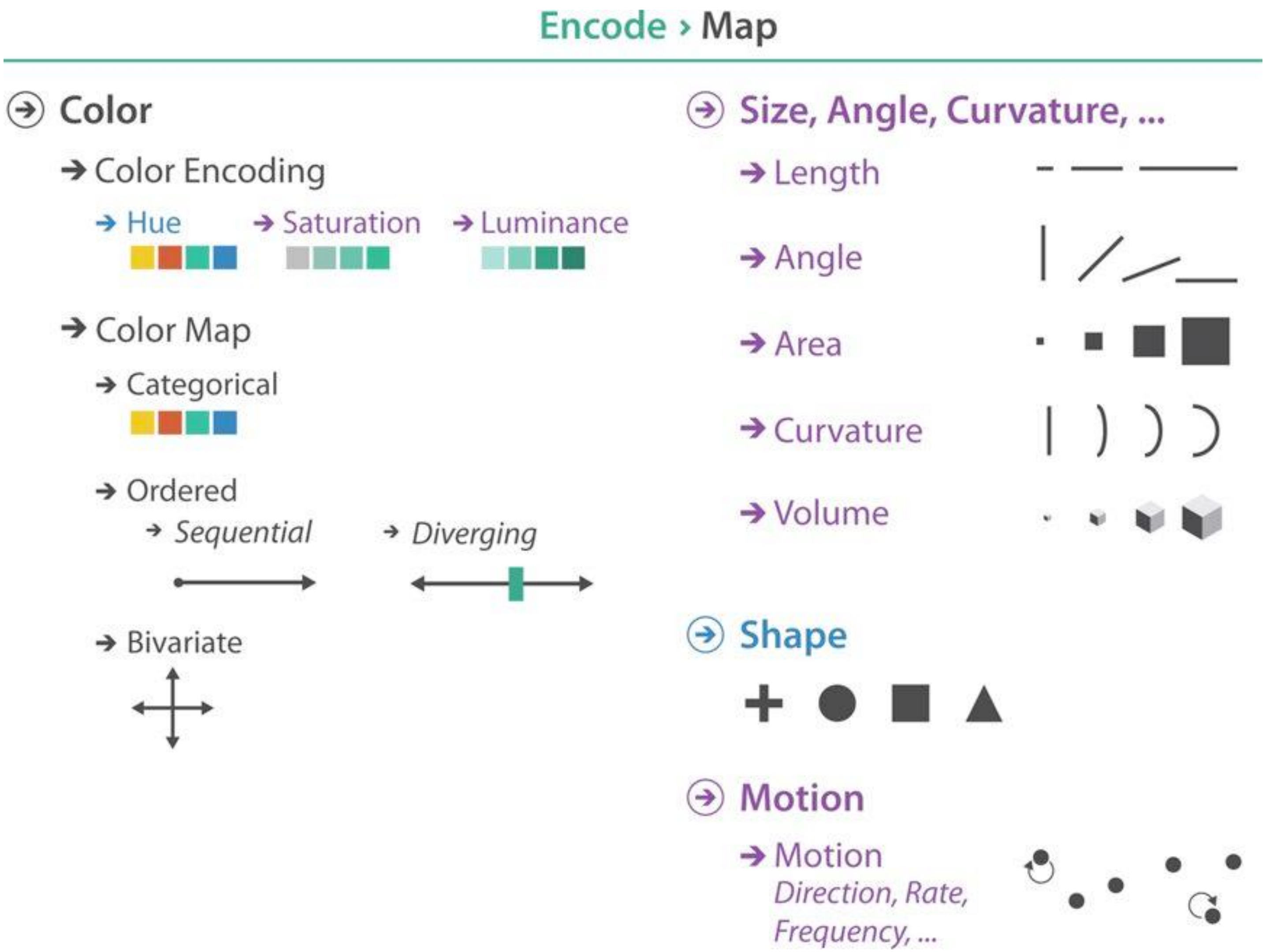
The Big Picture

- **Map color and other non-spatial channels**
- **Color**
  - **3 separate channels: Luminance, hue, saturation**
- **Color map construction**
  - **To distinguish between categorical attributes**
  - **To encode ordered attributes**
    - **Sequential ordered colormaps**
    - **Diverging ordered colormaps**
      - **Zero point in the center, diverge to negation on one side and positive on the other**
    - **Bivariate colormaps**
      - **Show two attributes simultaneously using carefully designed combinations of LHS**

The Big Picture

- **Other channels**
  - **Magnitude channels of size, angle, and curvature**
    - **Length, angle, area, curvature, volume**
  - **Identity channels of shape and motion**
    - **Shape**
    - **Motion**
      - **Motion direction, rate, frequency**

The Big Picture



Design choices for mapping color and other visual encoding channels.

