Information Visualization
Color, ArteryViz, ColorDiff
Ex: Colors

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Week 7, 16 Oct 2025

https://www.cs.ubc.ca/~tmm/courses/547-25

Plan for today

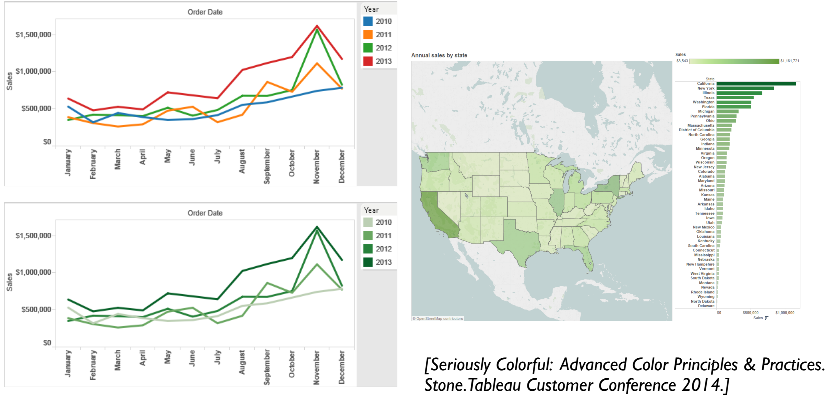
- mini-lecture / Q&A
  - Color
- small group exercises
  - Color
- mini-lecture
  - HemoViz
  - ColorDiff
- last week papers Q&A (if time)
- due Sun Oct 19 noon: written proposals
  - submit on Canvas (People - Project Groups)
  - format: subset of final report
    - final report must be in conference template; up to you whether to start with that now

Next week

- to read & discuss (async, before next class)
  - VAD book, Ch 8: Arrange Spatial Data
  - paper: Necklace Maps [technique / algorithm]
  - paper: Myriahedral Projections [technique / algorithm]

Mini-Lecture: Color

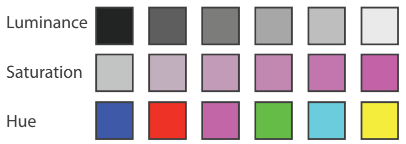
Categorical vs ordered color



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

Decomposing color

- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance: how bright
    - saturation: how colorful
  - categorical can show identity
    - hue: what color

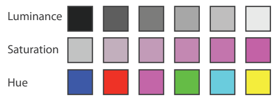


- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey: how many discriminable bins can we use?

Color Spaces

Many color spaces

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



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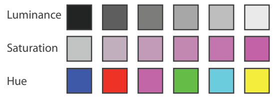

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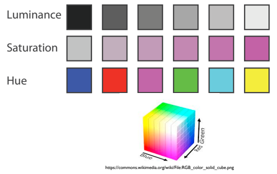

RGB

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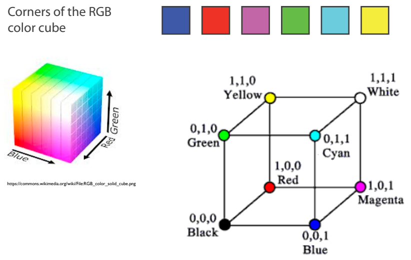
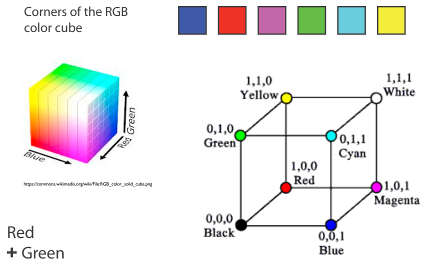
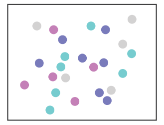


RGB

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



Red
+ Green



Major interference

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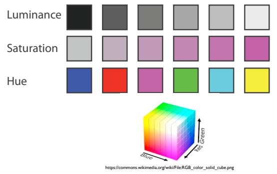

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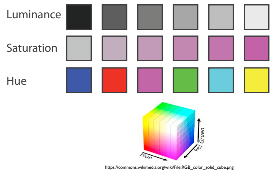

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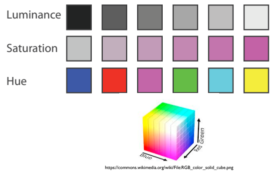
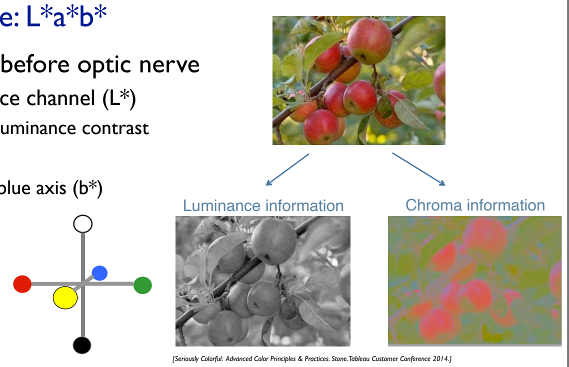
  - hard to interpret, poor for encoding



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*)



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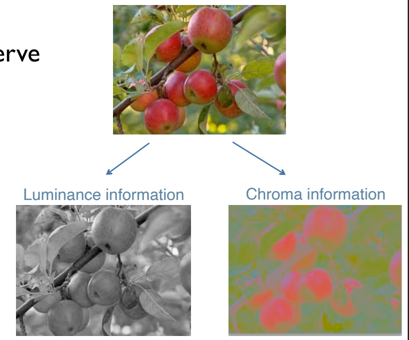
Perceptual colorspace: L*a*b*

