Information Visualization
Color

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Lecture 12/13, 13 & 25 Feb 2020

https://www.students.cs.ubc.ca/~cs-436v/20Jan/
Upcoming

- Foundations 4: out Feb 13, due Feb 26 (right after reading week)
- Programming 3: out Feb 13, due Mar 4 (1 week after reading week)
- D3 videos/readings week 6
  - Color and Size legends with D3.js [30 min]
  - Scatter Plot with Menus [46 min]
  - Circles on a Map [42 min]
  - Line Charts with Multiple Lines [42 min]
- Quiz 6, due by Fri Feb 14, 8am
- Team formation, due by Fri Feb 14 11:59pm
Outline

• Color in vision theory
• Color channels in vis
  – Decomposition
    • HSL
    • Other color spaces
  – Color deficiency
  – Interaction with others
• Practical advice
  – Colormaps
  – Tools and programming libraries
Channels: the big picture

**Magnitude Channels: Ordered Attributes**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

**Identity Channels: Categorical Attributes**
- Spatial region
- Color hue
- Motion
- Shape

Expressiveness Types And Effectiveness Ranks
Best

Effectiveness
Least
Color in Vision Theory
Light

If I tell you the wavelength, can you tell what color you are seeing?
Eye anatomy
Cone and Rod Cells on Retina

~120 million rods: black vs. white
~5-6 million cones: color

R 63% - G 31% - B 6%
Opponent process

- perceptual processing before optic nerve
  - one achromatic luminance channel ($L^*$)
  - edge detection through luminance contrast
  - 2 chroma channels
  - red-green ($a^*$) & yellow-blue axis ($b^*$)

If I tell you the wavelength, can you tell what color you are seeing?

Color != Wavelength
Color Appearance

• Given L, a, b, can we tell what color it is?
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann
Contrast with background
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJUQB
https://en.wikipedia.org/wiki/The_dress
Bezold Effect: Outlines matter

Color Appearance

• Given L, a, b, can we tell what color it is?

• Chromatic adaptation
• Luminance adaptation
• Simultaneous contrast
• Spatial effects
• Viewing angle
• …
Cognition (beyond retina, in brain)

• Given the L, a, b values, the lighting conditions, the surroundings, viewing angle ...

• Can you tell me what this color is?
  • Middle part of an apple
  • Bottom part of an apple
  • The branch
Name the colours

https://blog.xkcd.com/2010/05/03/color-survey-results/
Name the colours

http://www.thedoghousediaries.com/1406
Name the colours

*Actual* color names if you’re a girl ... *Actual* color names if you’re a guy ...

https://blog.xkcd.com/2010/05/03/color-survey-results/
Color is just part of vision system

- Does not help perceive
  - Position
  - Shape
  - Motion
  - …
Color Channels in Visualization
Decomposing color

• first rule of color: do not **JUST** talk about color!
  – color is confusing if treated as monolithic
HSL decomposition

• decompose into three channels
  – ordered can show magnitude
    • **luminance:** how bright
    • **saturation:** how colourful
  – categorical can show identity
    • **hue:** what color

• channels have different properties
  – what they convey directly to perceptual system
  – how much they can convey: how many discriminable bins can we use?
Quiz: Which color channels?

- Continuous quantitative attribute
Categorical vs ordered color

Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights

[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]
Categorical color: limited number of discriminable bins

Ordered color: Rainbow is poor default

• problems
  – perceptually unordered
  – perceptually nonlinear

• benefits
  – fine-grained structure visible
    and nameable
Ordered color: Rainbow is poor default

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• alternatives
  – large-scale structure: fewer hues
Ordered color: Rainbow is poor default

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• alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
Viridis

• colorful, perceptually uniform, colorblind-safe, monotonically increasing luminance

https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html
Ordered color: Rainbow is poor default

• problems
  – perceptually unordered
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• benefits
  – fine-grained structure visible and nameable

• alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
  – segmented rainbows for binned or categorical
Ordered color: how many bins?
Many color spaces

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance or L*
- Luminance, hue, saturation
  - good for encoding
  - but not standard graphics/tools colorspace
- CIE L*a*b*: good for computation
  - L*: intuitive: perceptually linear luminance
  - a*b* axes: perceptually linear but nonintuitive
- RGB: good for display hardware
  - poor for encoding
Opponent color and color deficiency

• perceptual processing before optic nerve
  – one achromatic luminance channel (L*)
  – edge detection through luminance contrast
  – 2 chroma channels
    – red-green (a*) & yellow-blue axis (b*)

• “color blind”: one axis has degraded acuity
  – 8% of men are red/green color deficient
  – blue/yellow is rare

Designing for color deficiency: Check with simulator

Normal vision  Deuteranope  Protanope  Tritanope

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape

Deuteranope simulation

Change the shape
Vary luminance

Color deficiency: Reduces color to 2 dimensions

Normal

Protanope

Deuteranope

Tritanope

Designing for color deficiency: Blue-Orange is safe
Interaction with the background

Marks with high luminance on a background with high luminance
Interaction with the background

Marks with high luminance on a background with low luminance
Interaction with the background

Contrast
The difference between foreground and background colors determines text legibility.
Interaction with other channels

• color channel interactions
  – size heavily affects salience
  – small regions need high saturation
  – large need low saturation
• saturation & luminance: 3-4 bins max
  – also not separable from transparency
How to use color in visualization
Color maps

- Categorical
  - Binary
  - Categorical

- Ordered
  - Sequential
  - Diverging

- Diverging

Colormaps

- Categorical
  - Binary
  - Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

Colormaps

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

use with care!

Colormaps

→ Categorical

→ Ordered
  → Sequential

→ Bivariate

→ Diverging

Tools and Libraries in Practice
ColorBrewer

- http://www.colorbrewer2.org
- saturation and area example: size affects salience!
- Limited customization: 2 parameters
Adobe Color Picker

- https://color.adobe.com/create
- For general design purpose, not particularly for vis
Colorgorical

- [http://vrl.cs.brown.edu/color](http://vrl.cs.brown.edu/color)
- Highly customized: #colors, perceptual distance, name uniqueness, hue, lightness range…
- Only targeted at categorical data
Color management in D3

• D3-color
  – https://github.com/d3/d3-color
  – Conversion to/from different color spaces
  – Low-level computations

• D3-scale
  – https://github.com/d3/d3-scale
  – Customize your own color scale using d3.scaleSequential() and d3.scaleOrdinal()
  – Use case: generate color schemes using the web tools mentioned before, then use d3-scale to implement it

• D3-scale-chromatic:
  – https://github.com/d3/d3-scale-chromatic
  – Implementation of the colormap
  – Lots of good color schemes and scales
  – High-level, ready-to-be-used for most vis
    – Use this for your project
Credits

• Visualization Analysis and Design (Ch 10)
• Enrico Bertini, NYU Tandon
• Alex Lex & Miriah Meyer, http://dataviscourse.net/
• Jeffrey Heer https://courses.cs.washington.edu/courses/cse512/19sp/