CPSC 583
Colour

Sheelagh Carpendale

References

Effective Colour

Aesthetics

Perception

Materials

Illustrators, cartographers
Artists, designers
A few scientific principles
From: M. Stone

What is Colour?

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
From: M. Stone
Physical World

- Spectral Distribution
  - Visible light
  - Power vs. wavelength
- Any source
  - Direct
  - Transmitted
  - Reflected
  - Refracted

Colour

The Retina

**photoreceptors**: rods and cones

**neurons** (receptive fields): intermediate neural layers – image processing

http://school.discovery.com/homeworkhelp/worldbook/atopictures/600108.html
http://www.ccrs.nrcan.gc.ca/ccrs/eduref/sradar/chap2/chp2e_g5e.html
Cone Response

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


Effects of Retinal Encoding

All spectra that stimulate the same cone response are indistinguishable

Metamer match

- [PDF] Elements of Color Perception - Metamerism

Chromaticity Diagram

The corners of this triangle is approximately where the phosphors of a typical color monitor plot.
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

Opponent Colour

- 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”
Colour Blindness

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

• www.vischeck.com

http://www.vischeck.com/examples/

Colour Blindness

normal
protanope
deuteranope
tritanope
colorvisiontesting.com
Genes in Vischeck

2D Colour Space
Colour Blindness

small-field tritanopia

**Colour Addition**
- computer monitors
- red, green, and blue
- absence all three colors gives black,
- all three gives white.

**Colour Subtraction**
- printers ink
- cyan, magenta, and yellow
- absence all three colors gives white,
- all three gives black.
Colour Paint

Perceptual Color Spaces

Unique black and white
Uniform differences
Perception & design

Lightness

Colorfulness

Hue
Color Appearance

- colour constancy
- colour perception
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
Bezold Effect

http://web.missouri.edu/~hoarda/colortheory/Syllabus/Projects/Bezold_Effect/bezold_effect.html

http://web.missouri.edu/~hoarda/colortheory/Syllabus/Projects/Bezold_Effect/bezold_effect.html

http://www.sapdesignguild.org/resources/optical_illusions/contrast_phenomena.html

Checker-shadow illusion: The squares marked A and B are the same shade of gray.

Edward H. Adelson
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
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…

“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*
• *See www.handprint.com for examples
• Chroma (saturation)
  – Intensity or purity
  – Distance from gray
• Value (lightness)
  – Dark to light
  – Applies to all colours, not just gray
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
Gradations

Colour

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

Colour

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

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
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
Fundamental Uses

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

To Label
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
Product Categories

Categorizing data by colour

The Internet: 2002
Categorizing data by colour

The Internet: 2002

22 colours, only ~8 distinguishable

### Grouping, Highlighting

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<th>Z</th>
<th>X</th>
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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”

Time proportional to the number of digits
13579345978274055
24937916478254137
23876597277103866
19874367259047362
95637283649105676
3254378954836754
56840378465485690

Time proportional to the number of 7’s
13579345978274055
24937916478254137
23876597277103866
19874367259047362
95637283649105676
3254378954836754
56840378465485690

Both 3’s and 7’s
“Pop out”

Contrast Creates Pop-out

Hue and lightness
Lightness only
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

To Measure
Heat maps

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

Cynthia Brewer, Pennsylvania State University
Colour Brewer

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
Multivariate Colour Sequences

Multi-dimensional Scatter plot

- Variable 1, 2 → X, Y
- Variable 3, 4, 5 → 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
Which has more information? Which would you rather look at?

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

<table>
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<th>R</th>
<th>G</th>
<th>B</th>
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<td>0</td>
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<td>255</td>
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</table>

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

Legibility
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?
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”
Grid Example

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](http://www.stonesc.com/Vis06)

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