IAT 814
Visual Encoding 2

Colour in Information Display

Lyn Bartram
Colour is Irrelevant…

• To perceiving object shapes

• To perceiving layout of objects in space

• To perceiving how objects are moving

• Therefore, to much of modern life
  • Laboratory assistant went 21 years without realizing he was colour-blind
Colour is Critical...

- To help us break camouflage
- To judge the condition of objects (food)
- To determine material types
- Extremely useful for coding information
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
Cone Response (photopic)

- Cone response sensitivity for colours occurs at different wavelengths in the spectrum
  - Cone response curve
  - Long, medium and short (LMS)

Sort of like a digital camera*
- BUT light sensors in a camera are equally distributed
- Uneven cone distribution
  - saccades for continuous image

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”
Comparing the Channels

- Spatial Sensitivity
  - Red/Green and Yellow/Blue about 1/3 detail of Black/White
- Stereoscopic Depth
  - Pretty much can’t do it with hue alone
- Luminance contrast is critical
  - Especially with small patterns
- Form
  - Shape-from shading works well
  - Shape-from-hue doesn’t

- Information Labeling: Hue works well!
**Opponent Process Theory**

- Cone signals transformed into new channels
  - Black/White (Luminance; ignores blue)
  - Red/Green
  - Yellow/Blue

---

Yet another reason not to use blue to indicate the shapes of objects; it seems to be ignored in the Luminance calculation.
Color Design Terminology

- **Hue (color wheel)**
  - Red, yellow, blue (primary)
  - Orange, green, purple (secondary)
  - Opposites complement (contrast)
  - Adjacent are analogous
  - Many different color wheels*
  - *See [www.handprint.com](http://www.handprint.com) for examples

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

- **Value (lightness)**
  - Dark to light
  - Applies to all colors, not just gray
Tints and Tones

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

- **Tint**
  - Hue + **white**
  - Decrease saturation
  - Increase lightness
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
Lightness Scales

• Lightness, brightness, luminance, and L*
  • Lightness is relative, brightness absolute
  • Absolute intensity has light power as units (measured)

• Luminance is perceived intensity
  • Luminance varies with wavelength
  • Variation defined by luminous efficiency function

• L* is perceptually uniform lightness

• Perceptual uniformity: equal spatial distances define equal perceptual differences
Luminance & Intensity

- **Intensity**
  - Integral of spectral distribution (power)

- **Luminance**
  - Intensity modulated by wavelength sensitivity
  - Integral of spectrum × luminous efficiency function
  - Is a *perceived* intensity

Green and blue lights of equal intensity have different luminance values.
Be careful: Colour models, luminance and L*
Colour Deficiency (VCD)

• Simulates color vision deficiencies
  • Photoshop plug-in (View → Proof Setup → Color Deficiency)
  • VisCheck (Robert Dougherty and Alex Wade)
2D Color Space

Normal  Protanope  Deuteranope  Tritanope
Color Appearance
Image courtesy of John MCann
Image courtesy of John MCan
Color Appearance

- More than a single color
  - Adjacent colors (background)
  - Viewing environment (surround)
- Appearance effects
  - Adaptation
  - Simultaneous contrast
  - Spatial effects
- Color in context

*Color Appearance Models*
Mark Fairchild
Simultaneous contrast

Affects Lightness Scale
Simultaneous Contrast

• Influence of immediate surround on perception of colour

• Simple example:

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

These samples will have both light/dark and hue contrast
Bezold Effect: outline makes a difference
Other contrast effects

Chromatic contrast

Small field tritanopia

[Diagram of chromatic contrast with examples a, b, c, d]

[Diagram of small field tritanopia with examples a, b, c, d]
Spreading

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

- Adjacent colors blend

- The higher the spatial frequency, the less saturated the colour

Redrawn from *Foundations of Vision* © Brian Wandell, Stanford University
Coding with Colour
What makes color effective?

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

Colour includes Grey
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
Data types: recap

- **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
Encoding data with colour

- **Data Types**
  - Nominal, ordinal, quantitative
  - Qualitative, sequential, diverging

- **colour 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
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**)

IAT 814 | Colour in Information Display
To Label

*(nominal coding)*
Colour great for classification

- Rapid visual segmentation
- Colour helps us determine type
- Only about six categories
## Grouping, Highlighting

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<thead>
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<th>Y</th>
<th>Z</th>
<th>X</th>
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Considerations for Labels (N)

- 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”

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)

Distinguishable on Inspection

RADIO SERVICES COLOR LEGEND

- **Aeronautical Mobile**
- **Aeronautical Mobile Satellite**
- **Aeronautical Radionavigation**
- **Amateur**
- **Amateur Satellite**
- **Broadcasting**
- **Broadcasting Satellite**
- **Earth Exploration Satellite**
- **Fixed**
- **Fixed Satellite**
- **Maritime Mobile**
- **Maritime Mobile Satellite**
- **Maritime Radionavigation**
- **Meteorological Aids**
- **Mobile**
- **Mobile Satellite**
- **Radioastronomy**
- **Radioastronomy Satellite**
- **Radiolocation**
- **Radionavigation**
- **Radionavigation Satellite**
- **Space Operation**
- **Space Research**
- **Standard Frequency and Time Signal**
- **Standard Frequency and Time Signal Satellite**

**ACTIVITY CODE**

- **Government Exclusive**
- **Government/Non-Government Shared**
- **Non-Government Exclusive**
Colour naming is constant

