IAT 355
Visual Analytics

Luminance, Contrast and Colour in Information Display

Lyn Bartram
Simultaneous contrast effects

- A gray patch placed on a dark background looks lighter than the same gray patch on a light background.
- [http://www.michaelbach.de/ot/lum_dynsimcontrast/index.html](http://www.michaelbach.de/ot/lum_dynsimcontrast/index.html)
Assimilation of lightness

- The gray background with black lines appears to be darker while the gray background with white lines appears to be lighter.
Mach bands

- Illusory Mach bands appear when gradients from darker to lighter shades are created.
Mach bands

• The effect is robust with different shapes and numbers of gradients

Image from perceptualstuff.org
Mach bands

• The effect is robust with different shapes and numbers of gradients

Image from perceptualstuff.org
Mach bands

- The effect is robust with different shapes and numbers of gradients

Image from perceptualstuff.org
Chevreuil Illusion

- When a sequence of gray bands is generated, the bands appear darker at one edge than at the other, even though they are uniform.
Chevreuil Illusion

- Again, this also works in colour and with irregular borders.

- Note we are not talking about hue change but luminance change.

Image from perceptualstuff.org
Dynamic Luminance

- Changes in apparent brightness with quick changes in viewing distance

Image from perceptualstuff.org
The Breathing Light Illusion

- Change in apparent brightness as you move closer in and farther away quickly

The Café Wall Illusion

• The tiles appear to be wedge shaped and the lines curved but are actually evenly rectangular.
Effects cause error!

- Simultaneous contrast effects can result in large errors of judgment when reading quantitative (value) information displayed using a gray scale.
- Ware et al showed an average error of 20% of the entire gray scale in a map encoding gravity fields using 16 levels of gray.
Cornsweet effect

- Which area is lighter than the other?

- These areas appear different in lightness, but are in fact the same.
Cornsweet effect

• These areas appear different in lightness, but are in fact the same
• On the other hand ..
• The enhancement of edges is also an important part of some artists’ techniques

• Seurat deliberately enhanced edge contrast to make his figures stand out.
Low spatial frequency modulation
Luminance, Brightness and Lightness

- **Luminance** refers to the measured amount of light coming from some region of space.
  - Physical measure, not perceptual quantity
- **Brightness** generally refers to the perceived amount of light coming from a source.
  - It is used to refer only to things that are perceived as self-luminous.
  - A bright light
- **Lightness** generally refers to the **perceived** reflectance of a surface.
  - A white surface is light. A black surface is dark
• Luminance is completely unrelated to perceived brightness or lightness
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• Luminance is completely unrelated to perceived brightness or lightness
Crispening
What about colour?

- Colour perception is *relative*

- We are sensitive to small differences
  - hence need sixteen million colours

- Not sensitive to absolute values
  - hence we can only use < 10 colours for coding
Vischeck

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

www.vischeck.com
**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](http://www.handprint.com) for examples
Tints and Tones

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

- **Tint**
  - Hue + **white**
  - Decrease saturation
  - **Increase** lightness
IAT355 | Colour for Information Display
Gradations
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 (retinal response)

L* values

L from HLS
All the same
What makes color effective?

“Good ideas executed with superb craft” — E.R. Tufte
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)
- Multivariate color encoding
- Color shading and textures
- And more
A quick revisit of data characteristics

- What kind of task are you hoping to support?
- What kind of data do you have?
- No single approach
Types of values

• **Nominal**: names without ordering
  • Continents: Africa, America, Asia, Australia, Europe
  • No concept of relative relationship other than inclusion in the set

• **Ordinal**: Before-than than relationship holds
  • Rental cars: Economy, Compact, Mid-sized, Full-sized
  • Distance is not uniform

• **Quantitative**: Relative measurements, equal distances, numeric
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 (colour as noun)
- To measure (colour as quantity/value)
- To represent (colour as representation)
  - to imitate reality
- To enliven or decorate (colour as beauty)
To Label

*(nominal coding)*
Colours great for classification

- Rapid visual segmentation
- Colour helps us determine type
- Only about six 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>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
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<td>0.04</td>
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<td>0.05</td>
<td>17.43</td>
<td>9.30</td>
<td>0.00</td>
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<td>20.68</td>
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<td>71.99</td>
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<td>52.96</td>
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<td>67.99</td>
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<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>
<td>0.44</td>
<td>0.54</td>
<td>0.71</td>
</tr>
</tbody>
</table>

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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 (discernible)?
Psychophysics of Labeling

- Preattentive, “pop out”

13579345978274055
24937916478254137
23876597277103866
19874367259047362
95637283649105676
32543787954836754
56840378465485690

Time proportional to the number of digits
Contrast Creates Pop-out

Hue and lightness

Lightness only

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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 controlled context
  - Usually need a legend
Radio Spectrum Map (33 colors)

