CSE 591: Visual Analytics

Lecture 3: Color

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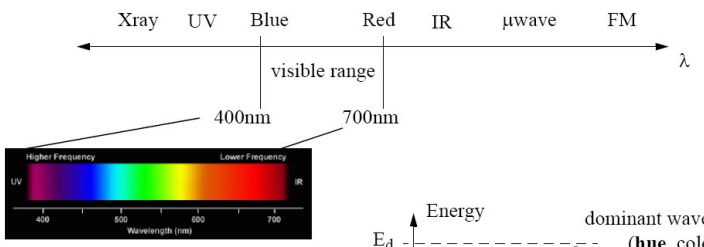
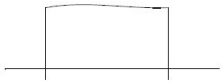
With some material from Robert Kosara, UNCC, and Daniel Keim, U Konstanz

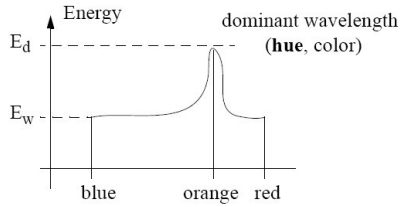
Spectrum of Wavelengths

Spectrum:



white light: all wavelengths



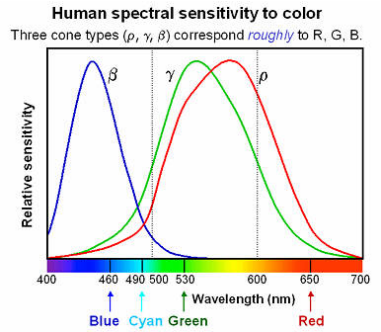


E(λ): overall intensity = **brightness** or **luminance**

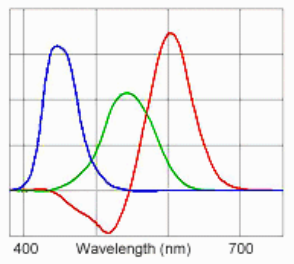
ratio of E_d vs. E_w = **saturation**

The human eye differentiates about 300 hues and 100-150 luminance variations

Perception Curves



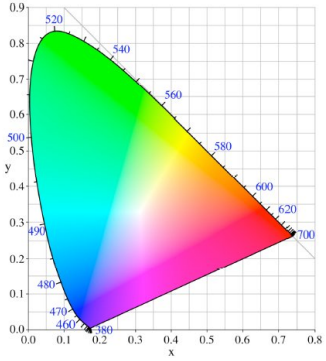
human color sensitivity curves



color generation with primaries

Perceptional Color Spaces

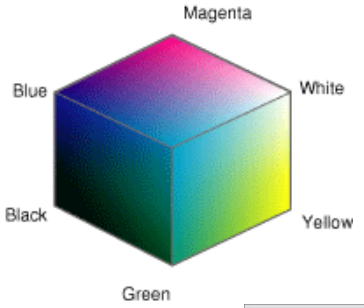
- *Commission Internationale de l'Eclairage*
- Model that combines rod information and removes luminance
- 2D horseshoe-shape
- white in center
- Saturated colors around perimeter



