Final project

Design new visualization method
- Pose problem, Implement creative solution

Deliverables
- Implementation of solution
- 8-12 page paper in format of conference paper submission
- 2 design discussion presentations

Schedule
- Project proposal: 10/24
- Initial problem presentation: 10/24, 10/29 or 10/31
- Midpoint design discussion: 11/19, 11/21 or 11/26
- Final paper and presentation: To be determined

Grading
- Groups of up to 3 people, graded individually
- Clearly report responsibilities of each member
Schedule

- Nate Agrin, Ken-ichi Ueda, Andrew McDiarmid 10/24
- Jimmy Andrews 10/31
- Andy Carle 10/31
- Robert Carroll 10/29
- Robin Held 10/24
- Jamie O'Shea 10/31
- David Purdy, Daisy Wang 10/29
- Amanda Alvarez 10/29
- Jonathan Chung 10/31
- Mark Howison 10/31
- Omar Khan 10/24
- Wes Willett 10/24
- Hannes Hesse, Kesava Mallela 10/29
- Kenghao Chang 10/29
- Jimmy Chen, Jerry Ye 10/24

Identifying Design Principles
Approach

**Identify design principles**
- Cognition and perception

**Instantiate design principles**
- Principles become constraints that guide an optimization process

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Route maps
Assembly instructions

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All parts

- Search
- Subdivide Steps
- Reorientation

**Step-by-step assembly sequence**

**Action Diagrams**
- Choose Direction
- Build Stacks
- Place Guidelines

**Step-by-step assembly diagrams**
Evaluation

- 30 Participants
- Given 1 of 3 instruction sets: factory, hand-drawn, computer
- Assemble TV stand using instructions

Factory
Hand-drawn

1. Draw the following box up as shown in the picture. (You should have two of the boxes, which is why the arrow)
2. Place the tilted and long box on the surface with the printed surface face up and the long box across the other side. Make sure the box is lined up with the correct height of the box. Then place the box with the arrow towards the box.
3. Place a white piece at each side of the bottom of the box.
4. Place the box on the boxes. Again, make sure the exact position is the same as in the diagram and the printed edges of the other boxes.
Results

<table>
<thead>
<tr>
<th></th>
<th>Factory</th>
<th>Hand-drawn</th>
<th>Computer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean time to assemble (min)</td>
<td>18.9</td>
<td>16.0</td>
<td>10.2</td>
</tr>
</tbody>
</table>

Errors: Factory 1.6  Hand-drawn 0.6  Computer 0.5
Task rated easiest in computer condition

Summary

Identification of design principles
- Production
- Preference
- Comprehension

Instantiation of design principles

Validation of design principles
Color in Information Display

Maureen Stone
StoneSoup Consulting

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

Perception and Cognition
Color Models

Physical World  Visual System  Mental Models

Light Energy  Cone Response  Opponent Encoding  Perceptual Models  Appearance Models
Spectral distribution functions  Encode as three values (L,M,S)  Separate lightness, chroma (A,R-G,Y-B)  Color “Space”  Color in Context
F(λ)  CIE (X,Y,Z)  CIELAB Munsell (HVC)  Hue lightness saturation  Adaptation Background Size …

Physical World

Spectral Distribution
- Visible light
- Power vs. wavelength

Any source
- Direct
- Transmitted
- Reflected
- Refracted
Cone Response

Encode spectra as three values
- Long, medium and short (LMS)
- Trichromacy: only LMS is “seen”
- Different spectra can “look the same”

Sort of like a digital camera*


Effects of Retinal Encoding

All spectra that stimulate the same cone response are indistinguishable

Metamer match
Color Measurement

CIE Standard Observer
CIE tristimulus values (XYZ)
All spectra that stimulate the same tristimulus (XYZ) response are indistinguishable


Chromaticity Diagram

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

\[ x = X/(X+Y+Z) \]
\[ y = Y/(X+Y+Z) \]
\[ z = Z/(X+Y+Z) \]
\[ 1 = x+y+z \]