Color Theory
Color vision

- Retina has two different receptors in human vision
  - Rods
    - Actively contribute to vision only in low-light setting and provide low-resolution black and white information
  - Cones
    - Sensors in normal lighting condition
    - Three types of cones, each with peak sensitivities at a different wavelength.
    - Visual system immediately process these signals into three opponent color channels
      - » One from red to green: low resolution
      - » One from blue to yellow: low resolution
      - } color
      - » One from black and white encoding luminance information: convey high-resolution edge information

Color Theory
Color Space

- What colors the human visual system can detect
  - 3D, can be described using 3 axes as color space
  - Some are convenient for computing, others are better match with human vision
  - RGB
    - Convenient for computer graphics
    - Very poor match with human vision
    - RGB axes are not useful as separable channels; they give rise to the integral perception of color

Color Theory
Color Space

- HSL (hue-saturation-lightness)
  - More intuitive, heavily used by artists/designers
  - Hue
    - Captures what we normally think of as pure colors
    - Not mixed with white or black
  - Saturation
    - Amount of white mixed with pure color
    - Ex: Pink is a partially de-saturated red
  - Lightness
    - Amount of black mixed with a color
  - Color picker design
    - A disk with white at the center
    - The hue axis wrapped around the outside (fully saturated color)
    - Linear control for the amount of darkness vs. lightness

Color Theory
Color Space

A common HSL/HSV colorpicker design, as in this example from Mac OS X, is to show a color wheel with fully saturated color around the outside and white at the center of the circle, and a separate control for the darkness.

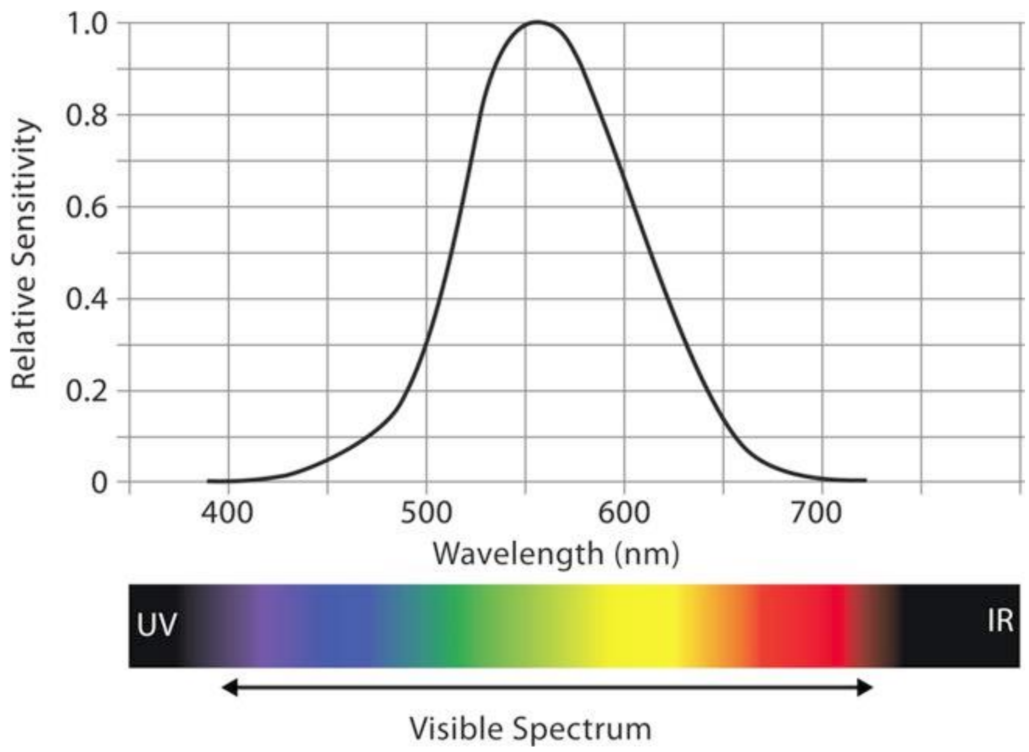
Color Theory
Color Space

- **HSL (hue-saturation-lightness)**
  - **Only pseudo-perceptual**
    - **Does not truly reflect how we perceive color**
      - » **Lightness L is wildly different from how we perceive luminance**
    - **EX. Fig in next page**
      - » **The six hues are arranged in order of their luminance**
      - » **The computed L are all identical**
      - » **Measured luminance is a better match with our perceptual experience**
      - » *** our perception of luminance does not match the measured luminance**
      - » **The amount of luminance human perceived depends on the wavelength**
      - » **Bell-shaped spectral sensitivity curve for daylight vision**

Color Theory
Color Space

Comparing HSL lightness, true luminance, and perceptually linear luminance L* for six colors. Six different hues, arranged in order Of their luminance. The computed HSL lightness L is the same for all of these colors, showing the limitations of that color system. The true luminance values of these same six colors, as could be measured with an instrument. The computed perceptually linear luminance L* of these colors is the best match with what we see.

Color Theory
Color Space



The spectral sensitivity of our eyes to luminance depends on the wavelength of the incoming light. Human are more sensitive to middle wavelengths of green and yellow than to the outer wavelengths of red and blue

Color Theory
Color Space

- **HSL (hue-saturation-lightness)**
  - **Only pseudo-perceptual**
    - **Does not truly reflect how we perceive color**
      - » **Lightness L is wildly different from how we perceive luminance**
- **L*a*b* space**
  - **Attempt to provide a perceptual uniform space**
  - **L*: A single black and white luminance channel**
    - **A nonlinear transformation of the luminance perceived by human**
    - **Designed to be perceptually linear**
  - **A*b*: two color axes**
    - **Designed to be perceptually linear**
  - **Well suitable for many computations, including interpolation and finding difference between colors**

RGB or HSL are perceptually nonlinear!!