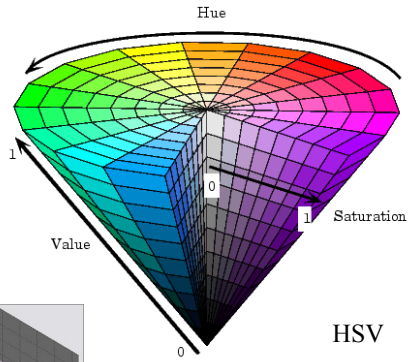
Robert Kosara

Visual Analytics
http://www.viscenter.uncc.edu/courses/visanalytics.html

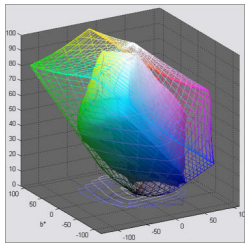
Non-Perceptional Color Spaces



RGB



HSV



compare to: CIE LAB in 3D

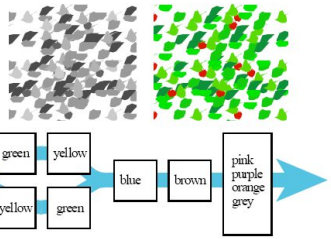
More on Color

- Color resolution
  - the human eye differentiates about 300 hues and 100-150 luminance variations
  - best resolution is for green and red, less resolution for blue
- Color response
  - the time to response to a signal varies according to the color used
  - color ranking (from best to worst): yellow > white > red > green > blue
  - important features should be visualized in light colors, such as yellow and white
  - background information is best visualized in dark colors, such as green and blue
- Channel properties:
  - luminance channel: detail, form, shading, stereo, motion
  - color: surfaces of things, labels, categories (about 10)
  - red, green, blue, yellow are special (unique hues)
- Chromatic channels have low resolution
  - luminance contrast needed to see detail (3:1 recommended, 10:1 for small text)

More on Color

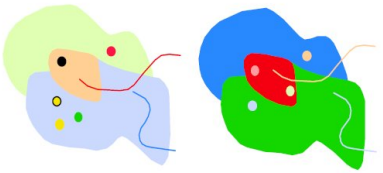
- Color blindness
  - a 3D to 2D space
  - 8% of males is R-G color blind
  - Y-B variation is OK

- Color resolution
  - color perception is relative
  - we are sensitive to small differences --> hence need millions of colors
  - but we are not sensitive to absolute colors --> hence we can only use < 10 colors for coding
- Color is very helpful for classification tasks
  - color aids in rapid visual segmentation
  - color helps to determine type
  - only about 6-11 categories

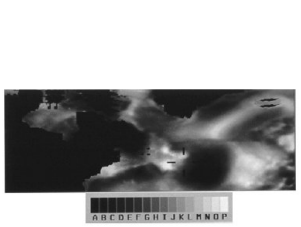


More on Color

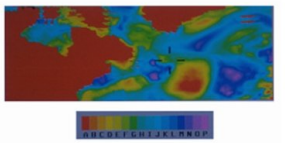
- Color coding
  - large areas: low saturation
  - small areas: high saturation
  - maintain luminance contrast
  - break iso-luminances with borders



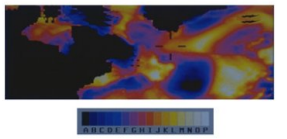
- Pseudo-coloring: assign colors to grey levels by indexing the grey levels into a color map



original greylevel map



simple spectrum sequence with iso-luminance



more effective:

spiral sequence through color space

luminance increases with hue

Use of Color

What is color for?

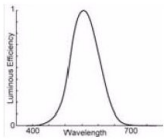
- labeling vs. aesthetics
- defines importance, function, set attention, mark controls
- but must keep luminance in mind!

Note: HSV, HLS are NOT perceptional models

- they cannot predict perceived lightness
- one must use CIE LUV or CIE LAB for this

Intensity vs. Luminance

- Intensity: integral of spectral distribution (power)
- Luminance: integral of spectrum x luminous efficiency

