Designing Colors for Data

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“Color is the most relative medium in art.”
—Josef Albers, Interaction of Color

“Good painting, good coloring, is comparable to
good cooking. Even a good cooking recipe
demands tasting and repeated tasting while it is
being followed. And the best tasting still
depends on a cook with taste.”
—Josef Albers

Successful Recipes

“You can think of an RGB or CMYK file as
containing, not color, but rather a recipe for color
that each device interprets according to its own
capabilities. If you give 20 cooks the same
recipe, you’ll almost certainly get 20 slightly
different dishes as a result”

Recipe 1

bananas
sugar
egg
butter
baking soda
baking powder
salt
flour
Bake

What is it?
Could you make it?

Real World Color Management
B. Fraser, C. Murphy, & F. Bunting
Recipe 2

<table>
<thead>
<tr>
<th>3 bananas</th>
<th>1/3 sugar</th>
<th>1 egg</th>
<th>1/3 butter</th>
<th>1 baking soda</th>
<th>1 baking powder</th>
<th>1/4 salt</th>
<th>1 1/2 flour</th>
</tr>
</thead>
</table>

Bake at 375 for 15

Banana Muffins

<table>
<thead>
<tr>
<th>3 bananas</th>
<th>1/3 c sugar</th>
<th>1 egg</th>
<th>1/3 c butter</th>
<th>1 t baking soda</th>
<th>1 t baking powder</th>
<th>1/4 t salt</th>
<th>1 1/2 c flour</th>
</tr>
</thead>
</table>

Bake at 375°F for 15 minutes

RGB to XYZ to xy

Mash bananas
Melt butter
Combine bananas, sugar, egg, butter
Combine dry ingredients
Add dry to wet, stir until just mixed
Spoon into muffin tins

Banana Muffins

Display Gamuts

Projector Gamuts
Computational Aesthetics
Alberta, Canada

Pixel to Intensity Mapping (“gamma curve”)

White point changes
Change relative amounts of R, G, B

Fundamental Uses
To label (identify or group)
To measure (color to quantity, color scales)
To represent or to imitate reality
To enliven or decorate

The problem
Design color for Tableau Software
“Visual Analysis for Everyday Data”

Goals
- Aesthetic “business graphics”
- Robust across displays and users
- UI encourages good practice, but allows choice

Commercial design task

Color design tasks
Categorical color palettes + UI
- Color as label
- Distinctly different, similar visual weight
- Scatter plots, line graphs, bar charts, text

Quantitative color palettes + UI
- Color as quantity
- Sequential and diverging scales
- Heat maps, scatter plots (but could be any above)

Formatting colors + UI
- Color to decorate (also group and label)
- Row, column and header shading
- Annotations (lines and text)

"... avoiding catastrophe becomes the first principle in bringing color to information: Above all, do no harm.” —E. R. Tufte
Global Issues
Subtlety vs. robustness
What can we assume about the display?
Not calibrated (except mine)
Clarity vs. expressiveness
How many colors?
What about the "color blind?"
Simplicity vs. power in the UI
Optimized for good practice
Data-to-color control, not color control

UI Design Process
Collaboration with Tableau implementers
• Meetings
• Design sketches
• Memos
Tableau developers did the implementation
• Jock Mackinlay, Andrew Beers, Chris Stolte, Iain Heath, Craig Hobbs
• Windows, C++
Key UI concepts
• Not editing colors, but defining data-to-color mapping
• Users are not experienced visual designers
• But may care very much about their colors

Color Design Process
Design on my calibrated (sRGB) display
Deliver RGB triples to client
Tools
• Photoshop
• Illustrator
• Visio
• Python
• Excel
• Tableau
Color spaces
• CIELAB
• HSB
• RGB

Roadmap
A bit on color spaces
Discuss each color task
For each
• Issues, process
• Solution, discussion
• Tableau visualization & UI demo
Color Vision Deficiencies ("color blindness")
Questions

"Perceptual" Color Spaces
Hue
• Color's "name"
• Angular scale
Lightness (brightness)
• Linear scale
Chroma (saturation)
• Intensity or purity
• Radial scale
Relative to white & black

RGB to XYZ to xy
Color Design Terminology

Hue (color wheel)
- Opposites complement (contrast)
- Adjacent are analogous
- Many different color wheels*
  *See 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