Cultural semantics

- The fact that certain colours are special is because they are hard wired
- The meaning of those colours is culturally determined
Summary: labeling

- Distinctiveness (perceptual distance)
- Unique hues
  - Don’t choose colours from the same category!
- Contrast with background
  - Luminance
- Compensate for colour blindness
- Limited number of codes
- Size
  - Objects should not be too small
- Cultural conventions
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

Quantized
- Signal varies continuously

Discretized
- Restricted to a prescribed set of values
Pseudocoloring

- Pseudocoloring is the technique of representing continuously varying map values with a sequence of colours
- Sometimes overlaid on luminosity information
  - Need to use an *isoluminant* color map to avoid distortion
- “intuitive” based on lightness, saturation
- No perceptually based hue scales
  - Need to be learned
Pseudocoloring
Density Map

Lightness scale

Lightness scale with hue and chroma variation

“Rainbow” hue scale

Unordered hue, lightness
Different Scales

Rogowitz & Treinish, “How not to lie with visualization”
Brewer Scales

• Qualitative scales
  • nominal
  • Distinct hues, but similar emphasis

• Sequential scale
  • Vary in lightness and saturation
  • Vary slightly in hue

• Diverging scale
  • Complementary sequential scales
  • Neutral at “zero”
  • Cross-fade through a neutral color
Brewer’s Categories

Qualitative Scale

Sequential Scale

Diverging Scale
Thematic Maps

US Census Map

Age-adjusted
(U.S. rate = 205.0)

<table>
<thead>
<tr>
<th>Rate per 100,000 population</th>
<th>Comparative mortality ratio (HSA to U.S.)</th>
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<td>253.8 – 328.6</td>
<td>1.24 – 1.60</td>
</tr>
<tr>
<td>236.8 – 253.7</td>
<td>1.16 – 1.24</td>
</tr>
<tr>
<td>215.2 – 236.7</td>
<td>1.05 – 1.16</td>
</tr>
<tr>
<td>199.9 – 215.1</td>
<td>0.98 – 1.05</td>
</tr>
<tr>
<td>179.5 – 199.8</td>
<td>0.88 – 0.98</td>
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<tr>
<td>166.7 – 179.4</td>
<td>0.81 – 0.88</td>
</tr>
<tr>
<td>112.4 – 166.6</td>
<td>0.55 – 0.81</td>
</tr>
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</table>

Color Brewer

www.colorbrewer.org

This material is based upon work supported by the National Science Foundation under Grant No. 9983461, 9983469, 9983461
Heat Map (default ramp)

Skewed Data

Slightly negative

www.tableausoftware.com
| Columns: Market.. |
|---------------|------------------|
| Rows: Region  |

<table>
<thead>
<tr>
<th></th>
<th>CONS..</th>
<th>CORPO..</th>
<th>HOME..</th>
<th>SMALL..</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENT..</td>
<td>FURNITURE</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>OFFICE SUPP..</td>
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<td>TECHNOLOGY</td>
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<tr>
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<td>FURNITURE</td>
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</tbody>
</table>

www.tableausoftware.com
### Stepped IAT355  |  Colour for Information Display

#### Skewed Data

<table>
<thead>
<tr>
<th>Columns: Market</th>
<th>Rows: Region</th>
<th>Product...</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>CONSU..</th>
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<tbody>
<tr>
<td><strong>FURNITURE</strong></td>
<td></td>
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<tr>
<td><strong>CENT..</strong></td>
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<td></td>
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<tr>
<td><strong>OFFICE SUPP..</strong></td>
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<td><strong>TECHNOLOGY</strong></td>
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<tr>
<td><strong>EAST</strong></td>
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<tr>
<td><strong>OFFICE SUPP..</strong></td>
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<td><strong>TECHNOLOGY</strong></td>
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<tr>
<td><strong>WEST</strong></td>
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<td><strong>OFFICE SUPP..</strong></td>
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<tr>
<td><strong>TECHNOLOGY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- 125.579 to 410.207

[www.tableausoftware.com](http://www.tableausoftware.com)
Threshold

Skewed Data

Columns: Market...
Rows: Region, Product...

Filters:

Level of Detail:

Mark:
- Square
- Text
- Color
- Size

Legend:
-410,207 to 410,207

www.tableausoftware.com
Color and Shading

- Shape is defined by lightness (shading)
- “Color” (hue, saturation) labels

Image courtesy of Siemens

CT image (defines shape)  PET color highlights tumor
Color Overlay (Temperature)

3D line integral convolution to visualize 3D flow (LIC).

Color varies from red to yellow with increasing temperature

http://www-users.cs.umn.edu/~interran/3Dflow.html
Multivariate Color Sequences
How many dimensions?

