Information Visualization
Color, ArteryViz, Rainbows Rev
Ex: Two Numbers, Colors

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https://www.cs.ubc.ca/~tmm/courses/547-21
Plan for today

• last week reading Q&A
  – Tables, LineUp, Bertifier

• small group exercises
  – Two Numbers
  – (break)
  – Color

• this week reading Q&A
  – Color, ArteryViz, Rainbows Revisited
Next week

• to read & discuss (async, before next class)
  – VAD book, Ch 9: Networks and Trees
  – paper: ABySS-Explorer [design study]
  – paper: Geneaological Graphs [technique]

• pre-proposal meetings
  – I'll use full class slot plus some extra slots
  – exact timing TBD after I see final number of groups (10-15 min)
  – stay tuned on Piazza for signup link
Q&A / Backup Slides
Visualization Analysis & Design

Color (Ch 10)

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Idiom design choices: Visual encoding

**Encode**

- **Arrange**
  - Express
  - Order
  - Use

- **Map**
  - from categorical and ordered attributes
    - Color
      - Hue
      - Saturation
      - Luminance
    - Size, Angle, Curvature, ...
    - Shape
    - Motion
      - Direction, Rate, Frequency, ...

**What?**
**Why?**
**How?**
Idiom design choices: Beyond spatial arrangement

Encode

- **Arrange**
  - Express
  - Order
  - Use

- **Map**
  - from *categorical* and *ordered* attributes
  - Color
    - Hue
    - Saturation
    - Luminance
  - Size, Angle, Curvature, ...
  - Shape
    - Direction, Rate, Frequency, ...

What? Why? How?

- **Express**
- **Separate**
- **Align**
- **Use**
- **Map**
- **Reduce**
- **Arrange**
- **Encode**
- **Manipulate**
- **Facet**
- **Juxtapose**
- **Partition**
- **Superimpose**
- **Filter**
- **Aggregate**
- **Embed**
- **Change**
- **Select**
- **Navigate**
- **Express**
- **Separate**
- **Order**
- **Align**
- **Use**
- **Juxtapose**
- **Partition**
- **Superimpose**
- **Filter**
- **Aggregate**
- **Embed**
- **Color**
- **Motion**
- **Position, Size, Angle, Curvature, ...**
- **Hue**
- **Saturation**
- **Luminance**
- **Region, Shape, ...**
- **Direction, Rate, Frequency, ...**
Channels: What's up with color?

**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
Decomposing color
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic

• decompose into three channels
  – ordered can show magnitude
    • luminance: how bright (B/W)
    • saturation: how colourful
  – categorical can show identity
    • hue: what color
Decomposing color

• first rule of color: do not (just) talk about color!
  – color is confusing if treated as monolithic

• decompose into three channels
  – ordered can show magnitude
    • **luminance**: how bright (B/W)
    • **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?
Color Channels in Visualization
Categorical vs ordered color

Categorical color: limited number of discriminable bins

• human perception built on relative comparisons

[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

- human perception built on relative comparisons
  - great if color contiguous

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Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons

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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

Mapping the Human 'Diseasome'
Researchers created a map linking different diseases, represented by circles, to the genes they have in common, represented by squares.
Related Article: Redefining Disease, Genes and All.

Ordered color: limited number of discriminable bins

Gregor Aisch, vis4.net/blog/posts/choropleth-maps/
Ordered color: Rainbow is poor default

• problems
  – perceptually unordered
  – perceptually nonlinear
Ordered color: Rainbow is poor default

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• 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

- **problems**
  - perceptually unordered
  - perceptually nonlinear
- **benefits**
  - fine-grained structure visible and nameable
- **alternatives**
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]


Viridis / Magma: sequential colormaps

- monotonically increasing luminance, perceptually uniform
- colorful, colorblind-safe
  - R, python, D3

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

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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]

• legit for categorical
  – segmented saturated rainbow is good!

Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation

http://colorbrewer2.org/
Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
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- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency

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Interaction between channels: Not fully separable

• color channel interactions
  – size heavily affects salience
  – small regions need high saturation
  – large regions need low saturation

• saturation & luminance:
  – not separable from each other!
  – also not separable from transparency
  – small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max
  – contiguous regions: many bins (use only one of these channels)

http://colorbrewer2.org/
Color Palettes
Color palettes: univariate

- Categorical
  - aim for maximum distinguishability
  - aka qualitative, nominal

Color palettes: univariate

- Categorical

- Ordered
  - Sequential
  - Diverging

- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints

- sequential
  - ramp luminance or saturation

Color palettes: univariate

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• Diverging
  - Useful when data has meaningful "midpoint"
  - Use neutral color for midpoint
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  - Use saturated colors for endpoints

• Sequential
  - Ramp luminance or saturation
  - If multi-hue, good to order by luminance

Color palettes: univariate

- Categorical
  - ![Categorical Colors]

- Ordered
  - Sequential
  - Diverging
  - Cyclic

- Cyclic multihue
  - ![Cyclic Multihue Colors]

https://github.com/d3/d3-scale-chromatic

Color palette design considerations: univariate

segmented

- diverging
- sequential
- categorical

continuous

- sequential single hue
- diverging two hue
- sequential multihue
- cyclic multihue

- segmented or continuous?
- diverging or sequential or cyclic?
- single-hue or two-hue or multi-hue?
- perceptually linear?
- ordered by luminance?
- colorblind safe?

https://github.com/d3/d3-scale-chromatic
Colormaps: bivariate

- Categorical
  - [Orange, Red, Blue]

- Ordered
  - Sequential
  - Diverging

- Bivariate

- bivariate best case
  - binary in one of the directions

```
# d3.schemePaired <>
```

Colormaps: bivariate

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

Bivariate

Colormaps

- Categorical
- Ordered → Sequential → Diverging
- Bivariate

use with care!