Wucius Wong, Principles of Color Design

Psuedo-Perceptual Models

HLS, HSV (HSB)
NOT perceptually accurate
Simple renotation of RGB
- View along gray axis
- See a hue hexagon
- L or V is grayscale pixel value
L & V do NOT predict perceived lightness

Get it right in black & white

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

Value difference (contrast)
- Defines legibility
- Controls attention
- Creates layering

CIELAB Space

Categorical Colors Issues

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
UI to encourage good practice
- But, must allow for personal expression
Questions
- What are parameters for legibility?
- Can we adapt color to size?
- Richness vs. clarity

Categorical Colors
- 10 basic colors
  - Simple names
  - Increase number with lightness variation
- Designed to balance
  - Legibly colored dots, lines and text
  - But not too gaudy for bars
  - Tasteful, yet colorful

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

Task and style
**Color Names**

Basic names (Berlin & Kay)
- Linguistic study of names across 20 languages
- Found 11 basic names, similar linguistic evolution
  - Black, white, gray
  - Red, green, blue, yellow
  - Orange, purple, brown, pink

Controversy about original hypothesis
Recent work by Kay et. al.
- Redefines as constraints, modulated by language
- World Color Survey

Recommended by Ware for labels

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**Tableau names**

Basic names (11)
- Black, white, gray
- Red, green, blue, yellow
- Orange, purple, brown, pink

Tableau names (10)
- Minus black & white
- Plus teal
- Yellow => gold

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**Tableau Visualization**

![Tableau Visualization](image)

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**Quantitative Color Issues**

Color sequences
- What colors, what sequences?
- Continuous or quantized? (and how?)
- Work at all sizes, and in isolation

Real numeric data
- All distributions, including outliers
- Can't visualize the histogram

UI to encourage good practice
- UI must be simple, not intimidating
- Users not expert in color or statistics

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**Types of Scales**

![Types of Scales](image)

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**Data Distribution**

![Data Distribution](image)
Proportional Distribution

Skewed Data

Slightly negative

www.tableausoftware.com

Full Range

Skewed Data

Stepped

Skewed Data

Threshold

Skewed Data

Color Brewer

www.colorbrewer.org

Ramp Design

Start with Brewer ramps
- Available as RGB
- Not calibrated

Modify
- For sRGB
- Eliminate darkest colors
- Reduce hue shift

Interpolate
- Custom Python code
- CIELAB, RGB
- Piecewise linear

From ColorBrewer
**Visualizing Ramps**

**Formatting Colors**

**Formatting Color Issues**

- Taste and style
  - Aesthetic, professional
  - Lots of choices
- Shading colors
  - How light can we go?
  - Visibility in the UI
- Annotation colors
  - Text legibility
  - Relationship to shading colors
- Limited space and time for UI implementation

**UI Evolution**
Expanded Palette

Visualize in Tableau

Color Vision Deficiencies (CVD)

Non-standard cone (SML) response
- Genetic
- Medical
- Mild to missing

Three modes
- L-weak (protanope)
- M-weak (deuteranope)
- S-weak (tritanope)

Modeled in opponent space
- Achromatic axis
- R-G and Y-B axis
### Incidence of CVD

- Monochromacy - 0.003%
- Dichromacy
  - Protanopia 1%
  - Deuteranopia 1.1%
  - Tritanopia 0.002%
- Anomalous trichromacy
  - Protanomaly 1%
  - Deuteranomaly 4.9%
  - Tritanomaly -
- Total - 8.005%


### Vischeck

Simulates dichromatic color vision deficiencies
- Web service or Photoshop plug-in
- Robert Dougherty and Alex Wade
  - [www.vischeck.com](http://www.vischeck.com)

### Genes in Vischeck

- Deuteranope
- Protanope
- Tritanope

### 2D Color Space

- Normal
- Protanope
- Deuteranope
- Tritanope
Similar Colors

<table>
<thead>
<tr>
<th>Protanope</th>
<th>Deuteranope</th>
<th>Luminance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Green</td>
<td>Blue</td>
</tr>
<tr>
<td>Orange</td>
<td>Yellow</td>
<td>Brown</td>
</tr>
</tbody>
</table>

Accommodation

No color set that works for all viewers
Even accommodating most common is limiting

Options:
- Minimize dependency on color
- Double encode
- Provide choices/customization

But the diagramatic maps of muscles in our illustrated anatomies are not "transcripts" of things seen, but the work of trained observers who build up the pictures of a specimen that has been revealed to them in years of patient study.

From Art and Illusion, E.H. Gombrich