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

Tamara Munzner
Department of Computer Science
University of British Columbia

Week 5, 6 Oct 2021

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

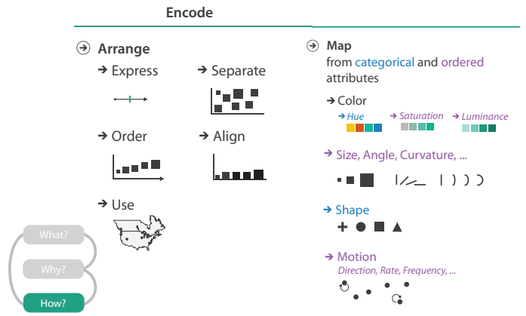
Q&A / Backup Slides

Visualization Analysis & Design

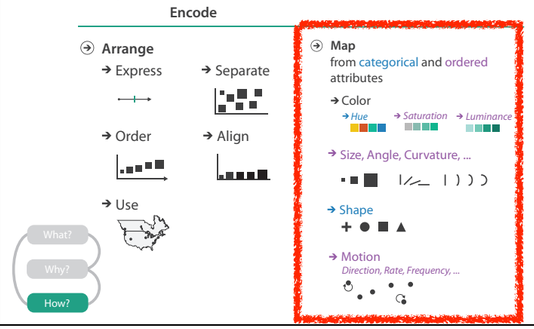
Color (Ch 10)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

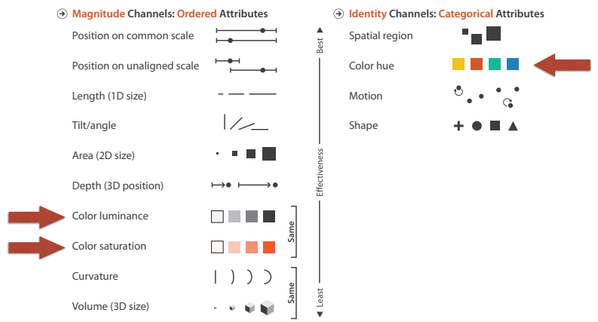
Idiom design choices: Visual encoding



Idiom design choices: Beyond spatial arrangement



Channels: What's up with color?



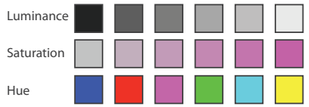
Decomposing color

Decomposing color

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

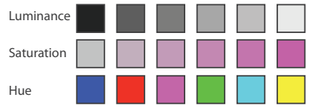
Decomposing color

- 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

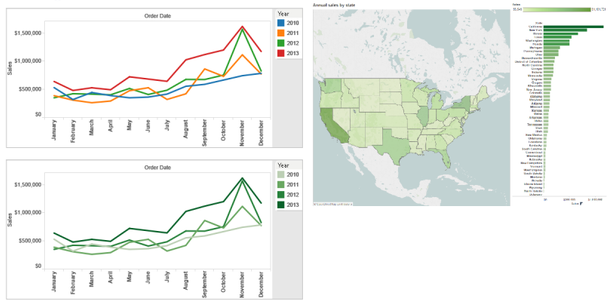
- first rule of color: do not (just) talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



- 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



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

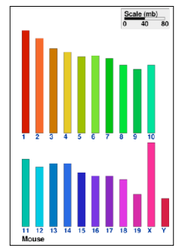
Categorical color: limited number of discriminable bins

- 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

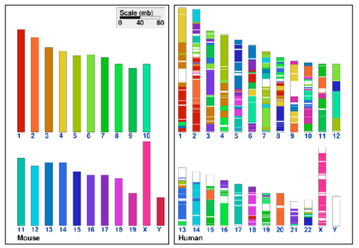
- human perception built on relative comparisons
  - great if color contiguous



[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

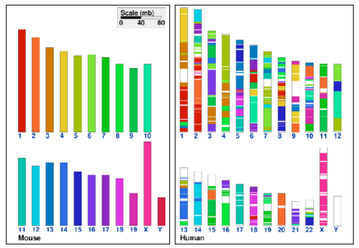
- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons



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

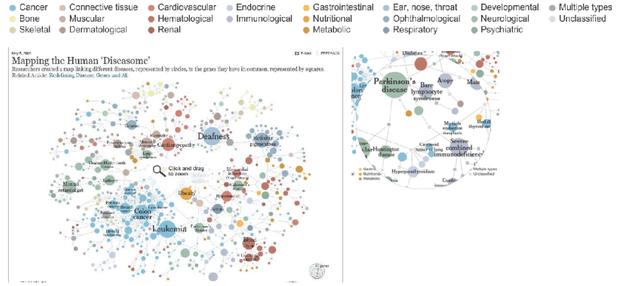
Categorical color: limited number of discriminable bins

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



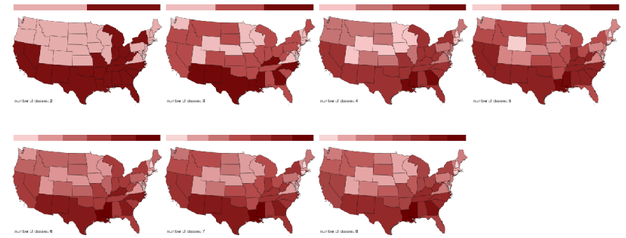
[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Categorical color: limited number of discriminable bins



https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

Ordered color: limited number of discriminable bins



Gregor Aisch, vis4.net/blog/posts/choropleth-maps/

Ordered color: Rainbow is poor default

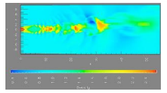
- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default

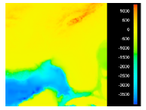
- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



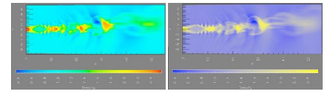
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



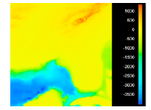
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues



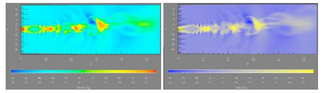
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



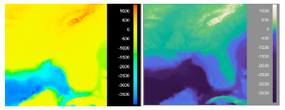
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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]



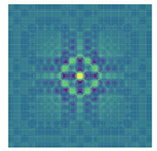
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

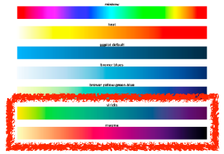


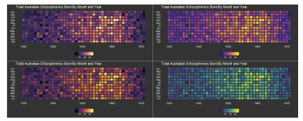
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Viridis / Magma: sequential colormaps

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



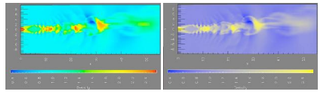




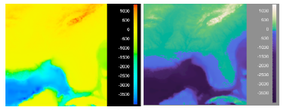
https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

Ordered color: Rainbow is poor default

- 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]
- legit for categorical
  - segmented saturated rainbow is good!



[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

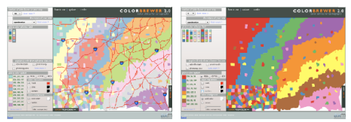
Interaction between channels: Not fully separable

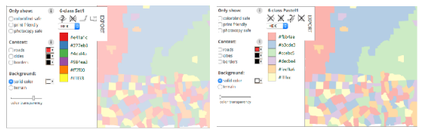
- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation

http://colorbrewer2.org/

Interaction between channels: Not fully separable

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

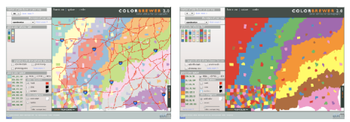


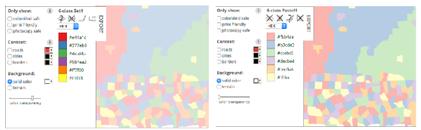


http://colorbrewer2.org/

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

- categorical
  - aim for maximum distinguishability
  - aka *qualitative*, *nominal*

other [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Color palettes: univariate

- Categorical
- Ordered
  - Sequential
  - Diverging

Categorical

- 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

Diverging -1 0 +1

Sequential 3 2 1

diverging sequential

Color palettes: univariate

- Categorical
- Ordered
  - Sequential
  - Diverging

Cividis
Viridis
Inferno
Magma
Plasma
Warm
Cool
CubeHelixDefault

- 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
  - if multi-hue, good to order by luminance

Diverging -1 0 +1

Sequential 3 2 1

diverging sequential

Color palettes: univariate

- Categorical
- Ordered
  - Sequential
  - Diverging
- Cyclic

cyclic multihue

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?

