Color in Information Display

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Information Display

Graphical presentation of information
• Charts, graphs, diagrams, maps, illustrations
• Originally hand-crafted, static
• Now computer-generated, dynamic
Color is a key component

“Color” includes Gray

Maps courtesy of the National Park Service (www.nps.gov)

Visualizing Flow

3D line integral convolution to visualize 3D flow (LIC). Color varies from red to yellow with increasing temperature

Victoria Interrante and Chester Grosch, U. Minnesota
http://www-users.cs.umn.edu/~interran/3Dflow.html

Visualizing Flow

Color is used to represent the magnitude of the vorticity across the flow volume. Note the pressure waves

Victoria Interrante and Chester Grosch, U. Minnesota
http://www-users.cs.umn.edu/~interran/3Dflow.html

Visualizing Flow

Simulated ink in a turbulent flow field

Jarke J. van Wijk
Technische Universiteit Eindhoven
http://www.win.tue.nl/~jvw/
Tableau “Heat Map”

Multi-dimensional Scatterplot

Effective Color

Overview

What is Color?

Why Color?
**Color in Information Display**

**Physical World**
- Lines, patches, shaded regions

**Visual System**
- Eye, optic nerve, visual cortex

**Mental Models**
- Roads, lakes, profit, loss, trends
- Failures, threats, ...and then to action

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**Why Should We Care?**

Poorly designed color is confusing
- Creates visual clutter
- Misdirects attention
- Obscures important information

Poor design devalues the information
- Visual sophistication
- Evolution of document and web design

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**Color Models**

**Physical World**
- Spectral distribution functions
- Light Energy
- Any source
  - Direct
  - Transmitted
  - Reflected
  - Refracted

**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 (SML)
- Trichromacy: only SML is “seen”
- Different spectra can “look the same”

Sort of like a digital camera*
Color Measurement

Commission Internationale de l’Eclairage (CIE)
- “Standard cones” (CMF)
- Tristimulus values (XYZ)
- Chromaticity coordinates (xy)
- Chromaticity diagram

Opponent Color

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

First level encoding
- Linear combination of SML
- Before optic nerve
- Basis for perception

Perceptual Color Spaces

Lightness
Colorfulness
Hue

Unique black and white
Uniform differences
Perception & design

Munsell Atlas

Color Appearance

More than a single color
- Adjacent colors (background)
- Viewing environment (surround)

Appearance effects
- Adaptation
- Simultaneous contrast
- Spatial effects
- Colors in context

Vischeck

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

www.vischeck.com

Deuteranope Protanope Tritanope
Color Models

Physical World

Light Energy
Spectral distribution functions F(λ)

Visual System

Cone Response
Encode as three values (L,M,S)
CIE (X,Y,Z)

Mental Models

Opponent Encoding
Separate lightness, chroma (A,R-G,Y-B)
Perceptual Models
Color "Space"
Hue, lightness saturation
Munsell (HVC)

Appearance Models

Color in Context
Adaptation, Background, Size, ...
CIECAM02

Effective Color

Aesthetics

Perception

Materials

Envisioning Information

"... avoiding catastrophe becomes the first principle in bringing color to information:
Above all, do no harm."
—E. R. Tufte

Envisioning Information

To label
To measure
To represent or to imitate reality
To enliven or decorate

Fundamental Uses

To Label

Information Visualization
Colin Ware

www.edwardtufte.com
Grouping, Highlighting

Preattentive “Pop-out”

13579345978274055
24937916478254137
23876597277103876
95637283649105676
32543787954836754
56840378465785690

Time proportional to the number of digits

1359/18/345/82/4056
2493/19/16/4/82/5413
238/16/59/27/710/3876
9563/28/36/49/2056/6
3254/3/8/54/36/54
5684/3/8/46/58/590

Time proportional to the number of 7’s

Both 3’s and 7’s “Pop out”

Pop-out vs. Distinguishable

Pop-out
- Typically, 5-6 distinct values simultaneously
- Up to 9 under controlled conditions

Distinguishable
- 20 easily for reasonable sized stimuli
- More if in a context

What is the color for?

Radio Spectrum Map (33 colors)


Distinguishable on Inspection

Color Names

Basic names (Berlin & Kay)
- Linguistic study of names
- Similar names
- Similar evolution

Distinct colors = distinct names?
Tableau Color Example

Color palettes
- How many? Algorithmic?
- Basic colors (regular and pastel)
- Extensible? Customizable?