Color Theory
Luminance, Saturation, and Hue

- For visual encoding
  - Luminance
    - Magnitude channel
      - Suitable for ordered data
    - One consideration
      - our low accuracy in perceiving whether noncontiguous regions have the same luminance because of contrast effects
        - » The number of discriminable steps is small, typically < 5 when the background is not uniform
    - A fundamental problem: Luminance is "used up" and cannot be used for other purposes
      - Luminance contrast is the ONLY way we can resolve fine detail and see crisp edges
        - » Hue contrast and saturation contrast can not do it!

Color Theory
Luminance, Saturation, and Hue

- Saturation
  - Magnitude channel. Suitable for ordered data
  - Shares the problem of low accuracy for noncontiguous regions
    - The number of discriminable steps ~ 3 bins
  - Interacts strongly with the size channel
    - It is more difficult to perceive in small regions than in large ones
      - » Point and link marks: small regions → using just two different saturation levels is safer
  - Saturation and hue are not separable channel within small regions for categorical color coding
  - For small regions: use bright, highly saturated colors to ensure distinguishable coding
  - For large regions: use low-saturation colors

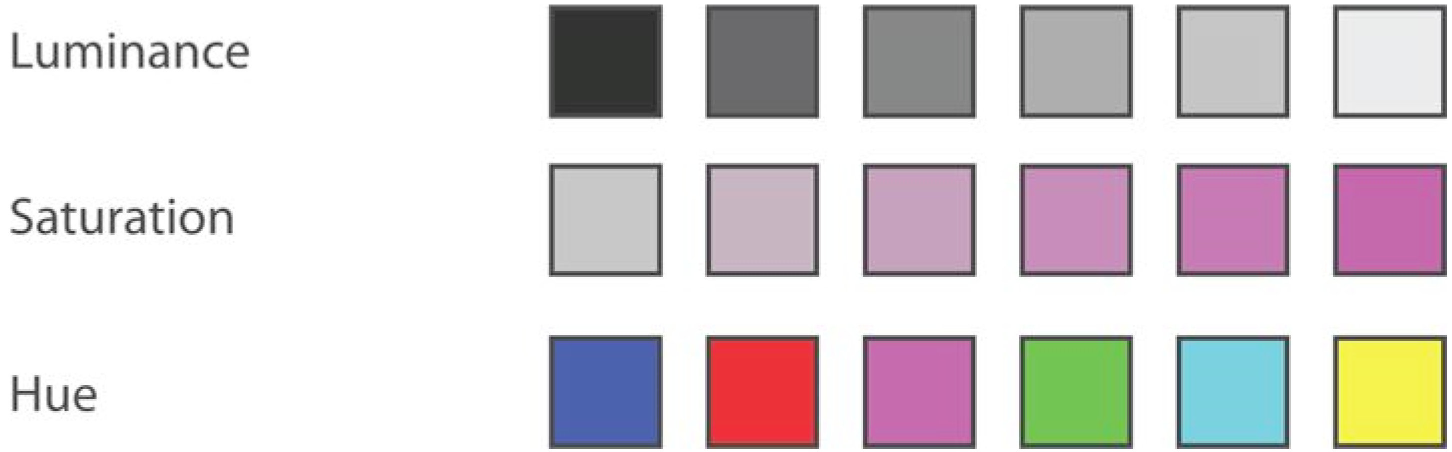
Color Theory
Luminance, Saturation, and Hue

- Hue
  - Identity channel.
  - Extremely effective for categorical data and showing groups
    - The highest ranked channel for categorical data after spatial position
  - Shares the same problems as saturation in interacting with size channel
    - Hue is harder to distinguish in small regions than large regions
  - Shares the same problems as saturation and luminance for separable regions
    - We can make fine distinctions in hue for continuous regions, but have very limited distinguishability between separable regions
      - » Around 6 or 7 bins for small separable regions

Color Theory
Luminance, Saturation, and Hue

– **Hue**
  - **Unlike luminance and saturation, hue does not have an implicit perceptual ordering**
    - **People can reliably order by luminance**
      - » **Always placing gray in between black and white**
    - **People can reliably order by saturation**
      - » **Can reliably place the less saturated pink between fully saturated red and zero-saturation white**
    - **For hue**
      - » **No way!**

Color Theory
Luminance, Saturation, and Hue



The luminance and saturation channels are automatically interpreted as ordered by our perceptual system, but the hue channel is not.

Color Theory Transparency

- Transparency
  - Strongly related to three color channels
    - Data can be encoded by decreasing the mark's opacity from fully opaque to completely see-through
    - Interacts strongly with luminance and saturation coding – should not be used in conjunction with them at all
    - Can be used in conjunction with hue encoding with a very small number of discriminable steps – just two!
    - Used most often with superimposed layers!