[A Study of Colormaps in Network Visualization. Karim et al. Appl. Sci. **2019**, 9, 4228; doi:10.3390/app9204228] https://github.com/d3/d3-scale-chromatic

Colormaps: bivariate

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

Binary y n

Categorical T F A

Diverging -1 0 +1

Sequential 3 2 1

- bivariate best case
  - binary in one of the directions

d3.schemePaired <>

binary saturation

categorical hue

Colormaps: bivariate

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

Binary y n

Categorical T F A

Diverging -1 0 +1

Sequential 3 2 1

Colormaps

- Categorical
- Ordered
  - Sequential
  - Diverging
- Bivariate

use with care!

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

Binary y n

Categorical T F A

Diverging -1 0 +1

Sequential 3 2 1

25 50 75

Visualization Analysis & Design

Color (Ch 10) II

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

Decomposing color

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

Luminance
Saturation
Hue

Color Deficiency

Luminance

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

Luminance information

Saturation/hue information

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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*)

Luminance information

Chroma information

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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

Luminance information

Chroma information

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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/

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape

Market
Central
East
South
West

$0 $40,000 $80,000 $120,000 $160,000 $200,000 $240,000 $280,000

COGS

Deuteranope simulation

Change the shape

Vary luminance

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions

Red Orange Yellow Green Blue Purple

Normal

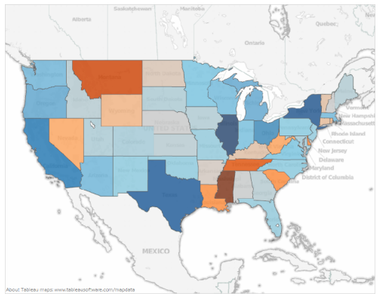
Protanope

Deuteranope

Tritanope

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Designing for color deficiency: Blue-Orange is safe



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Visualization Analysis & Design

Color (Ch 10) III

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

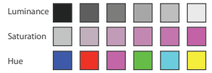
Color Spaces

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding

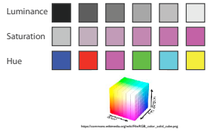
Many color spaces

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



Many color spaces

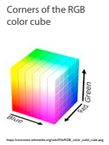
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware

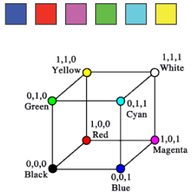


RGB

- RGB: good for display hardware

Corners of the RGB color cube

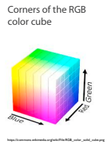


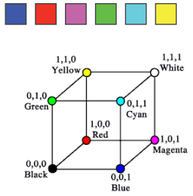


RGB

- RGB: good for display hardware
  - poor for encoding & interpolation

Corners of the RGB color cube



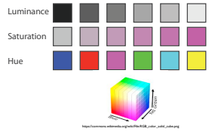


Red
+ Green

Major interference

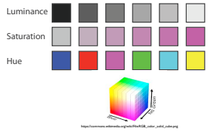
Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation



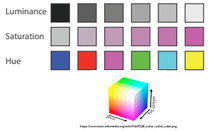
Many color spaces

- 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



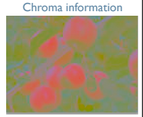
Many color spaces

- 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



Perceptual colorspace: L*a*b*

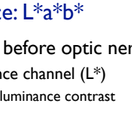
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

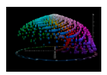


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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

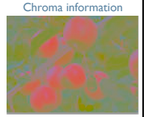




https://en.wikipedia.org/wiki/CIELAB_color_space

Luminance information

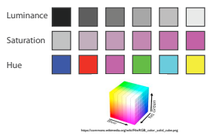
Chroma information



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

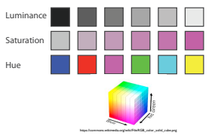
Many color spaces

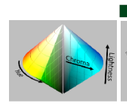
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding