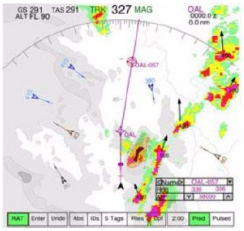


green and blue lights of equal intensity have different luminance values

example: cockpit

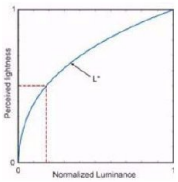
without color

with color



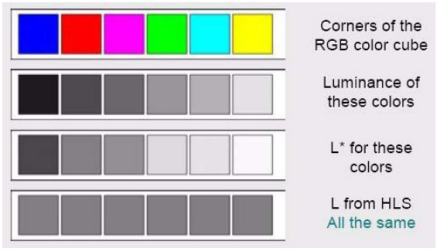
from Bergman/Rogowitz/Treinish Vis'95

Luminance Contrast



L* is a function of normalized luminance

$L^* = 116(Y/Y_n)^{1/3} - 16$



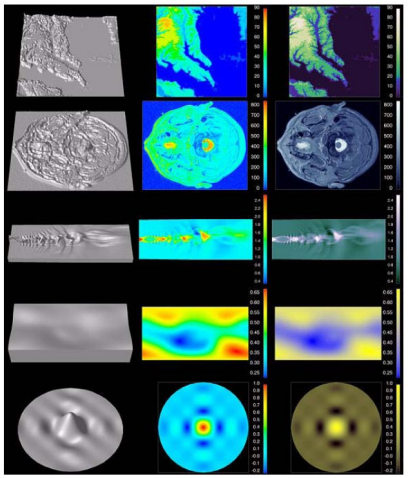
Use ΔL* for contrast

- 1 is ideally visible
- 10 is easily visible
- 20 is legible for text

What is value (luminance) for? (recall, color was for labeling, primary attention, etc.)

- perceived lightness/darkness
- no edge without lightness change
- no shading without lighness variation
- value difference defines contrast: defines legibility, controls attention

Luminance Contrast



luminance mapped to height | just hue | hue and luminance encode high frequency information by L

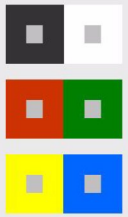
from Bergman/Rogowitz/Treinish Vis'95

Color Contrast and Harmony

Definition
- Achromatic axis
- R-G and Y-B axis
- Separate lightness from chroma channels

First level encoding
- Linear combination of LMS
- Before optic nerve
- Basis for perception
- Defines "color blindness"

Add Opponent Color
- Dark adds light
- Red adds green
- Blue adds yellow



These samples will have both light/dark and hue contrast

Color Harmony

Apply contrast and analogy to hue, value, chroma


Vary chroma


Contrasting hues


Analogous hues

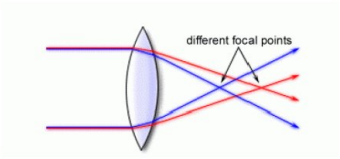

Vary value

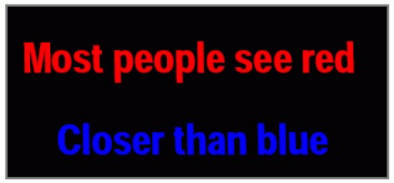
From Wong, *Principles of Color Design*, © 1997, John Wiley & Sons, Inc.

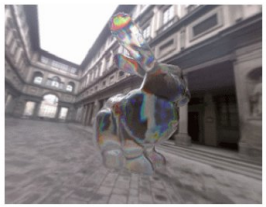
from Maureen Stone Tutorial Vis'05

Chromatic Aberration

- Different wavelengths of light are focused at different distances within the eye
- Short-wavelength blue light is refracted more than long-wavelength red light
- Focusing on a red patch, an adjacent blue patch will be significantly out of focus
- The human eye has no correction for chromatic aberration
- Inadvisable: fine blue patterns in visualizations!
- Strong illusory depth effects
- Visual effects in soap bubbles, crystal sculptures, etc.