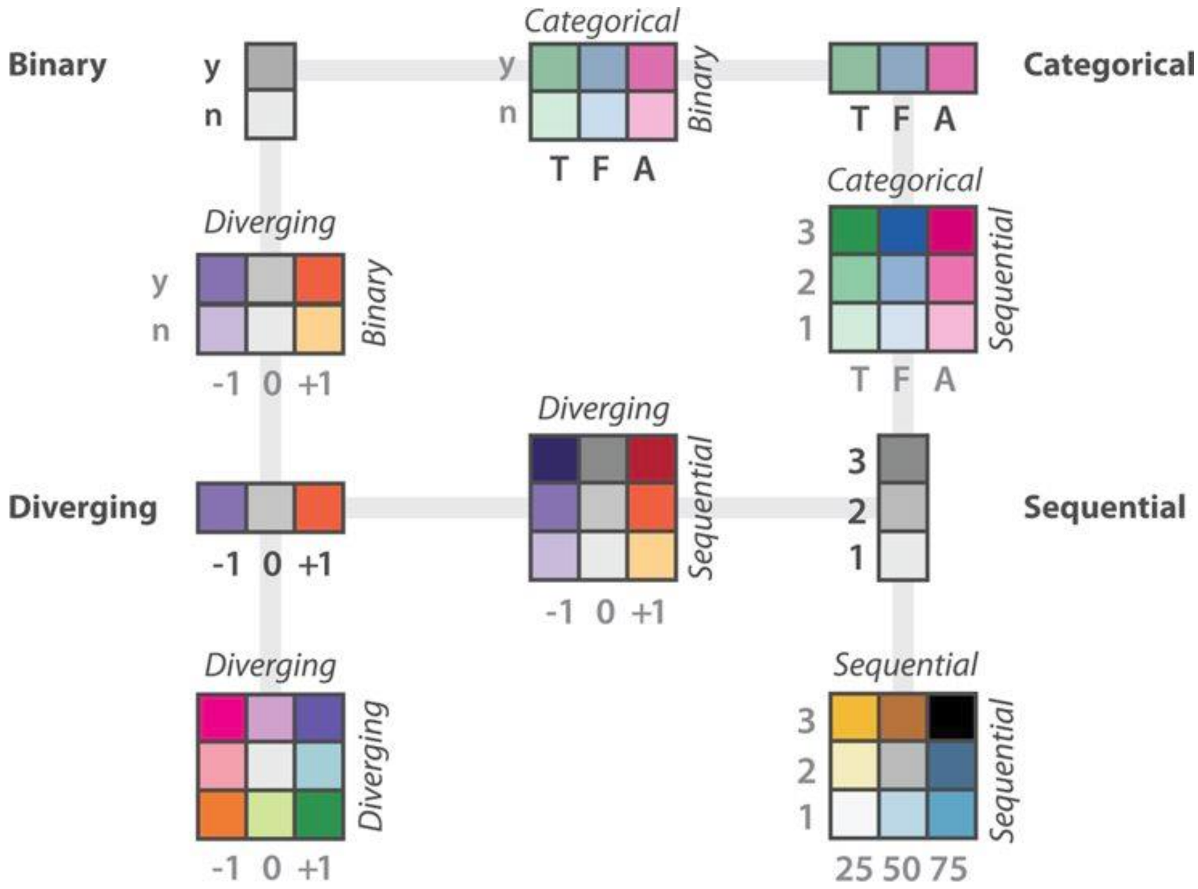
Colormaps

- **Specifies a mapping between colors and data values**
  - **Categorical**
  - **Ordered**
    - **Sequential**
    - **Diverging**
    - **Should use the magnitude channels of the luminance and saturation**
      - **The identity channel of hue des not have an implicit ordering!**

Colormaps

- Colormaps can be
  - Continuous range of values
    - Heavily used for showing quantitative attributes
  - Segmented into discrete bins of color
    - Suitable for categorical data

Colormaps



The colormap categorization partially mirrors the data types: categorical versus ordered, and sequential and diverging within ordered. Bivariate encodings of two separate attributes at once is safe if one has only two levels, but they can be difficult to interpret when both attributes have multiple levels.