- **Univariate scale** is a path in a colour space
  - Progression along a line

- **Multivariate** is:
  - Plane? 2D
  - Volume? 3D
  - Rules for color mixing

- **Only perceptual coding** is 2D
  - lightness x saturation

- **Color for multivariate** only works well for highly quantized data
  - Like a mnemonic for a labeling scheme
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

Change in percent of labor force employed in industry between 1960 and 1980
To Represent or Imitate Reality
Illustrative Color

Gray’s Anatomy of the Human Body

Map of Point Reyes

www.bartleby.com/107/illus520.html

www.nps.gov
ThemeScape (commercial)

Topics: Golan Peace Israeli Syria Israel X
1 WP: Barak Seeks Security, Prosperity
   * WP: Syria: Israel Peace Accord Is Near
   * WP: Jewish Settlers Fight Peace Plan

[12/12/99] KATZRIN, Golan Heights Jewish settlers inaugurated a new neighborhood in the Golan Heights on Sunday, vowing to block...
To Enliven or Decorate
Visualization of isoelectron density surfaces around molecules
Marc Levoy (1988)

Which has more information?

Which would you rather look at?
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
Controlling Value
Get it right in black & white

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

• Value defines shape
  • No edge without lightness difference
  • No shading without lightness variation

• Value difference (contrast)
  • Defines legibility
  • Controls attention
  • Creates layering
Controls Legibility

\[
\text{Helvetica-plain/Helvetica-plain/Helvetica-plain/Helvetica-plain/Helvetica-plain/}
\]

\[
\text{Helvetica-plain/Helvetica-plain/Helvetica-plain/Helvetica-plain/Helvetica-plain/}
\]

\[
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\[
\text{255,255,255/127,127,127/0,0,0}
\]

\[
\text{colorusage.arc.nasa.gov}
\]
Legibility

Drop Shadows

Drop shadow adds edge

Primary colors on black
Primary colors on black
Primary colors on black
Primary colors on black
Primary colors on black
Primary colors on black
Primary colors on black
Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white
Readability

If you can’t use color wisely, it is best to avoid it entirely. Above all, do no harm.
Why does the logo work?
Why does this logo work so well?

Value control
Contrast and Layering

- Value contrast creates layering

[Diagram showing contrast and layering with labels: Urgent, Context, Normal, Normal, Context]
What Defines Layering?

- Perceptual features
  - Contrast (especially lightness)
  - Color, shape and texture
- Task and attention
  - Attention affects perception
- Display characteristics
  - Brightness, contrast, “gamma”
General guidelines … or from Tufte to practice  [Stone, Ware]

• Assign colour according to function

• Use contrast to highlight

• Use analogy to group

• Control value contrast for legibility

• Break isoluminance with borders
From principles to palettes

• Limit palette to 2 or 3 of them

• Different choices convey different messages
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
<table>
<thead>
<tr>
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<th>Regular</th>
<th>Medium</th>
<th>Light</th>
<th>Ultra-light</th>
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<td>text</td>
<td>text</td>
<td>text</td>
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<tr>
<td>Orange</td>
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<td>Green</td>
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<td>text</td>
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<tr>
<td>Red</td>
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<td>text</td>
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<td>Purple</td>
<td></td>
<td></td>
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<td>Brown</td>
<td></td>
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</tr>
<tr>
<td>Pink</td>
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<tr>
<td>Gray</td>
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<td>Gold</td>
<td>text</td>
<td>text</td>
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<tr>
<td>Teal</td>
<td></td>
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</tr>
</tbody>
</table>

www.tableausoftware.com
Maximum hue separation
Analogous, yet distinct

SUM(Sales Total)

Sunday Monday Tuesday Wednesday

2004

Q1 Q2 Q3 Q4

SUM(Sales Total)

Sunday Monday Tuesday Wednesday Thursday Friday Saturday

2004

Q1 Q2 Q3 Q4

IAT355 | Colour for Information

SFU
Stephen Few’s practical rules on charts

1. If you want different objects of the same color in a table or graph to look the same, make sure that the background—the color that surrounds them—is consistent.

2. If you want objects in a table or graph to be easily seen, use a background color that contrasts sufficiently with the object.

Don’t do this!
3. Use colour only when needed to serve a particular communication goal

4. Use different colours only when they correspond to differences of meaning in the data
5. Use soft, natural colors to display most information and bright and/or dark colors to highlight information that requires greater attention.

6. When using color to encode a sequential range of quantitative values, stick with a single hue (or a small set of closely related hues) and vary intensity from pale colors for low values to increasingly darker and brighter colors for high values.
Few (4)

7. Non-data components of tables and graphs should be displayed just visibly enough to perform their role, but no more so, for excessive salience could cause them to distract attention from the data.

8. Avoid using red/green display without redundant cueing.

Additional Resources on Color

- Even without the “u” ....

- Stone Soup website
  - http://www.stonesc.com/Vis06
  - Final copy of slides, references

- A Field Guide to Digital Color
  - Maureen C. Stone
  - Published by A.K. Peters

- Stephen Few’s articles on color
  - http://www.perceptualedge.com