Color in Information Display

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What is Color?

Physical World    Visual System    Mental Models

Lights, surfaces, objects → Eye, optic nerve, visual cortex → Red, green, brown

Bright, light, dark, vivid, colorful, dull

Warm, cool, bold, blah, attractive, ugly, pleasant, jarring
Why Color?

Physical World | Visual System | Mental Models
---|---|---
Lights, surfaces, objects | Eye, optic nerve, visual cortex | Red, green, brown
Apple, leaf, bark
Ripe, fresh, eatable
…and then to action.
Color in Information Display

Physical World | Visual System | Mental Models
---|---|---
Lines, patches, shaded regions | Eye, optic nerve, visual cortex | Roads, lakes
| | | Profit, loss, trends
Illustrators, graph makers Artists, designers A few scientific principles
Failures, threats
...and then to action
Why Should We Care?

• Poorly designed color is confusing
  – Creates visual clutter
  – Misdirects attention
• Poor design devalues the information
  – Visual sophistication
  – Evolution of document and web design
• “Attractive things work better”

  – Don Norman
Effective Color

Aesthetics

Materials

Perception
Color Models

Physical World
- Light Energy
  - Spectral distribution functions $F(\lambda)$

Visual System
- Cone Response
  - Reduce to three values (LMS)
  - CIE tristimulus values (XYZ)

Mental Models
- Opponent Encoding
  - Separate Lightness, Chroma (A,R-G,Y-B)
- Perceptual Models
  - Unique White
  - CIELAB
  - Munsell (HVC)
- Appearance Models
  - Hue, chroma, saturation, colorfulness
  - lightness, brightness
  - CIECAM02
Visual System

• Light path
  – Cornea, pupil, lens, retina, optic nerve, brain

• Retinal cells
  – Rods and cones
  – Unevenly distributed

• Cones
  – Three “color receptors”
  – Concentrated in fovea
Cone Response

- Encode spectra as three values
- Long, medium and short (LMS)
- Trichromacy

Effects of Retinal Encoding

- All spectra that stimulate the same cone response are indistinguishable
- *Metameric match*
CIE Standard “Cones”

- CIE Color Matching Functions (CMF)
- CIE tristimulus values (XYZ)
- Foundation for color measurement

CIE Chromaticity Coordinates

Project X,Y,Z on a plane to separate colorfulness from brightness

\[
x = \frac{X}{X+Y+Z} \\
y = \frac{Y}{X+Y+Z} \\
z = \frac{Z}{X+Y+Z}
\]

\[1 = x + y + z\]

\[XYZ = xyY\]

Courtesy of PhotoResearch, Inc.
Tristimulus models (CIE XYZ)

- Absolute specification, based on cone response to a spectral stimulus
- **Single colors, neutral background, constant adaptation**
- Many different values for “white” and “black”
- **Do two colors match exactly?**
Color Models

Physical World
- Light Energy
- Spectral distribution functions \( F(\lambda) \)

Visual System
- Cone Response
  - Three numbers (LMS)
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Trichromacy
Metamerism
Color matching
Opponent Color

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

• Occurs in retina
Effects of Opponent Color

• Unique hues
  — No reddish-green
• Afterimages
  – Red-green, blue-yellow, black-white
• Color vision deficiencies
  – Red-green anomalies *
  – Blue-yellow anomalies
• Foundation for perceptual color spaces
Model “Color blindness”

• Flaw in opponent processing
  – Red-green common (deuteranope, protanope)
  – Blue-yellow possible (tritanope)
  – Luminance channel almost “normal”

• Effect is 2D color vision model
  – Flatten color space
  – Can be simulated (Brettel et. al.)
  – Vischeck (www.vischeck.com)
Vischeck (www.vischeck.com)

- Simulates color vision deficiencies
- Web service or Photoshop plug-in
- Robert Dougherty and Alex Wade
Genes in Vischeck

Deuteranope

Protanope
Perceptual Color Spaces

Lightness

Colorfulness

Hue

Unique black and white
Perceptual models

- Relative specification
- Unique values for “white” and “black”
- How similar are two colors?
Munsell Color

- Hue, Value, Chroma
  - 5 R 5/10 (bright red)
  - N 8 (light gray)

