Spatial History Data for Visualization Projects

- 10 rich data sets, 10s of 1,000s of historical records, over 100s of years, for visualizing spatial, temporal, and network patterns in:
  - The Republic of Letters and the Enlightenment
  - Travelers on the Grand Tour in Italy
  - Railroads in the American West
  - Social Life in 19th Century Rio de Janeiro
  - Mapping botanical discoveries and scientific networks in California, 1840-2009

Color in Visualization

Identify, Group, Layer, Highlight

Purpose of Color

To label
To measure
To represent and imitate
To enliven and decorate

Above all, do no harm. - E. R. Tufte
Topics

Perception of Color
  · Light, Visual system, Mental models

Color in Information Visualization
  · Categorical color
  · Color sequences
  · ColorBrewer

Perception of Color

What color is this?

“Yellow”
Perception of Color

Light Cone Response Opponent Signals

“Yellow”

Color Perception Color Appearance Color Cognition

Physicist’s view of color

Light with different spectral distribution
- Light energy
- Wavelength

Emissive vs. reflective colors

Additive RGB Space
Subtractive CMY Space

Perception of Color
As light enters our retina...

Cone responses
- Long, Median, Short (LMS)
- Integration with cone response curves

Effects of retina encoding
Spectra that stimulate the same LMS response are indistinguishable.

“Tri-stimulus”
- Computer displays
- Digital scanners
- Digital cameras

CIE XYZ color space
Standardized in 1931 to mathematically represent tri-stimulus response.
- Standard observer response curves

CIE chromaticity diagram
Colorfulness vs. Brightness
- \( x = X/(X+Y+Z) \)
- \( y = Y/(X+Y+Z) \)
Mixture of two lights appears as a straight line.
**RGB chromaticity**

Display gamut
- Convex regions defined by RGB colorants

**Display gamuts**

Deviation from sRGB specification

**Perception of Color**

Light Cone Response Opponent Signals

“Yellow” Color Cognition Color Appearance Color Perception

**Opponent processing**

LMS are recombined to create
- Lightness
- Red-green contrast
- Yellow-blue contrast
Opponent processing

LMS are recombined to create
- Lightness
- Red-green contrast
- Yellow-blue contrast

Experiments
- No reddish green, or bluish yellow
- Color after images
CIE LAB and LUV color spaces

Standardized in 1976 to mathematically represent opponent processing theory.
- Non-linear function of CIE XYZ

Axes of CIE LAB

Correspond to opponent signals
- $L^*$ = Luminance
- $a^*$ = Red-green contrast
- $b^*$ = Yellow-blue contrast

Scaling of axes to represent “color distance”
- JND = Just noticeable difference

Color blindness

Missing one or more retina cones or rods

VisCheck

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

Albert Munsell
Developed the first perceptual color system based on his experience as an artist (1905).

Hue, Value, Chroma
Hue, Value, Chroma

Munsell color system

Perceptually-based
Precisely reference a color
Intuitive dimensions
Look-up table (LUT)
Perceptual brightness

Color palette

Luminance Y (CIE XYZ)

Perceptual brightness

Color palette

HLS (Photoshop)

Perceptual brightness

Color palette

Munsell Value

Perceptual brightness

Color palette

Munsell Value
L* (CIE LAB)
Perceptually-uniform color space

- Munsell colors in CIE LAB coordinates

Color appearance

If we had a perceptually-uniform color space, can we predict how we perceive colors?

Simultaneous contrast

The inner and outer thin rings are in fact the same physical purple.
Bezold effect

Perceived difference depends on background

Spreading

- Spatial frequency
  - The paint chip problem
  - Small text, lines, glyphs
  - Image colors
- Adjacent colors blend

Color appearance

If we had a perceptually-uniform color space, can we predict how we perceive colors?

- Chromatic adaptation
- Luminance adaptation
- Simultaneous contrast
- Spatial effects
- Viewing angle
Meet iCAM

iCAM models (2002)
- Chromatic adaptation
- Appearance scales
- Color difference
- Crispening
- Spreading
- HDR tone mapping

Mark Fairchild

Perception of Color

Basic color terms

Chance discovery by Brent Berlin and Paul Kay.

Basic color terms

Chance discovery by Brent Berlin and Paul Kay.
Basic color terms
Chance discovery by Brent Berlin and Paul Kay
Initial study in 1969
- Surveyed speakers from 20 languages
- Literature from 69 languages

Universality of BCT
Basic color terms are universal across languages.

Evolution of BCT
Universal evolution model across languages.

World color survey
World color survey

Naming information from 2616 speakers from 110 languages on 330 Munsell color chips

Results from WCS

Language #6 (Catalan)
Mutual info = 0.365 / Contributions = 0.446

Language #4 (Chinese)
Mutual info = 0.402 / Contributions = 0.573

Language #7 (Italian)
Mutual info = 0.381 / Contributions = 0.530
We associate and group colors together, often the name we assign to the colors.

Rainbow color ramp

Naming affects color perception

- Color name boundaries

Green | Blue
Icicle tree with colors

Perception of Color

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Gray’s anatomy

Superficial dissection of the right side of the neck, showing the carotid and subclavian arteries. (http://www.bartleby.com/107/illus520.html)

Color in Information Visualization

Categorical Color
Molecular models

Organic Chemistry Molecular Model Set
http://www.indigo.com/models/gphmodel/62003.html

Resistor color codes

Hints for the colorist

Use only a few colors (~6 ideal)
Colors should be distinctive and named
Strive for color harmony (natural colors)
Use cultural conventions; appreciate symbolism
Beware of bad interactions (red/blue etc.)
Get it right in black and white
Respect the color blind
Color in Information Visualization

Color sequences

1. People segment colors into classes
2. Hues are not naturally ordered
3. Different lightness emphasizes certain scalar values
4. Low luminance colors (blue) hide high frequencies

Default rainbow maps

Singularity in Phase (M. Berry)

Phase is periodic \( \Rightarrow \) Hue circle which is also periodic
Radar interferogram

From Howard Zebker

Compressible turbulence

http://www.lcse.umn.edu/research/lanlrun/imagery.html

Color in Information Visualization

ColorBrewer

Classing quantitative data

Age-adjusted mortality rates for the United States.
Classing quantitative data

1. Equal interval (arithmetic progression)
2. Quantiles (recommended)
3. Box-plot
4. Standard deviation
5. Optimal [Jenks] (minimize error)
6. Equal area
7. Minimal length boundaries
8. Natural breaks
9. Minimal gaps

Sequential color scheme

Sequential Scheme One Hue

Percent of labor force employed in agriculture 1966

Sequential Scheme Hue Transition

Percent of labor force employed in agriculture 1966
Sequential color scales

Hue-Lightness (Recommended)
- Higher values mapped to darker colors
- ColorBrewer schemes have 3-9 steps

Hue Transition
- Two hues
- Neighboring hues interpolate better
- Couple with change in lightness

Diverging color scheme
Diverging color scheme

Hue Transition
- Carefully handle midpoint
- Critical class
  - Low, Average, High
  - ‘Average’ should be gray
- Critical breakpoint
  - Defining value e.g. 0
  - Positive & negative should use different hues
- Extremes saturated, middle desaturated

Class Project in Color?

Automated color design
Color palettes
- Aesthetics & color harmony
- Well-named colors
Automated color design

Color ramps
• Data with multimodal distributions?

ColorBrewer diverging schemes

Color name saliency

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Categorical color

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