# Chapter 10: Color
# Paper: Representing Colors as Three Numbers

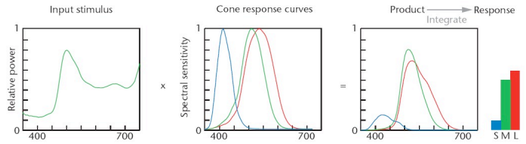
**Tamara Munzner**
Department of Computer Science
University of British Columbia

*UBC CPSC 547: Information Visualization*
*Mon Oct 20 2014*

http://www.cs.ubc.ca/~tmm/courses/547-14#chap10

## Colors as Three Numbers

- trichromacy
  - different cone responses: area function of wavelength
  - for a given spectrum
    - multiply by response curve
    - integrate to get response

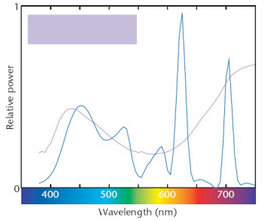



[Representing Colors as Three Numbers, Stone, IEEE Computer Graphics and Applications, 25(4), July 2005, pp. 78-85]



## Metamerism

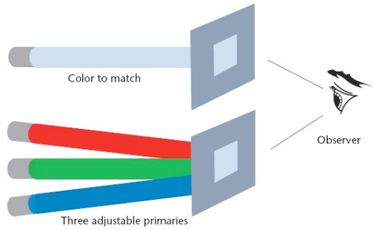
- brain sees only cone response
  - different spectra appear the same




[Representing Colors as Three Numbers, Stone, IEEE Computer Graphics and Applications, 25(4), July 2005, pp. 78-85]



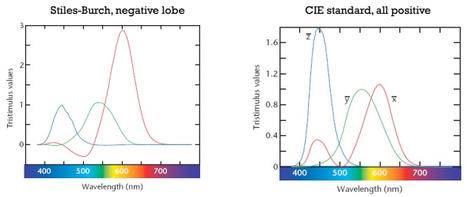
## Color Matching Experiments




[Representing Colors as Three Numbers, Stone, IEEE Computer Graphics and Applications, 25(4), July 2005, pp. 78-85]



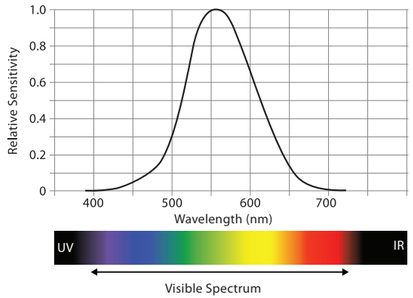
## Color Matching Functions




[Representing Colors as Three Numbers, Stone, IEEE Computer Graphics and Applications, 25(4), July 2005, pp. 78-85]



## Spectral Sensitivity





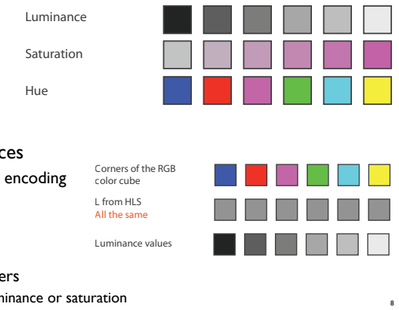

## Color Spaces

- RGB: convenient for machines
  - these three channels *not* separable
- CIE XYZ: from color matching functions
  - perceptually based
- L*a*b*: from XYZ + reference whitepoint
  - perceptually linear, so safe to interpolate
- HLS: simple transformation of RGB
  - good: separates out lightness from hue and saturation
  - bad: lightness not true luminance
  - careful: only pseudo-perceptual



## Color: Luminance, saturation, hue

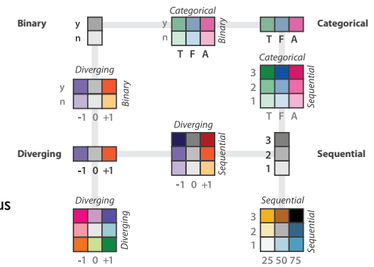
- 3 channels
  - identity for categorical
    - hue
  - magnitude for ordered
    - luminance
    - saturation
- other common color spaces
  - RGB: poor choice for visual encoding
  - HSL: better, but beware
    - lightness ≠ luminance
- transparency
  - useful for creating visual layers
    - but cannot combine with luminance or saturation






## Colormaps

- → Categorical
- → Ordered
  - → *Sequential*
  - → *Diverging*
- → Bivariate



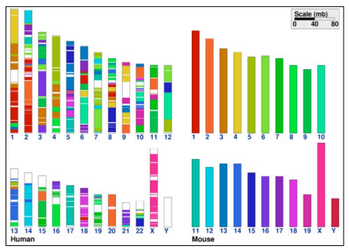

- categorical limits: noncontiguous
  - 6-12 bins hue/color
    - far fewer if colorblind
  - 3-4 bins luminance, saturation
  - size heavily affects salience
    - use high saturation for small regions, low saturation for large

*after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]*



## Categorical color: Discriminability constraints

- noncontiguous small regions of color: only 6-12 bins

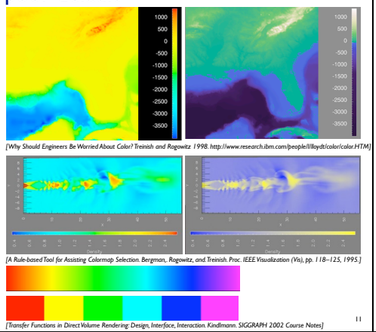



[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]



## Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - fewer hues for large-scale structure
  - multiple hues with monotonically increasing luminance for fine-grained
  - segmented rainbows good for categorical, ok for binned



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

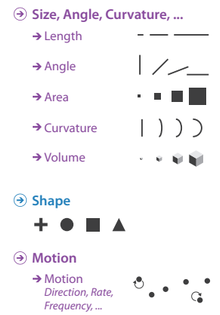
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]



## Map other channels

- size
  - length accurate, 2D area ok, 3D volume poor
- angle
  - nonlinear accuracy
    - horizontal, vertical, exact diagonal
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - binary: great for highlighting
  - use with care to avoid irritation






## Angle

Sequential ordered line mark or arrow glyph

Diverging ordered arrow glyph

Cyclic ordered arrow glyph



## Further reading


- Visualization Analysis and Design. Munzner. AK Peters / CRC Press, Oct 2014.
  - *Chap 10: Map Color and Other Channels*
- ColorBrewer, Brewer.
  - http://www.colorbrewer2.org
- *Color In Information Display*. Stone. IEEE Vis Course Notes, 2006.
  - http://www.stonesc.com/Vis06
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- *Rainbow Color Map (Still) Considered Harmful.* Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14–17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.