Courtesy of PhotoResearch, Inc.
Chromaticity Diagram

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

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

\[ 1 = x+y+z \]

RGB Chromaticity

R,G,B are points (varying lightness)

Sum of two colors lies on line

Gamut is a triangle
- White/gray/black near center
- Saturated colors on edges
Display Gamuts

Projector Gamuts

Color Models

<table>
<thead>
<tr>
<th>Physical World</th>
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<th>Mental Models</th>
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<tr>
<td>Light Energy</td>
<td>Cone Response</td>
<td>Opponent Encoding</td>
</tr>
<tr>
<td>Spectral distribution functions $F(\lambda)$</td>
<td>Encode as three values $(L,M,S)$</td>
<td>Separate lightness, chroma $(A,R-G,Y-B)$</td>
</tr>
<tr>
<td></td>
<td>CIE $(X,Y,Z)$</td>
<td>Separation lightness, chroma</td>
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<tr>
<td></td>
<td></td>
<td>Color blindness</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Image encoding</td>
</tr>
</tbody>
</table>

Perceptual Models

- Color “Space”
- Hue, lightness saturation
- CIELAB
- Munsell $(HVC)$
- CIECAM02

Appearance Models

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

Opponent Color

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"
Vischeck

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

Deuteranope  Protanope  Tritanope

2D Color Space

Normal  Protanope  Deuteranope  Tritanope
Perceptual Color Spaces

- Unique black and white
- Uniform differences
- Perception & design

Munsell Atlas

Courtesy Gretag-Macbeth
CIELAB and CIELUV

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

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 values
- $L^*$ values
- $L$ from HLS
  All the same

Luminance & Intensity

Intensity
- Integral of spectral distribution (power)

Luminance
- Intensity modulated by wavelength sensitivity
- Integral of spectrum $\times$ luminous efficiency function

Green and blue lights of equal intensity have different luminance values
## Color Models

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</tr>
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### Color Appearance

[Image of yellow and gray crosses]
Color Appearance

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

Appearance effects
- Adaptation
- Simultaneous contrast
- Spatial effects

Color in context

Simultaneous Contrast

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

These samples will have both light/dark and hue contrast
Affects Lightness Scale

Bezold Effect
**Crispening**

Perceived difference depends on background

From Fairchild, *Color Appearance Models*

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**Spreading**

Spatial frequency
- The paint chip problem
- Small text, lines, glyphs
- Image colors

Adjacent colors blend

Redrawn from *Foundations of Vision*

© Brian Wandell, Stanford University
Color Models

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

- **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
    - CIELAB Munsell (HVC)
  - Appearance Models
    - Color in Context
    - Adaptation, Background, Size, ...
    - CIECAM02
    - Adaptation
    - Contrast effects
    - Image appearance
    - Complex matching
What makes color effective?

“Good ideas executed with superb craft”
—E.R. Tufte

Effective color needs a context
• Immediate vs. studied
• Anyone vs. specialist
• Critical vs. contextual
• Culture and expectations
• Time and money

Why Should You 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
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 labels and groups
- Color scales (colormaps)
- Multi-variate color encoding
- Color shading and textures
- And more...

Color Design Terminology

Hue (color wheel)
- Red, yellow, blue (primary)
- Orange, green, purple (secondary)
- Opposites complement (contrast)
- Adjacent are analogous
- Many different color wheels*

Chroma (saturation)
- Intensity or purity
- Distance from gray

Value (lightness)
- Dark to light
- Applies to all colors, not just gray

*See www.handprint.com for examples
Tints and Tones

Tone or shade
- Hue + black
- Decrease saturation
- Decrease lightness

Tint
- Hue + white
- Decrease saturation
- Increase lightness

Gradations
Color Design Principles

Control value (lightness)
- Ensure legibility
- Avoid unwanted emphasis

Use a limited hue palette
- Control color “pop out”
- Define color grouping
- Avoid clutter from too many competing colors

Use neutral backgrounds
- Control impact of color
- Minimize simultaneous contrast

Envisioning Information

“... avoiding catastrophe becomes the first principle in bringing color to information:
Above all, do no harm.”