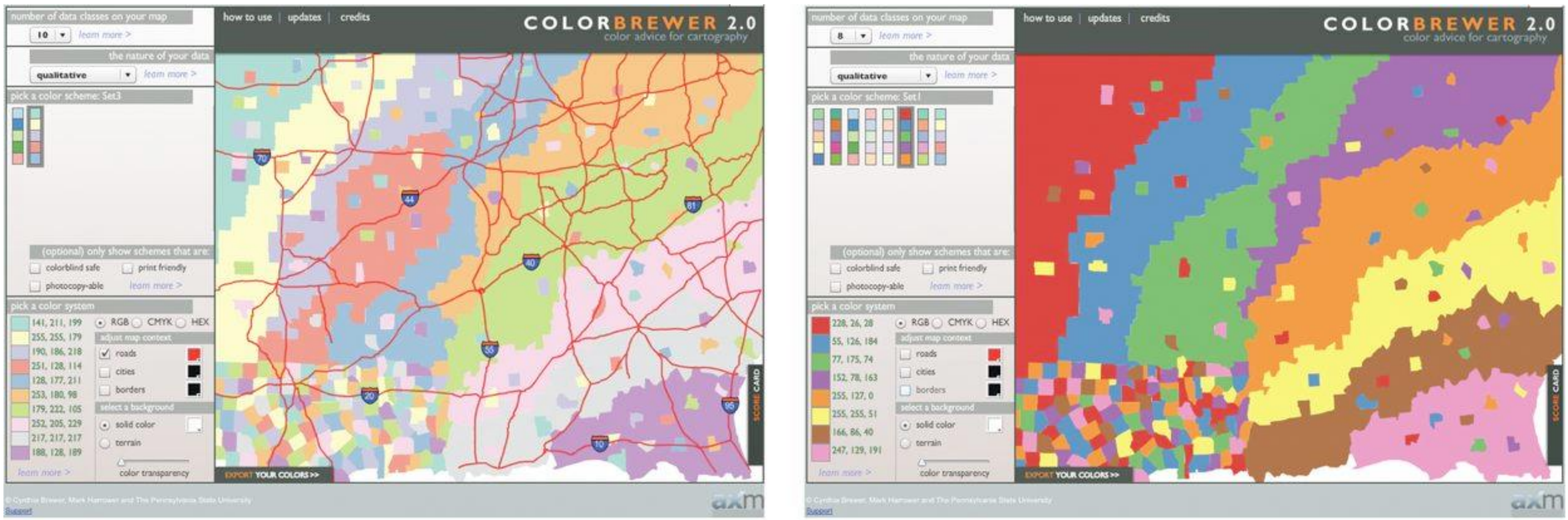
Colormaps
Categorical colormaps

- To encode categories and groupings
  - Normally segmented
  - Very effective
    - The next best channel after spatial position.
  - Typically use color as an integral identity channel to encode a single attribute
    - Not to encode 3 completely separate attributes with the hue, saturation, and luminance channels
  - The number of discriminable colors for coding small separated regions is limited between 6 and 12 bins

Colormaps
Categorical colormaps

- Colormap design is tricky!
  - Careful attention must be paid to luminance and saturation
    - Major issue: luminance contrast
      - For some cases, the colors should be close in luminance to avoid major difference in salience and to ensure that all can be seen against the same background
      - For other cases, colors should be sufficiently different in luminance that they can be distinguished even in black and white
    - For saturation
      - For small regions (Ex. line mark) -- highly saturated
      - For large regions (Ex. areas) – low saturation
  - ColorBrewer – a good resource for creating colormaps

Colormaps
Categorical colormaps



(a) (b)

Saturation and area. (a) The ten-element low-saturation map works well with large areas. (b) The eight-element high-saturation map would be better suited for small regions and works poorly for these large areas.

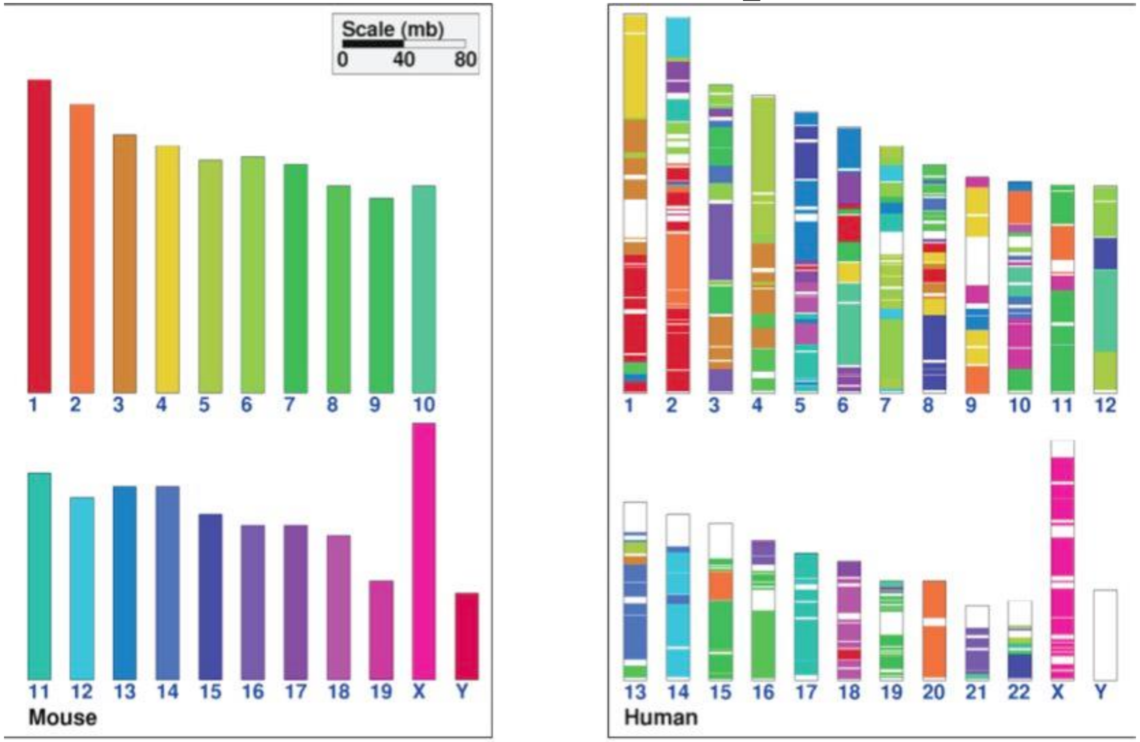
Colormaps
Categorical colormaps

- **Ineffective cases because of a mismatch between**
  - **the number of color bins that we can distinguish in non-contiguous small regions and number of levels in the categorical attribute being encoded**