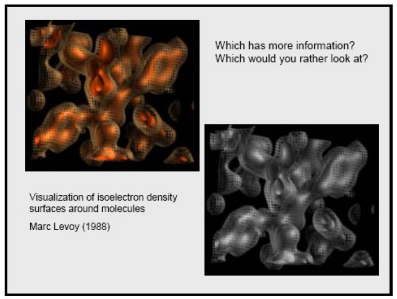


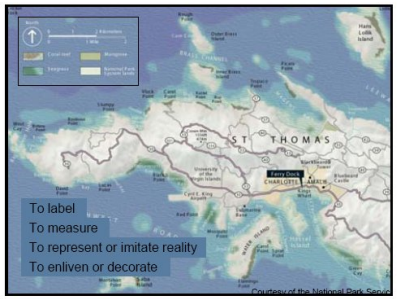
from: Jürgen Döllner

Color Adds More Dimensions

source: Maureen Stone

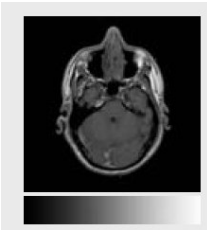
Color Adds Aesthetics



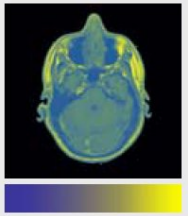


source: Maureen Stone

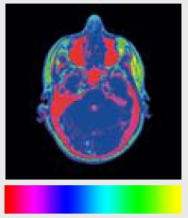
But… Mapping to Color Can Cause Problems



Lightness scale



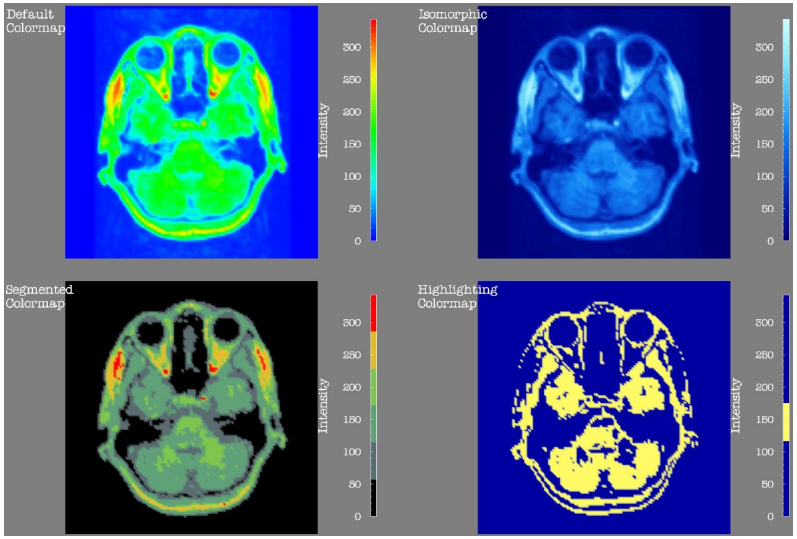
Lightness scale with hue and chroma variation



