What makes colour effective?

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

- Effective colour needs a context
  - Immediate vs. studied
  - Anyone vs. specialist
  - Critical vs. contextual
  - Culture and expectations
  - Time and money
Why Should You Care?

- Poorly designed colour 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
- Colour is a key component
  - Colour labels and groups
  - Colour scales (colourmaps)
  - Multi-variate colour encoding
  - Colour shading and textures
  - And more...

www.nps.gov
“Color” includes Gray

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

Colour Design

• Goals
  – Highlight, emphasize
  – Create regions, group
  – Illustrate depth, shape
  – Evoke nature
  – Decorate, make beautiful

• Colour harmony
  "...successful color combinations, whether these please the eye by using analogous colors, or excite the eye with contrasts."
  –Principles of Color Design, by Wucius Wong
Colour Design Terminology

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

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

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

*TSee www.handprint.com for examples

Tints and Tones

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

- Tint
  - Hue + white
  - Decrease saturation
  - Increase lightness
**Colour**

Hi-Key/Low Key Colours
- choosing a value range
- another way to unify

Hi-Key colour schemes
- **tints** of colours (paler)
  - bright, cheerful.
Low-Key colour scheme.
- **Shades (tones)** of colours (darker)
  - subdued gloomy mysterious

---

**Colour Triads**

- color scheme composed of three colours spaced equally apart on the colour wheel
- tend to be uncomfortable
- good visual distinction
- Primary colours form one triad
  - (red, blue, yellow).
- Secondary colours
  - (orange, green, purple)
Maximum hue separation

**Analogous Colours**
- colours next to each other on the colour wheel with a common hue
- the common hue creates a feeling of unity in the design
Analogous, yet distinct

Colour

Complementary Colors

– Complementary colors are opposite each other on the color wheel
– Two pure complementary hues placed next to each other attract attention
Colour

Split Complements
• two colors on either side of its complement are used together.
• similar to complementary colors
• offers a little more variety to work with

Colour

Warm and Cool Colours
• two specific sets of analogous colours.
  Cool
  – blue, green and purple
  – cold, icy feeling
  Warm
  – red, orange and yellow
  – warm, sunny feeling.
When used together
  – cool colours seem to move away
  – warm colours move towards
Colour

Monochromatic Colors
– shades, tints and tones of only one color.
– causes an immediate unifying or harmonious effect.
– all parts of the design have something in common,
– pulls it all together.

Sequential

Sequential
Colouring categorical data

– limited number readily distinct (spatially separate colour patches)
– think about selection, association, and adjacent distinction
– Ware’s maximally discriminable colours
**Colour Design Principles**

- Control value (lightness)
  - Ensure legibility
  - Avoid unwanted emphasis
- Use a limited hue palette
  - Control colour “pop out”
  - Define colour grouping
  - Avoid clutter from too many competing colours
- Use neutral backgrounds
  - Control impact of colour
  - 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](http://www.edwardtufte.com)
Fundamental Uses

• To label
• To measure
• To represent or to imitate reality
• To enliven or decorate
Colour | Cross-cultural naming

Appearance of colour names in languages around the world (Berlin and Kay 1969)

Colour | Opponent Process Theory - continued

Many lines of scientific evidence worth examining

- Naming
- Cross-Cultural naming
- Unique Hues
- Neurophysiology
- Categorical colours
Color Names

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

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 Colour Survey (Kay & Cook)
  - http://www.icsi.berkeley.edu/wcs/

Identify by Color

Information Visualization
Colin Ware
Product Categories

Categorizing data by colour

22 colours, only ~8 distinguishable
Grouping, Highlighting

Considerations for Labels

• How critical is the colour 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 colours?

• 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?

Psychophysics of Labeling

- Preattentive, “pop out”

<table>
<thead>
<tr>
<th>Time proportional to the number of digits</th>
<th>Time proportional to the number of 7’s</th>
<th>Both 3’s and 7’s “Pop out”</th>
</tr>
</thead>
<tbody>
<tr>
<td>13579345978274055</td>
<td>24937916478254137</td>
<td>13579345978274055</td>
</tr>
<tr>
<td>24937916478254137</td>
<td>23876597277103866</td>
<td>24937916478254137</td>
</tr>
<tr>
<td>23876597277103866</td>
<td>19874367259047362</td>
<td>23876597277103866</td>
</tr>
<tr>
<td>19874367259047362</td>
<td>95637283649105676</td>
<td>19874367259047362</td>
</tr>
<tr>
<td>95637283649105676</td>
<td>32543787954836754</td>
<td>95637283649105676</td>
</tr>
<tr>
<td>32543787954836754</td>
<td>56840378465485690</td>
<td>32543787954836754</td>
</tr>
<tr>
<td>56840378465485690</td>
<td></td>
<td>56840378465485690</td>
</tr>
</tbody>
</table>
Contrast Creates Pop-out

- **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
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

Colour scales (maps)

Rainbow (hue)
- No ordering
- Good name space

Greyscale/luminance/saturation
- ordered

Hue trajectory

Luminance trajectory

Saturation trajectory

Rainbow scale
- No ordering - Good name space (green part, yellow part ....)
- Jet engine noise simulation


Two-Hue scale
- Easier to see small variations

Heat scale

- Ordering? (Surface Magnetic Field)

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. [Winfree, 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

US Census Map

Brewer’s Categories

Colour Brewer

Cynthia Brewer, Pennsylvania State University

www.colorbrewer.org
Colour and Shading

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

CT image (defines shape)  PET color highlights tumor

Image courtesy of Siemens

Colour Overlay (Temperature)

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

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

Multi-dimensional Scatter plot

• Variable 1, 2 $\rightarrow$ X, Y
• Variable 3, 4, 5 $\rightarrow$ R, G, B

Do people interpret colour blends as sums of variables?

Using Color Dimensions to Display Data Dimensions
Beatty and Ware
Colour 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

http://www.colorbrewer.org
Brewer Examples

To Represent or Imitate Reality
Illustrative Color

Gray’s Anatomy of the Human Body
www.bartleby.com/107/illus520.html

Map of Point Reyes
www.nps.gov

ThemeView (original)

Courtesy of Pacific Northwest National Laboratories
ThemeScape (commercial)

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

Drop Shadows

Drop Shadow

Drop shadow adds edge
Readability

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?

Google™
Value Control

Legibility and Contrast

- **Legibility**
  - Function of contrast and spatial frequency
  - “Psychophysics of Reading” Legge, et al.
- **Legibility standards**
  - 5:1 contrast for legibility (ISO standard)
  - 3:1 minimum legibility
  - 10:1 recommended for small text
- **How do we specify contrast?**
  - Ratios of foreground to background luminance
  - Different specifications for different patterns
Contrast and Layering

- Value contrast creates layering

What Defines Layering?

- Perceptual features
  - Contrast (especially lightness)
  - Color, shape and texture
- Task and attention
  - Attention affects perception
- Display characteristics
  - Brightness, contrast, “gamma”

Source: colorusage.arc.nasa.gov
Grid Example

Grid sits unobtrusively in the background

Grid sits in foreground, obscuring map

Great Grids: How and Why? (APGV06 and SIGGRAPH poster)
Maureen Stone, Lyn Bartram and Diane Gromala

Additional Resources

• Maureen Stone’s website
  – http://www.stonesc.com/Vis06

• A Field Guide to Digital Color
  – A.K. Peters