—E. R. Tufte

www.edwardtufte.com
Fundamental Uses

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

To Label
Identify by Color

Product Categories
Grouping, Highlighting

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
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<tbody>
<tr>
<td>red</td>
<td>25.37</td>
<td>13.70</td>
<td>0.05</td>
<td>26.27</td>
<td>14.13</td>
<td>0.04</td>
<td>18.41</td>
<td>10.16</td>
<td>0.05</td>
</tr>
<tr>
<td>green</td>
<td>22.14</td>
<td>51.24</td>
<td>0.35</td>
<td>20.68</td>
<td>49.17</td>
<td>0.44</td>
<td>21.11</td>
<td>46.00</td>
<td>0.20</td>
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<tr>
<td>blue</td>
<td>13.17</td>
<td>3.71</td>
<td>74.89</td>
<td>15.38</td>
<td>5.20</td>
<td>86.83</td>
<td>11.55</td>
<td>3.37</td>
<td>65.53</td>
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<tr>
<td>gray</td>
<td>83.46</td>
<td>73.30</td>
<td>78.05</td>
<td>64.66</td>
<td>71.99</td>
<td>90.08</td>
<td>52.96</td>
<td>82.49</td>
<td>57.99</td>
</tr>
<tr>
<td>black</td>
<td>0.66</td>
<td>0.70</td>
<td>0.77</td>
<td>0.63</td>
<td>0.66</td>
<td>1.09</td>
<td>0.47</td>
<td>0.58</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Considerations for Labels

How critical is the color encoding?
- Unique specification or is it a “hint”?
- Quick response, or time for inspection?
- Is there a legend, or need it be memorized?

Contextual issues
- Are there established semantics?
- Grouping or ordering relationships?
- Surrounding shapes and colors?

Shape and structural issues
- How big are the objects?
- How many objects, and could they overlap?
- Need they be readable, or only visible?
Controls and Alerts

Aircraft cockpit design
- Quick response
- Critical information and conditions
- Memorized
- 5-7 unique colors, easily distinguishable

Highway signs
- Quick response
- Critical but redundant information
- 10-15 colors?

Typical color desktop
- Aid to search
- Redundant information
- Personal and decorative
- How many colors?

Radio Spectrum Map (33 colors)

Distinguishable on Inspection

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
# Tableau Colors

<table>
<thead>
<tr>
<th>Color</th>
<th>Regular</th>
<th>Medium</th>
<th>Light</th>
<th>Ultra-light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td><img src="image1" alt="Blue Regular" /></td>
<td><img src="image2" alt="Blue Medium" /></td>
<td><img src="image3" alt="Blue Light" /></td>
<td><img src="image4" alt="Blue Ultra-light" /></td>
</tr>
<tr>
<td>Orange</td>
<td><img src="image5" alt="Orange Regular" /></td>
<td><img src="image6" alt="Orange Medium" /></td>
<td><img src="image7" alt="Orange Light" /></td>
<td><img src="image8" alt="Orange Ultra-light" /></td>
</tr>
<tr>
<td>Green</td>
<td><img src="image9" alt="Green Regular" /></td>
<td><img src="image10" alt="Green Medium" /></td>
<td><img src="image11" alt="Green Light" /></td>
<td><img src="image12" alt="Green Ultra-light" /></td>
</tr>
<tr>
<td>Red</td>
<td><img src="image13" alt="Red Regular" /></td>
<td><img src="image14" alt="Red Medium" /></td>
<td><img src="image15" alt="Red Light" /></td>
<td><img src="image16" alt="Red Ultra-light" /></td>
</tr>
<tr>
<td>Purple</td>
<td><img src="image17" alt="Purple Regular" /></td>
<td><img src="image18" alt="Purple Medium" /></td>
<td><img src="image19" alt="Purple Light" /></td>
<td><img src="image20" alt="Purple Ultra-light" /></td>
</tr>
<tr>
<td>Brown</td>
<td><img src="image21" alt="Brown Regular" /></td>
<td><img src="image22" alt="Brown Medium" /></td>
<td><img src="image23" alt="Brown Light" /></td>
<td><img src="image24" alt="Brown Ultra-light" /></td>
</tr>
<tr>
<td>Pink</td>
<td><img src="image25" alt="Pink Regular" /></td>
<td><img src="image26" alt="Pink Medium" /></td>
<td><img src="image27" alt="Pink Light" /></td>
<td><img src="image28" alt="Pink Ultra-light" /></td>
</tr>
<tr>
<td>Gray</td>
<td><img src="image29" alt="Gray Regular" /></td>
<td><img src="image30" alt="Gray Medium" /></td>
<td><img src="image31" alt="Gray Light" /></td>
<td><img src="image32" alt="Gray Ultra-light" /></td>
</tr>
<tr>
<td>Gold</td>
<td><img src="image33" alt="Gold Regular" /></td>
<td><img src="image34" alt="Gold Medium" /></td>
<td><img src="image35" alt="Gold Light" /></td>
<td><img src="image36" alt="Gold Ultra-light" /></td>
</tr>
<tr>
<td>Teal</td>
<td><img src="image37" alt="Teal Regular" /></td>
<td><img src="image38" alt="Teal Medium" /></td>
<td><img src="image39" alt="Teal Light" /></td>
<td><img src="image40" alt="Teal Ultra-light" /></td>
</tr>
</tbody>
</table>