Hue scale with lightness variation

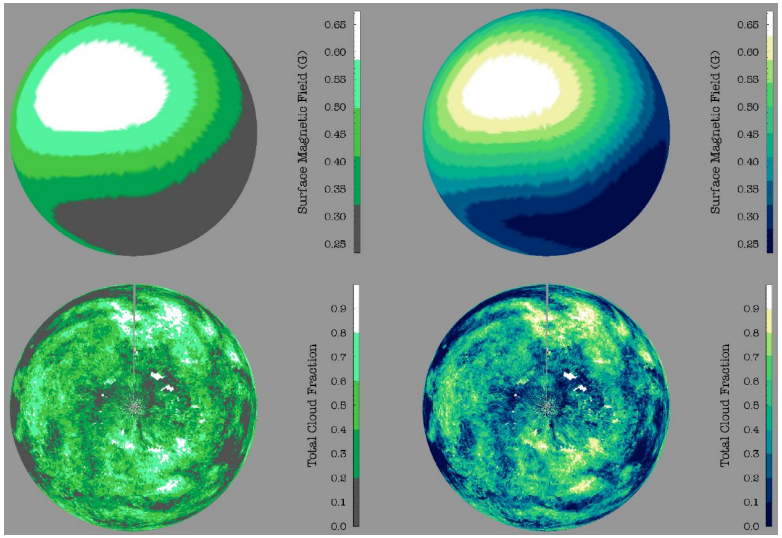
source: Maureen Stone

Color Maps



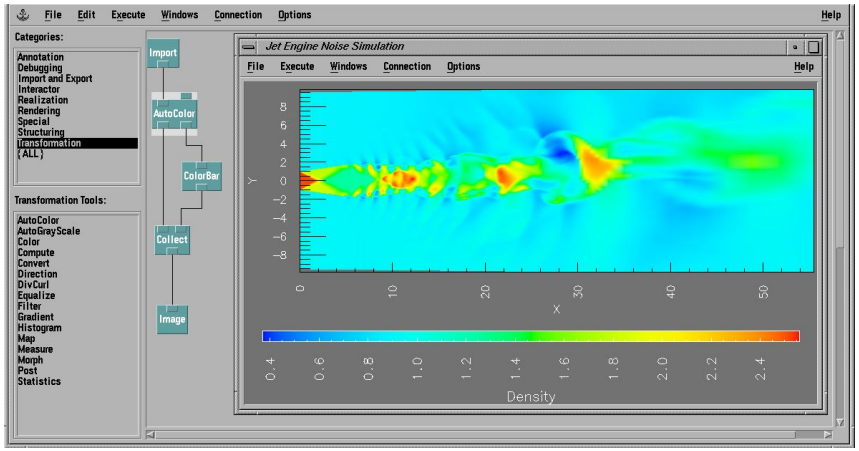
source: Rogowitz/Treinish

Color Map: Segmentation Tasks



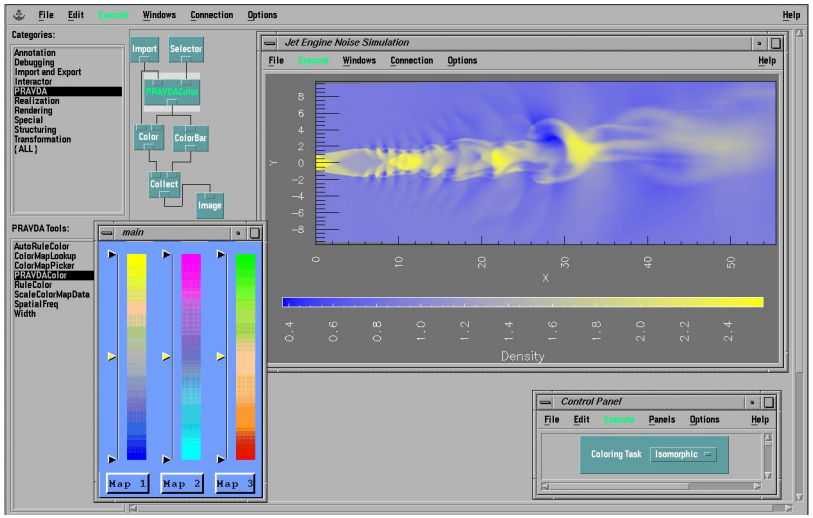
source: Rogowitz/Treinish

Color Map: Rainbow



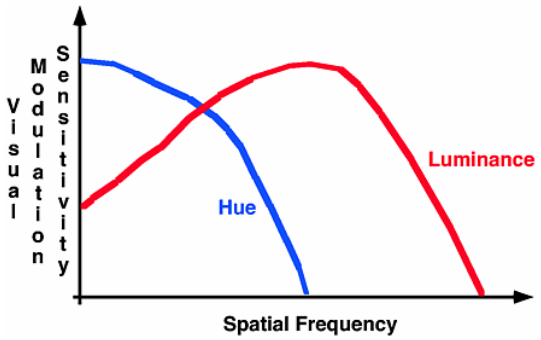
source: Rogowitz/Treinish

Color Map: Linear Hue



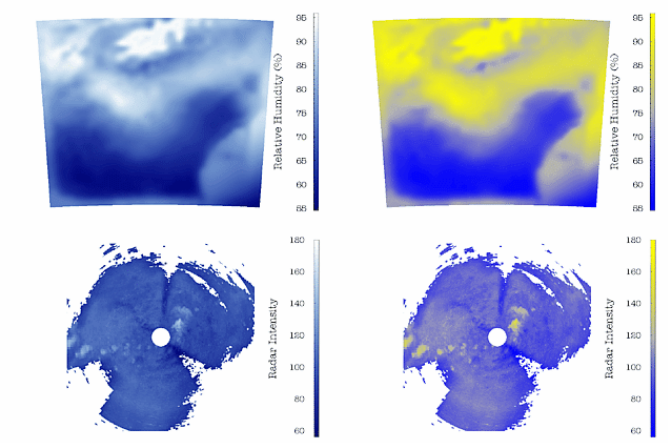
source: Rogowitz/Treinish

Color Maps: Spatial Frequency Issues



source: Rogowitz/Treinish

Color Maps: Low vs. High Frequency

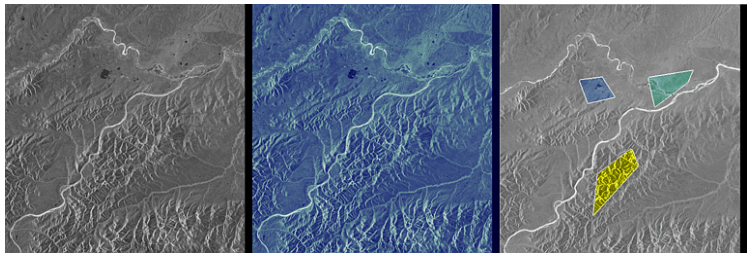


weather model
low frequency

radar scan
high frequency

source: Rogowitz/Treinish

Color Maps: Highlighting



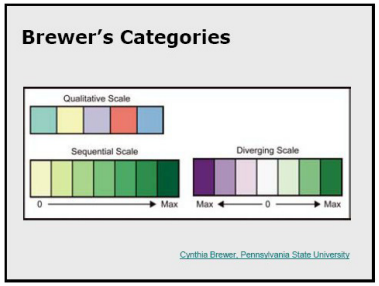
source: Rogowitz/Treinish

Brewer Scale

Nominal scales