Colormaps
Categorical colormaps

- **Ineffective because of A mismatch between**
  - the number of color bins that we can distinguish in non-contiguous small regions and number of levels in the categorical attribute being encoded
- **Two good design choices**
  - To reduce the number of bins explicitly through a deliberate data transformation that takes into account the nature of data and task, so that each bin can be encoded with a distinguishable color
    - **Derive a new and smaller set of attributes**
    - **Filter the attributes to only encode a small set of important cases, and aggregate all others into "other"**

Colormaps
Categorical colormaps



(a) (b)

Ineffective categorical colormap use. (a) The 21 colors used as an index for each mouse chromosome(染色體) can indeed be distinguished in **large** regions next to each other. (b) In noncontiguous small regions only about 12 bins of color can be distinguished from each other, so a lot of information about how regions in the mouse genome(基因組) map to the human genome is lost.

Colormaps
Categorical colormaps

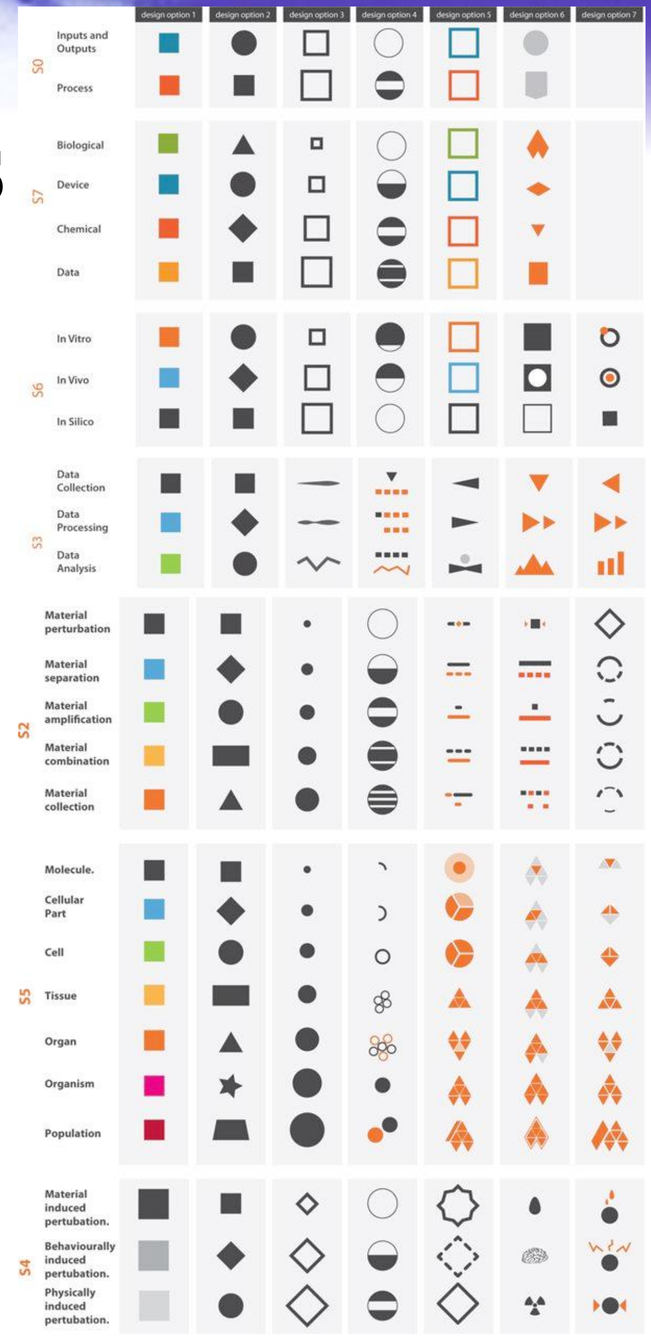
- **Two good design choices**
  - To use a different visual encoding idiom that use other visual channels instead of, or in addition to, the color channel alone
    - See next figure

Colormaps
Categorical colormaps

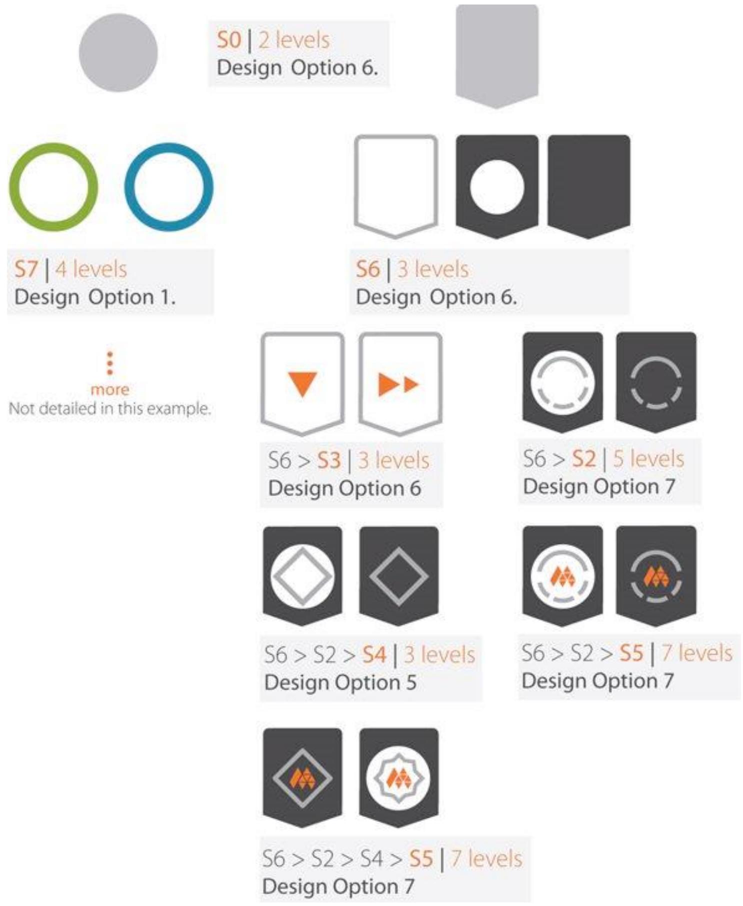
Choice II:

Effective categorical colormap use:

A large space of visual encoding possibilities for 27 categories was considered systematically in addition to the color channel, including size and shape channels and more complex glyphs.



Colormaps
Categorical colormaps



Effective categorical colormap use:
The final design uses the color channel for only four of the categories.

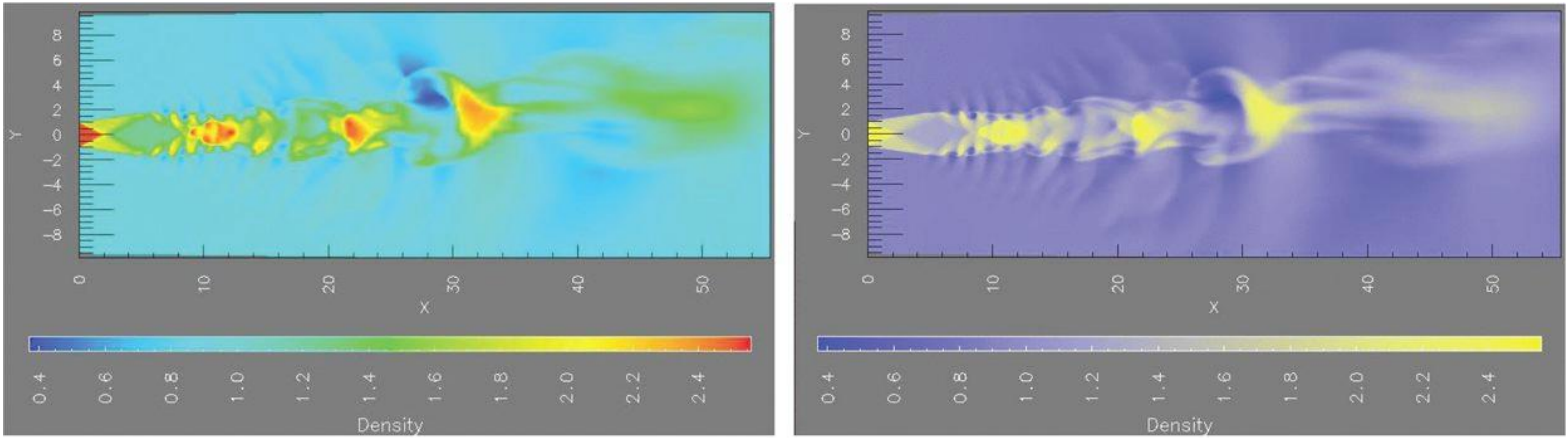
Colormaps
Ordered colormaps

- Ordered colormap
  - Appropriate for encoding ordinal or quantitative attributes
  - Two major variants of continuous colormap
    - Sequential: range from a min to max value
      - If only luminance is used, the result is a grayscale ramp
      - Incorporating hue, one end is a specific hue at full saturation and brightness
        - » If saturation is the variable, the other end is pale (灰白) or white
        - » When luminance is the varying quantity, the other end is dark or black
    - Diverging: has two hues at endpoints and a neutral color as a midpoint (such as white, gray, or black, or a high-luminance color such as yellow)

Colormaps
Ordered colormaps

- How many hues to use in continuous map?
  - Depends on what level of structure should be emphasized
    - High-level structure
      - Less hue
    - Middle range of local neighborhoods
      - More hues
    - Fine-grained detail

Colormaps
Ordered colormaps



(a) (b)

Rainbow versus two-hue continuous colormap.

(a) Using many hues, as in this rainbow colormap, emphasizes mid-scale structure.

(b) Using only two hues, the blue–yellow colormap emphasizes large-scale structure. (endpoint: fully saturated, middle point: gray)