Color appearance
- As a function of size
- As a function of background

Robust and reliable color names

To Measure

Color as quantity
- Density map
- Thematic maps
- Color scales/maps

Color Scales

Long history in graphics and visualization
- Ware, Robertson et. al, Levkowitz et. al
- Rheingans

PRAVDA Color
- Rogowitz and Treinish
- IBM Research

Cartography
- Cynthia Brewer
- ColorBrewer

Data to Color

Type of data values
- Nominal, ordinal, numeric
- Qualitative, sequential, diverging

Hue = nominal

Lightness or saturation scales
- Lightness best for high frequency
- More = darker (or more saturated)
Brewer's Categories

<table>
<thead>
<tr>
<th>Qualitative Scale</th>
<th>Sequential Scale</th>
<th>Diverging Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distinct hues, but similar emphasis</td>
<td>Vary in lightness and saturation</td>
<td>Complementary sequential scales</td>
</tr>
<tr>
<td>Neutral at &quot;zero&quot;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Brewer Scales

Nominal scales
- Distinct hues, but similar emphasis
Sequential scale
- Vary in lightness and saturation
- Vary slightly in hue
Diverging scale
- Complementary sequential scales
- Neutral at "zero"

Tableau Color Example

Color scales for encoding data
Displayed as charts and graphs
Issues
- Color ramps based on Brewer's principles
- Not single hue/ chroma varying in lightness
- Create a ramp of the "same color"
- Legible different than distinguishable
- Center, balance of diverging ramps

Color and Shading

Shape is defined by lightness (shading)
"Color" (hue, saturation) labels

Images Courtesy of Siemens

Images Courtesy of TeraRecon, Inc
To Represent or Imitate Reality

Color as representation
- Key color to real world
- Iconographic vs. photographic

ThemeView (original)

To Enliven or Decorate

Color as beauty
- Aesthetic use of color
- Emotional, personal

“Attractive things work better” —Don Norman

More Tufte Principles

Limit the use of bright colors
- Small bright areas, dull backgrounds
Use the colors found in nature
- Familiar, naturally harmonious
Use grayed colors for backgrounds
- Quiet, versatile
Create color unity
- Repeat, mingle, interweave

Storm example
Storm Example (continued)

Get it right in black & white

Value
- Perceived lightness/darkness
- Controlling value primary rule for design

Value alone defines shape
- No edge without lightness change
- No shading with out lightness variation

Value difference defines contrast
- Defines legibility
- Controls attention

Controls Legibility

Controls Attention, Clutter

Drop Shadows
Drop Shadow

Drop shadow adds edge

Cockpit Controls (before)

Cockpit Controls (after)

Layered, prioritized use of color, contrast

From "After the Storm," Baker and Bushell

Maureen Stone, StoneSoup Consulting
Controlling Value

Scale from black to white
  • Luminance
  • Munsell value, L*
  • Density, reflectance

RGB displays
  • Non-linear function of intensity
  • “Gamma function”
  • Sensitive to display settings, ambient light

What is best way to define “contrast?”

Effective Color

Aesthetics  
Perception  
Materials

RGB Specifications

Display Gamuts


Projector Gamuts


Pixel to Intensity Variation

Intensity Transfer Function (ITF), or “gamma”
### Display Appearance

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tristimulus characterization</td>
<td>Relatively easy to accomplish</td>
</tr>
<tr>
<td>Want RGB to color appearance</td>
<td>Robust and reliable color names</td>
</tr>
<tr>
<td></td>
<td>Robust and reliable contrast control</td>
</tr>
<tr>
<td></td>
<td>As robust as print appearance</td>
</tr>
<tr>
<td>Visual feedback and simple controls</td>
<td></td>
</tr>
</tbody>
</table>

### Appearance Models

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adaptable Color</td>
<td>Same color, different sizes</td>
</tr>
<tr>
<td></td>
<td>Same color, different backgrounds</td>
</tr>
<tr>
<td>Interactive Color</td>
<td>Does it appear the same?</td>
</tr>
<tr>
<td></td>
<td>User has controls: Zoom, tool tips, etc.</td>
</tr>
<tr>
<td>Cross-media rendering</td>
<td>Maintain encoding</td>
</tr>
<tr>
<td></td>
<td>Names and relationships?</td>
</tr>
</tbody>
</table>

### Conclusion

<table>
<thead>
<tr>
<th>Topic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color in information display</td>
<td>Tufte’s rules</td>
</tr>
<tr>
<td></td>
<td>“Get it right in black and white”</td>
</tr>
<tr>
<td>Easier than images</td>
<td>Fewer colors, larger areas</td>
</tr>
<tr>
<td></td>
<td>Doesn’t match a real world scene</td>
</tr>
<tr>
<td>Harder than images</td>
<td>Doesn’t match a real world scene</td>
</tr>
<tr>
<td></td>
<td>Critical for information content</td>
</tr>
</tbody>
</table>