Color Design for Effective Visualization

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Outline

• What is color?
• Design Guidelines
  ▪ By Physics of Color Vision
  ▪ By Color Perception
  ▪ By Display Device
• Principles of Color Design
• Design Rules for Information Visualization
• Conclusion
What is color?

- **Physics:**
  - Spectrum of light (electromagnetic waves) in the visible range of 380-700 nm of wavelength
  - Different colors correspond to different *wavelengths*
  - Intensity of each wavelength specified by *amplitude*

- **Visual Perception:**
  - What we “see”: A function of light sources, surfaces, sensor response functions, and viewing geometry.
What is color?

- Gamma rays: 10^{-3} nm
- X-rays: 10^{-1} nm
- Ultraviolet: 10^{1} nm
- Visible Spectrum:
  - Blue: 436 nm
  - Green: 546 nm
  - Red: 700 nm
- Infrared: 10^{3} nm
- Radio waves: 10^{8-13} nm

Amplitude

Wavelength $\lambda$

UV | Visible | IR
What is color?

• Physics:
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  – Different colors correspond to different wavelengths
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What is color?
What is color?
Color Spaces

• The human vision in trichromatic
  – Three classes of photo-sensitive receptors (cone cells) for short (S), middle (M), and long (L) wavelengths (within the range of 380-700 nm)
    => three parameters (tristimulus values) describe a color sensation.

• Any specific method for associating tristimulus values with each color is called a color space model:
  – RGB (Display technologies)
  – CYM (Printing technologies)
  – HSV/HSI
  – HSL/HSB
  – CIE XYZ, CIE LUV, ...(human perception)
Spectral sensitivities of 3 classes of cone cells in human retina
RGB/CYM cube model
HSL color space model
Color Vision: Design Guidelines

• Color–Depth effect: Avoid juxtaposing strong blue and strong red in a display to prevent unwanted depth effects

• After-image effect: Avoid large areas of bright color in a display to prevent visual stress

• Relative luminance of colors:
  – blue text on a black background
  – yellow text on a white background,…

• Color-deficient viewer: Do not use hue alone to encode information in a display
After-image effect
Color Perception: Design Guidelines

• Simultaneous contrast effect: same colors look different, different colors look the same
  – Animated examples: http://www.purveslab.net/seeforyourself/index.html
  – Surrounding colors, field size, and viewing condition can each change the perceived color in human eye/brain
    ⇒ Where accurate judgment of a color is required, use neutral mid-gray for the surrounding color.
    ⇒ Use perceptual color spaces such as HSL, or HSV to describe a color more meaningfully

• Memory colors:
  – Is sky as blue as we think
Color Perception: Design Guidelines

The same colors look different

Different colors look the same
Color Perception: Design Guidelines

• Simultaneous contrast effect: same colors look different, different colors look the same
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• Memory colors:
  – Is sky as blue as we think?
Color of the sky

J. Parkkinen and P. Silfsten
Display Device Matters!

- The color gamuts:

- Use device-independent perceptual color models based on CIE uniform color spaces (CIELAB, CIE uniform)
Color Design Principles

• Get it right in black and white, then add color considering:
  – Application
  – User needs
  – Gestalt laws: association or differentiation
  – Common color associations: positive, negative
  – Color intent: functional, decorative

• Choose harmonious palette of colors for use throughout an application for consistency

• Use common thematic color(s) for each design (unifying attribute)
Common Color Association: An Example

<table>
<thead>
<tr>
<th>Color</th>
<th>Positive Associations</th>
<th>Negative Associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Passion, strength, energy, heat, love</td>
<td>Blood, war, fire, danger, anger, aggression</td>
</tr>
<tr>
<td>Green</td>
<td>Nature, spring, fertility, safety, environment</td>
<td>Inexperience, decay, envy, misfortune</td>
</tr>
<tr>
<td>Yellow</td>
<td>Sun, summer, gold, harvest, optimism</td>
<td>Cowardice, treason, hazard, illness, folly</td>
</tr>
<tr>
<td>Blue</td>
<td>Sky, sea, stability, peace, unity, depth</td>
<td>Depression, obscenity, conservatism, passivity</td>
</tr>
<tr>
<td>White</td>
<td>Snow, purity, peace, cleanliness, innocence</td>
<td>Cold, clinical, surrender, sterility, death, banality</td>
</tr>
<tr>
<td>Gray</td>
<td>Intelligence, dignity, restraint, maturity</td>
<td>Shadow, concrete, drabness, boredom</td>
</tr>
<tr>
<td>Black</td>
<td>Coal, power, formality, depth, solidity, style</td>
<td>Fear, void, night, secrecy, evil, anonymity</td>
</tr>
</tbody>
</table>
Color Design in GUI