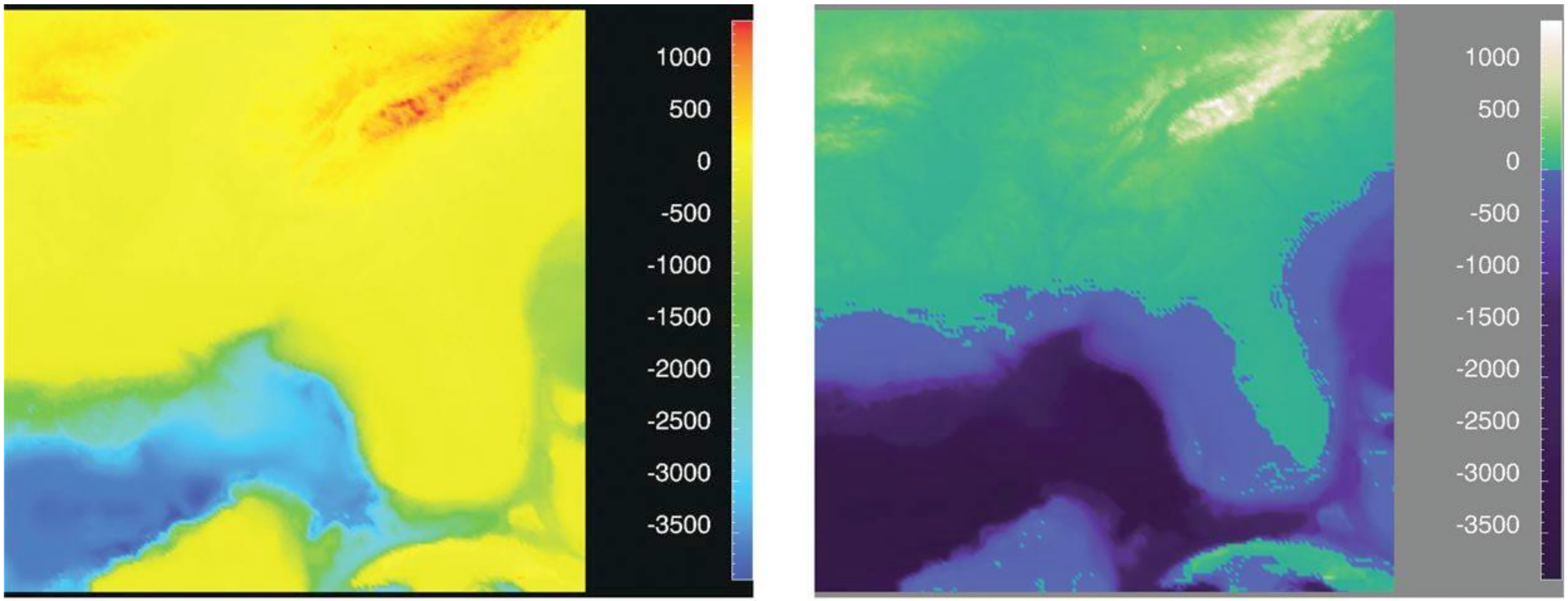
Colormaps
Ordered colormaps

- **Advantage of rainbow colormap**
  - People can easily discuss specific subrange because the differences are easily nameable
    - The red part vs. the blue part vs. the green part
- **Problems of rainbow colormap**
  - Hue is used to indicate color, despite being an identity channel w/o an implicit perceptual ordering
  - The scale is not perceptually linear
    - Steps of the same size at different points in the colormap range are not perceived equally by eyes
  - Fine detail cannot be perceived with the hue channel. Luminance is a better choice!

Colormaps
Ordered colormaps

- **Problems of rainbow colormap**
  - **One way to address all three problem**
    - **To design monotonically increasing luminance colormap (hue: creates a semantically meaningful categorization)**
      - **Multiple hues are ordered according to their luminance from lowest to highest**
      - **The varying hue allows easy segmentation into categorical regions, for both seeing and describing mid-level neighborhoods**
      - **Luminance is a magnitude channel, providing perceptual ordering**
        - » **Support both high-level distinction between one end (dark part) and the other (light part)**
        - » **Support low-level structure perception because subtle changes in luminance are more accurately perceived than that for hue**

Colormaps
Ordered colormaps



(a) (b)

Rainbow versus multiple-hue continuous colormap with monotonically increasing luminance. (a) Three major problems with the common continuous rainbow colormap are perceptual nonlinearity, the expressivity mismatch of using hue for ordering, and the accuracy mismatch of using hue for fine-grained detail. (b) A colormap that combines monotonically increasing luminance with multiple hues for semantic categories, with a clear segmentation at the zero point, succeeds in showing high-level, mid-level, and low-level structure.

Colormaps
Bivariate colormaps

- **Deal with two separable attributes**
  - **One is binary (only two levels)**
    - **It is straightforward to create a bivariate colormap**
      - **With two families of colors by fixing a base set of hues and varying their saturation**
  - **Both are with multiple levels**
    - **Results will be poor!**

Other channels

- **Spatial position and color are highly salient**
- **Other channels are important too**
  - **Magnitude channels**
    - **Size channel of length, area, and volume**
    - **Angle/orientation/tilt channel**
    - **Curvature**
  - **Identity channels**
    - **Shape**
    - **Motion**
  - **Combination of multiple channels**
    - **Texture**
    - **Stippling**
      - **fill in regions with short strokes. A special case of texture**

Other channels
Size channel

- A magnitude channel suitable for ordered data
- Interacts with most other channels
  - Particularly strongly with color hue and color saturation
- Perceptual judgement
  - Length: is extremely accurate
  - Area: Significantly less accurate
  - Volume: quite inaccurate

Other channels Angle channel

- Encode magnitude information based on the mark's orientation
  - Angle
    - orientation of one line w.r.t. another line
  - Tilt
    - Orientation is judged against the global frame of display
  - Less accurate than length and position, more accurate than area