- Perceptually uniform

Munsell Renotation System maps between HVC and XYZ
Interactive Munsell Tool

• From www.munsell.com
CIELUV and CIELAB

- Lightness (L*), two color axis (u*, v*) or (a*, b*)
- Non-linear function of CIE XYZ
- Defined for computing color differences

From Principles of Digital Image Synthesis by Andrew Glassner. SF: Morgan Kaufmann Publishers, Fig. 2.4 & 2.5, Page 63 & 64 © 1995 by Morgan Kaufmann Publishers. Used with permission.
Lightness Scales

- Lightness, brightness, luminance, and L*
  - Lightness is relative, brightness absolute
  - Absolute intensity is light power (cd/m\(^2\))
- Luminance is perceived intensity
  - Luminance varies with wavelength
  - Luminous efficiency function
  - Equivalent to CIE Y

Green and blue lights of equal intensity have different luminance values
Psuedo-Perceptual Models

- HLS, HSV, HSB
- NOT perceptual models
- Simple renotation of RGB
  - View along gray axis
  - See a hue hexagon
  - L or V is grayscale pixel value
- Cannot predict perceived lightness
L vs. Luminance, L*

Corners of the RGB color cube

Luminance of these colors

L* for these colors

L from HLS All the same

All the same
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Appearance Models
- Hue, chroma, saturation, colorfulness, lightness, brightness
- CIECAM02

Trichromacy
Metamerism
Color matching

Color differences
“Intuitive” color spaces
Image encoding
Color scales
2. Color Appearance
Color Appearance

• More than a single color
  – Adjacent colors (background)
  – Viewing environment (surround)
• Appearance effects
  – Adaptation
  – Simultaneous contrast
  – Spatial effects
Light/Dark Adaptation

• Adjust to overall brightness
  – 7 decades of dynamic range
  – 100:1 at any particular time

• Absolute illumination effects
  – Hunt effect
    Higher brightness increases colorfulness
  – Stevens effect
    Higher brightness increases contrast
Chromatic Adaptation

- Change in illumination
- Cones “white balance”
  - Scale cone sensitivities
  - von Kries
  - Also cognitive effects
- Creates unique white

From Color Appearance Models, fig 8-1
Simultaneous Contrast

“After image” of background adds to the color

Reality is more complex
Affects Lightness Scale
Effect of Spatial Frequency

- Smaller = less saturated
- The paint chip problem
- Color image perception
- S-CIELAB

Redrawn from *Foundations of Vision*, fig 6
© Brian Wandell, Stanford University
Color Appearance Models

• From measurements to color appearance
  • Models
    – CIELAB, RLAB, LLAB
    – S-CIELAB
    – CIECAM97s, CIECAM02
    – Hunt
    – Nayatani, Guth, ATG

Measure physical stimuli
  Stimulus, background, surround, etc.

Calculate tristimulus values XYZ (LMS)
  Stimulus, background, surround, etc.

Calculate correlates of perceptual attributes
  Lightness, brightness, chroma, hue, colorfulness, saturation
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- Adaptation
- simultaneous contrast
- Image appearance
- Complex matching
Effective Color

- Aesthetics
- Perception
- Materials
Design Basics

• Four basic principles
  – Proximity: Related items should be close
  – Alignment: Create visual connections
  – Repetition: Unify by reusing elements
  – Contrast: Identical, or very different

• Practice
  – Visual literacy
  – Design experience
Color Design Basics

• Basic principles
  – Contrast & analogy (contrast, proximity)
  – Color schemes & palettes (repetition, alignment)
  – “Get it right in black and white”

• Practice
  – Visual literacy
  – Design experience
Color “Space”

- **Value**
  - Perceived lightness

- **Hue**
  - Color’s “name”
  - Color wheel

- **Chroma**
  - Intensity or purity with respect to gray
  - Similar to saturation

*Munsell Color Space*

*Principles of Color Design*
*Wucius Wong*
Value

- Perceived lightness/darkness of a color
- Scale from black to white
  - Power scale
  - Munsell value, L*
- Single most important factor in color design
Get it right in black and white

- Value alone defines shape
  - No edge without lightness change
  - No shading without lightness variation
- Value difference defines contrast
  - Defines legibility
  - Controls attention
Controls Legibility

Larry Arend, colorusage.arc.nasa.gov

Drop Shadows

Need an edge
Controls Attention, Clutter
A Brief Plug