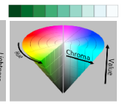


Many color spaces

- 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

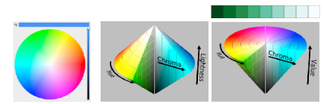


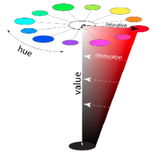




HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
-

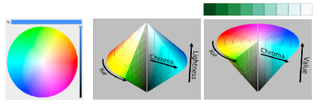


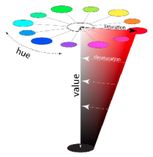


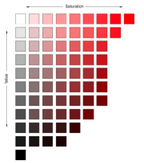
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv/#

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







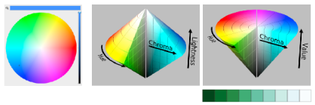
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsl/

http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsl/

65

HSL/HSV: Pseudo-perceptual colorspace

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



Corners of the RGB color cube

L from HLS
All the same

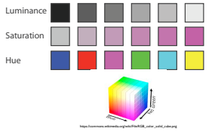
Luminance values

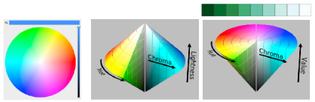
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

66

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*)



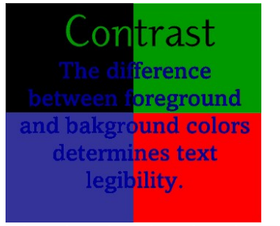


67

Color Constrast & Naming

68

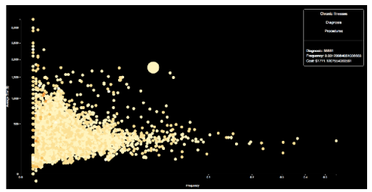
Interaction with the background



69

Interaction with the background: tweaking yellow for visibility

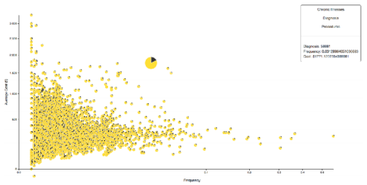
- marks with high luminance on a background with low luminance



70

Interaction with the background: tweaking yellow for visibility

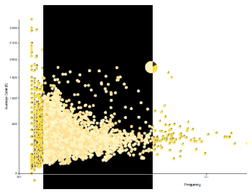
- marks with medium luminance on a background with high luminance



71

Interaction with the background: tweaking yellow for visibility

- change luminance of marks depending on background



72

Color/Lightness constancy: Illumination conditions

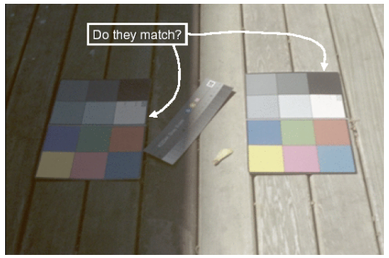


Image courtesy of John McCann via Maureen Stone

73

Color/Lightness constancy: Illumination conditions

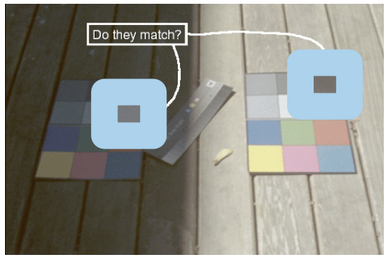


Image courtesy of John McCann via Maureen Stone

74

Contrast with background

75

Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJjUQB

https://en.wikipedia.org/wiki/The_dress

76

Bezold Effect: Outlines matter

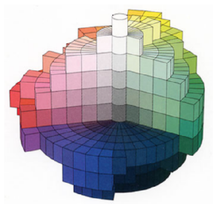
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

77

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
- …



78

Color naming

79

Color naming

http://www.thedoghousediaries.com/11406

80

Color naming

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
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins

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

Motion
Direction, Rate, Frequency, ...