In design of GUI components such as window frames, sliders, buttons, icons, and dialogue boxes:

- Design it in monochrome and then **add color** very discretely and consistently (throughout an application) **only where it enhances usability**
- Use a limited palette of colors preferably with predefined harmonious combinations
- Use strong colors only in small regions (up to 2mm in diameter)
Color Design in Advertising

• Las Vegas effect:
  – Use bright and highly saturated colors to grab attention
  – Period of viewer’s engagement: less than 1 minute
Color Design in Advertising

• Color psychology

• Browser safe palette
  • A subset of 216 (out of 256) colors
  • de facto standard for encoding color graphics and images for web display
Color Design in Text

• Legibility, Legibility, Legibility
  – Color either text or background, not both
  – Provide adequate contrast based on Relative luminance table:
    – Min contrast ratio: 3:1
    – Preferred contrast ratio: 10:1
  – Use highlighter to draw attention where needed
Relative luminance of colors

<table>
<thead>
<tr>
<th>Color</th>
<th>Primaries</th>
<th>Relative luminance (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>R G B</td>
<td>100</td>
</tr>
<tr>
<td>Yellow</td>
<td>R G</td>
<td>90</td>
</tr>
<tr>
<td>Cyan</td>
<td>G B</td>
<td>70</td>
</tr>
<tr>
<td>Green</td>
<td>G</td>
<td>60</td>
</tr>
<tr>
<td>Magenta</td>
<td>R B</td>
<td>40</td>
</tr>
<tr>
<td>Red</td>
<td>R</td>
<td>30</td>
</tr>
<tr>
<td>Blue</td>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>Black</td>
<td>—</td>
<td>0</td>
</tr>
</tbody>
</table>
Color Design in Images

- **Objective:** to portray a real-world scene, object, or product as realistically as possible:
  - **Examples of Applications:**
    - photo libraries/browsers, product catalogues, computer graphics modeling and rendering techniques, computer animation

- **Golden rules:**
  - Neutral gray backgrounds
  - A narrow (3-6 mm) white border around an image for more accurate visual perception
  - Absence of bright color graphics in surrounding areas
Color Design in Information and Scientific Visualization

- Golden Rule: Do not use color if it does not add to the meaning of the information displayed
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  – Nominal color coding
    • Limit the number of colors to 7 or less
Color Design in Information and Scientific Visualization

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  - Nominal color coding
    - Limit the number of colors to 7 or less
  - Ordinal/bivariate color coding
    - Use natural or application-related association
Color Design in Information and Scientific Visualization

• Golden Rule: Do not use color if it does not add to the meaning of the information displayed
  
  – Nominal color coding
    • Limit the number of colors to 7 or less
  – Ordinal color coding
    • Use natural or application-related association
  – Layering effect
    • Use color saturation to depict depth or priority of the object
Standard Palettes of Colors

• Bright, dark palette → for highlighting data
  
• Medium shades palette → for grouping items
  
• Light, pale palette → for non-informative parts of display and to de-emphasize
Standard Palettes of Colors

- Sequential palette: Single hue and vary intensity from pale colors for low values to increasingly darker and brighter colors for high values.
Grouping Items