- bivariate can be very difficult to interpret
- when multiple levels in each direction

Visualization Analysis & Design

Color (Ch 10) II

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Decomposing color

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    • luminance: how bright (B/W)
    • saturation: how colourful
  – categorical can show identity
    • hue: what color
Color Deficiency
Luminance

• need luminance for edge detection
  – fine-grained detail only visible through luminance contrast
  – legible text requires luminance contrast!

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*)
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*)
- “colorblind”: degraded acuity, one axis
  - 8% of men are red/green color deficient
  - blue/yellow is rare
Designing for color deficiency: Check with simulator

Normal vision

Deuteranope green-weak

Protanope red-weak

Tritanope blue-weak

https://www.color-blindness.com/coblis-color-blindness-simulator/
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
Visualization Analysis & Design

Color (Ch 10) III

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Color Spaces
Many color spaces

• Luminance (L*), hue (H), saturation (S)
  – good for encoding
Many color spaces

- Luminance ($L^*$), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
Many color spaces

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- RGB: good for display hardware
RGB

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RGB

- RGB: good for display hardware

- poor for encoding & interpolation
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- CIE LAB ($L^*a^*b^*$): good for interpolation
Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
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- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
Perceptual colorspace: L*a*b*

- 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*)
Perceptual colorspace: L*a*b*

- 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*)

- CIE LAB
  - perceptually uniform
    - great for interpolating
  - complex shape
    - poor for encoding


https://en.wikipedia.org/wiki/CIELAB_color_space
Many color spaces

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  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey

HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation

HSL/HSV: Pseudo-perceptual colorspace

- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance

Corners of the RGB color cube

| Blue | Red | Magenta | Green | Cyan | Yellow |

L from HLS

All the same

| Gray | Gray | Gray | Gray | Gray | Gray |

Luminance values

| Black | Dark gray | Gray | Light gray | White |

Many color spaces

• Luminance (L*), hue (H), saturation (S)
  – good for encoding
  – but not standard graphics/tools colorspace

• RGB: good for display hardware
  – poor for encoding & interpolation

• CIE LAB (L*a*b*): good for interpolation
  – hard to interpret, poor for encoding

• HSL/HSV: somewhat better for encoding
  – hue/saturation wheel intuitive
  – beware: only pseudo-perceptual!
  – lightness (L) or value (V) ≠ luminance (L*)
Color Contrast & Naming
Interaction with the background

Contrast
The difference between foreground and background colors determines text legibility.
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance
Interaction with the background: tweaking yellow for visibility

• marks with medium luminance on a background with high luminance
Interaction with the background: tweaking yellow for visibility

- change luminance of marks depending on background
Color/Lightness constancy: Illumination conditions

*Image courtesy of John McCann via Maureen Stone*
Color/Lightness constancy: Illumination conditions

Image courtesy of John McCann via Maureen Stone
Contrast with background
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxjJUQB

https://en.wikipedia.org/wiki/The_dress
Bezold Effect: Outlines matter
Color Appearance

• given L, a*, b*, can we tell what color it is?
  – no, it depends

• chromatic adaptation
• luminance adaptation
• simultaneous contrast
• spatial effects
• viewing angle
• …
Color naming
Color naming

Color names if you're a girl...

Maraschino
Cayenne
Maroon
Plum
Eggplant
Grape
Orchid
Lavender
Carnation
Strawberry
Bubblegum
Magenta
Salmon
Tangerine
Cantaloupe
Banana
Lemon
Honeydew
Lime
Spring
Clover
Fern
Moss
Flora
Sea Foam
Spindrift
Teal
Sky
Turquoise

Color names if you're a guy...

Red
Purple
Pink
Orange
Yellow
Green
Blue

http://www.thedoghousediaries.com/1406
Color naming

*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 naming

• nameability affects
  – communication
  – memorability

• can integrate into color models
  – in addition to perceptual considerations

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

• Does not help perceive
  – Position
  – Shape
  – Motion
  – …
Map Other Channels
Angle / tilt / orientation channel

- different mappings depending on range used

Sequential ordered line mark or arrow glyph

Diverging ordered arrow glyph

Cyclic ordered arrow glyph

- nonlinear accuracy
  - high: exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (eg 37 vs 38 degrees)
Map other channels

• size
  – aligned length best
  – length accurate
  – 2D area ok
  – 3D volume poor
Map other channels

• size
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  – length accurate
  – 2D area ok
  – 3D volume poor

• shape
  – complex combination of lower-level primitives
  – many bins

Size
Length
Area
Volume

Shape
Map other channels

• size
  – aligned length best
  – length accurate
  – 2D area ok
  – 3D volume poor

• shape
  – complex combination of lower-level primitives
  – many bins

• motion
  – highly separable against static
    • great for highlighting (binary)
  – use with care to avoid irritation