- Consistent set of colour names [Berlin & Kay]:
  - blue, brown, green, orange, pink, purple, red, yellow, black, grey, white

Colour naming is constant

- Differences (salience) are not constant,
  - naming confusion between “greens” and “blues”
  - Orange and red

Colour palettes for nominal encoding

- Minimise name overlap
- Maximise salience
- Reduce ambiguity
- Enhance memory

Cultural issues

- certain colours are special because they are hard wired
- These colours are often assigned cultural meaning
- E.g. red, white, black
- Red-green, red-blue
Summary: labeling

• Distinctiveness (perceptual distance) vs identification
• Unique hues
  • Don’t choose colours from the same category!
• Contrast with background
  • Luminance
• Compensate for colour deficiency
• 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
False coloring

- RGB signals are remapped to enhance distinction of features
- Satellite imagery
- 2- channels

Image courtesy NASA/GSFC/MITI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team
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

- Derived from a grayscale image
- Maps data channel to colour
Frequently used in medicine
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”
Chloropleth

- areas are colored or patterned proportionally to the category or value of one or more variables being represented

- Discrete

- Typically maps
Thematic Maps

US Census Map

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

Cynthia Brewer, Pennsylvania State University
# Heat Map (default ramp)

## Skewed Data

Slightly negative

---

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<thead>
<tr>
<th>Columns: Market..</th>
<th>Rows: Region.. Product..</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FURNITURE</strong></td>
<td><strong>CONSU.</strong>, <strong>CORPO.</strong>, <strong>HOME.</strong>, <strong>SMALL.</strong></td>
</tr>
<tr>
<td><strong>CENT..</strong></td>
<td><strong>OFFICE SUPP.</strong></td>
</tr>
<tr>
<td><strong>TECHNOLOGY</strong></td>
<td><strong>CONSU.</strong>, <strong>CORPO.</strong>, <strong>HOME.</strong>, <strong>SMALL.</strong></td>
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www.tableausoftware.com
## Full Range

### IAT 814 | Colour in Information Display

### Skewed Data

<table>
<thead>
<tr>
<th>Region</th>
<th>CONSU.</th>
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<td></td>
<td>Technology</td>
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Legend:

```
-6.567 410.207
```

[www.tableausoftware.com](http://www.tableausoftware.com)
Stepped IAT 814 | Colour in Information Display

Skewed Data

www.tableausoftware.com
### Threshold

**Skewed Data**

<table>
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<tr>
<th>Region</th>
<th>FURNITURE</th>
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<tr>
<td>WEST</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Filters:**

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

**Level of Detail:**

- Mark: Square
- Text
- Color: SUM(Gr...)
- Size

**Legend:**

- -410,207 to 410,207

[www.tableausoftware.com](http://www.tableausoftware.com)
Color and Shading

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

CT image (defines shape)  PET color highlights tumor

Image courtesy of Siemens
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

Diverging

Qualitative

Sequential
Brewer Examples

Sequential/Sequential Scheme

Percent of labor force employed in agriculture, 1960

<30 30-39 ≥40

Percent of labor force employed in industry, 1960

Diverging/Sequential Scheme

Percent of labor force employed in industry, 1980

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

Gray’s Anatomy of the Human Body

Map of Point Reyes

www.bartleby.com/107/illus520.html

www.nps.gov
ThemeView (original)

Courtesy of Pacific Northwest National Laboratories
ThemeScape (commercial)

[Image description]

**Topics:**
- Golan
- Peace
- Israeli
- Syria
- Israel

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

**Courtesy of Cartia**
Visualization of isoelectron density surfaces around molecules

Marc Levoy (1988)
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

- Helvetica-plain

[Color usage diagram with RGB values: R: 0, G: 0, B: 0, R: 0, G: 31, B: 0, R: 0, G: 63, B: 0, R: 0, G: 95, B: 0, R: 0, G: 127, B: 0, R: 0, G: 159, B: 0, R: 0, G: 191, B: 0, R: 0, G: 223, B: 0, R: 0, G: 255, B: 0]

[Color usage website: colorusage.arc.nasa.gov]
Legibility

Drop Shadows

Drop Shadow

Drop shadow adds edge

Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white
Primary colors on white

Primary colors on black
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Primary colors on black
If you can’t use color wisely, it is best to avoid it entirely.
Above all, do no harm.

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 of contrast and layering]

[Source: colorusage.arc.nasa.gov]
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 colours and use variations within 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
# Tableau™ Colors

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<td>text</td>
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</tr>
<tr>
<td>Red</td>
<td>text</td>
<td>text</td>
<td>text</td>
<td>text</td>
</tr>
<tr>
<td>Purple</td>
<td></td>
<td></td>
<td>text</td>
<td>text</td>
</tr>
<tr>
<td>Brown</td>
<td></td>
<td></td>
<td></td>
<td>text</td>
</tr>
<tr>
<td>Pink</td>
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<td></td>
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</tr>
<tr>
<td>Gray</td>
<td></td>
<td></td>
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<td>text</td>
</tr>
<tr>
<td>Gold</td>
<td>text</td>
<td>text</td>
<td>text</td>
<td>text</td>
</tr>
<tr>
<td>Teal</td>
<td></td>
<td></td>
<td></td>
<td>text</td>
</tr>
</tbody>
</table>
Maximum hue separation
Analogous, yet distinct

SUM(Sales Total)

Sunday  Monday  Tuesday  Wednesday

Q1  Q2  Q3  Q4

2004
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.
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