DANGER!

*Inappropriate use of colour can be disasterous to the application*
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

Courtesy of Maureen Stone
Background affects Lightness Scale

Courtesy of Maureen Stone
Lightness Scales

- **Lightness**: perceived reflectance
- **Brightness**: perceived amount of light coming from a surface
- **Luminance**: a measured value weighted by human spectral sensitivity
  - Varies with wavelength
  - Luminous efficiency function

Green and blue lights of equal intensity have different luminance values.
L vs. Luminance

Corners of the RGB color cube

Luminance of these colors

L from HLS
All the same
Wrong!

Modified from Maureen Stone
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
  – Use at least 3:1 luminance contrast for text clarity
  – Controls attention

Modified from Maureen Stone
Controls Legibility

Larry Arend, colorusage.arc.nasa.gov

Drop Shadows

Need an edge

Courtesy of Maureen Stone
Controls Attention, Clutter

Courtesy of Maureen Stone
# Color Models

## Physical World
- **Light Energy**
  - Spectral distribution functions $F(I)$

## Visual System
- **Cone Response**
  - Reduce to three values (LMS)
  - CIE tristimulus values (XYZ)
- **Opponent Encoding**
  - Separate Lightness, Chroma
  - (A,R-G,Y-B)

## Mental Models
- **Perceptual Models**
  - Unique White
  - CIELAB
  - Munsell (HVC)
- **Appearance Models**
  - Hue, chroma, saturation, colorfulness
  - Lightness, brightness
  - CIECAM02

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Courtesy of Maureen Stone
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*


Courtesy of Maureen Stone
Effects of Retinal Encoding

- All spectra that stimulate the same cone response are indistinguishable
- *Metamerism match*

Courtesy of Maureen Stone
CIE Standard “Cones”

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

Courtesy of Maureen Stone

Opponent Color

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

• Occurs in retina

Courtesy of Maureen Stone
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)

Courtesy of Maureen Stone
Vischeck
(www.vischeck.com)

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

Courtesy of Maureen Stone
Rainbow in Vischeck

Deuteranope Simulation

Protanope Simulation

Tritanope Simulation
Color Appearance

Depends on many factors

– Adjacent colors (background)
– Viewing environment (surround)
– Adaptation
– Spatial effects
Chromaticity contrast
Chromatic Adaptation

www.usd.edu/psyc301/coloradapt.htm
Effect of Spatial Frequency

- Smaller = less saturated
- The paint chip problem

Courtesy of Maureen Stone

Redrawn from Foundations of Vision, fig 6
© Brian Wandell, Stanford University
Categorical Data

• Limited distinguishability (8-14)
  – Best with Hue
  – Best choices from Ware:
Brightness & saturation draw attention
Ordered Data

- Greyscale
- Saturation
- Brightness

- Rainbow is a learned order!
Quantitative Data - to show order

- Mediocre
  - rainbow (hue)
- Good
  - Greyscale
  - Luminance
  - Brightness

[www.research.ibm.com/visualanalysis/perception.html]
Rainbow colour map

- Learned order
- Visually segmented
  - Solution - isoluminant rainbow
But colour choice also depends on task.

Understand relative height

Find high & low values

Find height 120
Additional notes about greyscale

- Hard to distinguish in small areas
- 3D shading interferes
Color Brewer

• Useful for designing colour scales

• [http://colorbrewer2.org/](http://colorbrewer2.org/)
Perceptual Color Spaces

Unique black and white

Courtesy of Maureen Stone
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

Courtesy of Maureen Stone
Munsell Atlas

Courtesy Gretag-Macbeth
Interactive Munsell Tool

- From www.munsell.com

Courtesy of Maureen Stone