• Work well for bars
Grouping Items

- Does not work for small data points
Grouping Items

• Thicken the lines or enlarge the data points
Heatmap
<table>
<thead>
<tr>
<th>State</th>
<th>Laptops</th>
<th>Desktop PCs</th>
<th>Harddisks</th>
<th>Flash Memory</th>
<th>Screens</th>
<th>Keyboards</th>
<th>Printers</th>
<th>Scanners</th>
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<tbody>
<tr>
<td>California</td>
<td>-2,216</td>
<td>4,497</td>
<td>884</td>
<td>3,252</td>
<td>8,564</td>
<td>3,418</td>
<td>6,582</td>
<td>-3,891</td>
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<td>Colorado</td>
<td>3,410</td>
<td>0</td>
<td>2,338</td>
<td>2,676</td>
<td>1,567</td>
<td>367</td>
<td>1,361</td>
<td>3,249</td>
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<tr>
<td>Connecticut</td>
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<td>0</td>
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<td>2,998</td>
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<td>673</td>
<td>0</td>
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<tr>
<td>Florida</td>
<td>0</td>
<td>0</td>
<td>583</td>
<td>765</td>
<td>2,305</td>
<td>940</td>
<td>1,737</td>
<td>2,727</td>
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<tr>
<td>Illinois</td>
<td>0</td>
<td>0</td>
<td>9,384</td>
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<td>4,362</td>
<td>2,331</td>
<td>4,495</td>
<td>3,464</td>
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<tr>
<td>Iowa</td>
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<td>6,577</td>
<td>210</td>
<td>4,487</td>
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<td>Louisiana</td>
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<td>2</td>
<td>1,455</td>
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<tr>
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<td>986</td>
<td>367</td>
<td>1,011</td>
<td>1,125</td>
</tr>
<tr>
<td>Nevada</td>
<td>0</td>
<td>0</td>
<td>875</td>
<td>374</td>
<td>884</td>
<td>45</td>
<td>11,934</td>
<td>410</td>
</tr>
<tr>
<td>New Hampshire</td>
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<td>0</td>
<td>-166</td>
<td>0</td>
<td>897</td>
<td>376</td>
<td>0</td>
<td>0</td>
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<tr>
<td>New Mexico</td>
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<tr>
<td>New York</td>
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<tr>
<td>Ohio</td>
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<td>700</td>
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<tr>
<td>Oregon</td>
<td>-139</td>
<td>357</td>
<td>818</td>
<td>708</td>
<td>395</td>
<td>487</td>
<td>2,671</td>
<td>834</td>
</tr>
<tr>
<td>Texas</td>
<td>0</td>
<td>1,356</td>
<td>3,415</td>
<td>808</td>
<td>5,452</td>
<td>0</td>
<td>2,336</td>
<td>1,567</td>
</tr>
<tr>
<td>Utah</td>
<td>1,130</td>
<td>1,006</td>
<td>1,501</td>
<td>1,009</td>
<td>678</td>
<td>-156</td>
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<td>979</td>
</tr>
<tr>
<td>Washington</td>
<td>0</td>
<td>768</td>
<td>488</td>
<td>2,998</td>
<td>1,661</td>
<td>1,452</td>
<td>1,418</td>
<td>564</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>497</td>
<td>0</td>
<td>1,418</td>
<td>1,450</td>
<td>576</td>
<td>916</td>
<td>767</td>
<td>1,740</td>
</tr>
</tbody>
</table>
Demo

Color Brewer

www.colorbrewer.org

Cynthia Brewer (Penn State University)
Non-data Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Default color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axis lines</td>
<td>Thin gray lines of medium intensity</td>
</tr>
<tr>
<td>Borders</td>
<td>Thin gray lines of medium intensity</td>
</tr>
<tr>
<td>Background</td>
<td>White (“None” color in Excel)</td>
</tr>
</tbody>
</table>
# Data Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Default color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bars</td>
<td>Distinct hue of medium intensity for each data series</td>
</tr>
<tr>
<td>Lines and data points</td>
<td>Thin and small: a distinct hue of fairly high intensity</td>
</tr>
<tr>
<td></td>
<td>Otherwise: distinct hues of medium intensity.</td>
</tr>
</tbody>
</table>
Conclusion

• Design the screen layout considering all available visual variables.

• Use color sparingly, never more than necessary.

• Take account of human visual needs and expectations.

• Conform to the color conventions for the application.

• Be consistent in the use of color throughout all screens in an application.