Spectrum of Wavelengths

Perception Curves

Perceptual 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

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

  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 perceptual 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

Luminance Contrast

$L^*$ is a function of normalized luminance
$L^* = 116(y/Y_0)^{1/3} - 16$

Use $\Delta L^*$ 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 lightness variation
- value difference defines contrast: defines legibility, controls attention

Luminance Contrast

Color Contrast and Harmony

Definition
- Achromatic axis
- $R-O$ and $Y-D$ 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 lightness and hue contrast

Color Harmony

Apply contrast and analogy to hue, value, chroma

Contrasting hues
Analogous hues
Vary cinema

from Bergman/Regowitz/Trenish Vis ’95

from Moreman Scene Tutorial Vis ’09
**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.

**Most people see red closer than blue**

**Color Adds More Dimensions**

(source: Maureen Stone)

**Color Adds Aesthetics**

(source: Maureen Stone)

**But... Mapping to Color Can Cause Problems**

(source: Maureen Stone)
Color Maps: Spatial Frequency Issues

Color Maps: Low vs. High Frequency

Color Maps: Highlighting

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: Rogowitz/Treinish

source: Rogowitz/Treinish

source: Rogowitz/Treinish

source: Maureen Stone
Brewer Scales

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

source: Maureen Stone

use of luminance to indicate direction

from: Colis Ware