www.tableausoftware.com

### Maximum hue separation

![Graph showing maximum hue separation]
Analogous, yet distinct

Sequential
Basic names (Berlin & Kay)
- Linguistic study of names
- Similar names
- Similar evolution
- Hierarchy of names
  - Names appear in languages in order from left to right

Distinct colors = distinct names?
Distinct, but hard to name

Color Names Research

Selection by name
- Berk, Brownston & Kaufman, 1982
- Meier, et. al. 2003

Image recoloring
- Saito, et. al.

Labels in visualization
- D’Zmura, Cowan (pop out conditions)
- Healey & Booth (automatic selection)

Web experiment
- Moroney, et. al. 2003

World Color Survey (Kay & Cook)
- http://www.icsi.berkeley.edu/wcs/
To Measure

Data to Color

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

Types of color scales
- Hue scale
  - Nominal (labels)
  - Cyclic (learned order)
- Lightness or saturation scales
  - Ordered scales
  - Lightness best for high frequency
  - More = darker (or more saturated)
  - Most accurate if quantized
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

Different Scales

Rogowitz & Treinish, “How not to lie with visualization”
**Density Map**

- Lightness scale
- Lightness scale with hue and chroma variation
- Hue scale with lightness variation

**Phase Diagrams (hue scale)**

Singularities occur where all colors meet

- The optical singularities of bianisotropic crystals, by M. V. Berry
Phases of the Tides

Figure 1.9. Cotidal chart. Tide phases relative to Greenwich are plotted for all the world’s oceans. Phase progresses from red to orange to yellow to green to blue to purple. The lines converge on anphidromic points, singularities on the earth’s surface where there is no defined tide. [Wintree, 1987 #1195, p. 17].

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”
Thematic Maps


Brewer’s Categories

Cynthia Brewer, Pennsylvania State University
Color Brewer

Multivariate Color Sequences
Multi-dimensional Scatter plot

Variable 1, 2 → X, Y
Variable 3, 4, 5 → R, G, B

Do people interpret color blends as sums of variables?

Using Color Dimensions to Display Data Dimensions
Beatty and Ware

Color Weaves

6 variables = 6 hues, which vary in brightness

Additive mixture (blend) Spatial texture (weave)

Weaving versus Blending (APGV06 and SIGGRAPH poster)
Haleh Hagh-Shenas, Victoria Interrante, Christopher Healey and Sunghee Kim
Brewer System

Binary

Qualitative

Diverging

Sequential

http://www.colorbrewer.org

Brewer Examples

Sequential/Sequential Scheme

Diverging/Sequential Scheme