- distinct hues, but similar emphasis

Sequential scales
- vary in lightness and saturation
- vary slightly in hue

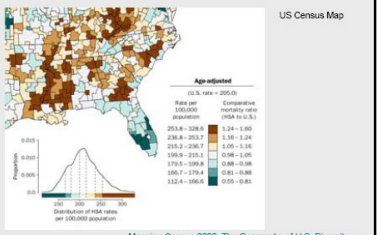
Diverging scale
- complementary sequential scales
- neutral at “zero”



source: Maureen Stone

Brewer Scales

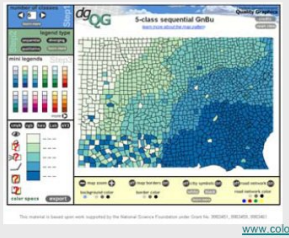
Thematic Maps



US Census Map

Mapping Census 2000: The Geography of U.S. Diversity

Color Brewer

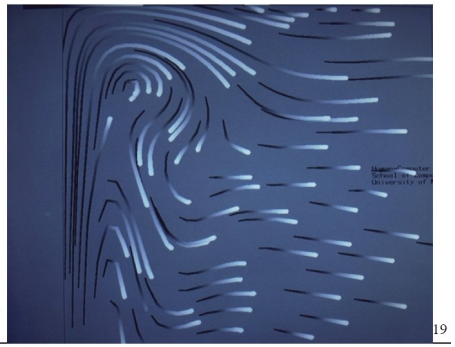


www.colorbrewer.org

source: Maureen Stone

Example for Proper Use of Color

- Use luminance for detail, shape, and form
- Use color for coding - few colors
- Minimize contrast effects
- Strong colors for small areas - contrast in luminance with background
- Subtle colors can be used to segment large areas



use of luminance to indicate direction

from: Colin Ware