- 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



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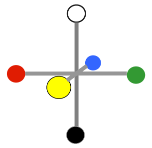

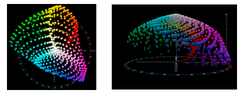

https://en.wikipedia.org/wiki/CIELAB_color_space

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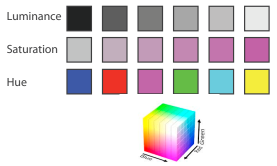

https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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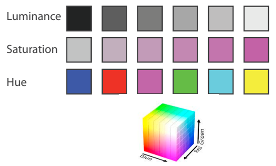
- HSL/HSV: somewhat better for encoding



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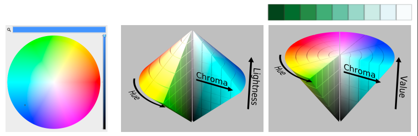
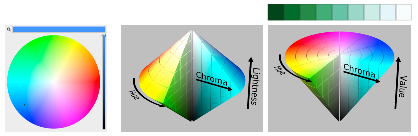
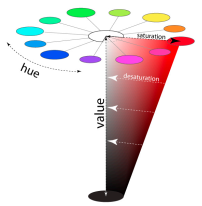


HSL/HSV

- 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/hsv8/

HSL/HSV

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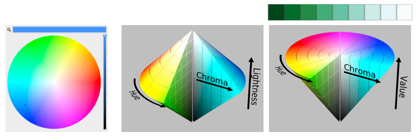
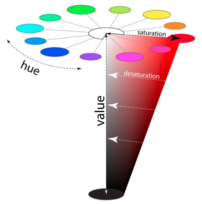
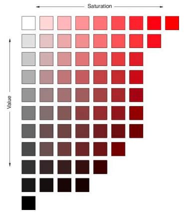
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation







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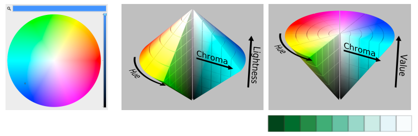
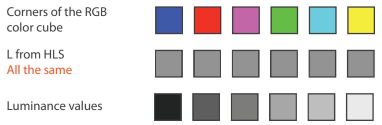
HSL/HSV: Pseudo-perceptual colorspace

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





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- RGB: good for display hardware
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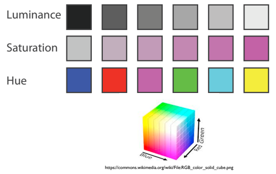
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)



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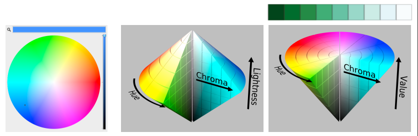
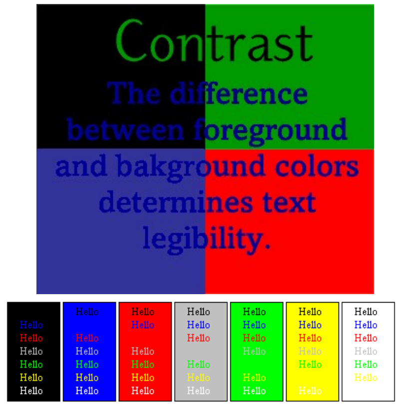


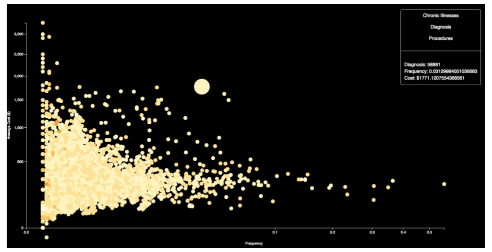
Color Constrast & Naming

Interaction with the background



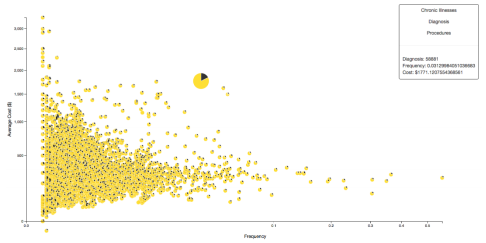
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



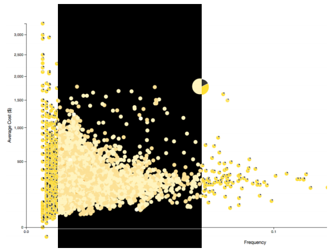
Interaction with the background: tweaking yellow for visibility

- 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

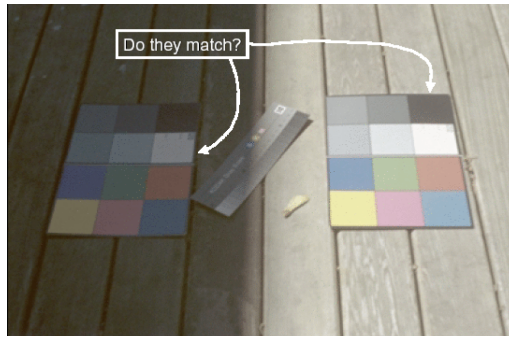


Image courtesy of John McCann via Maureen Stone

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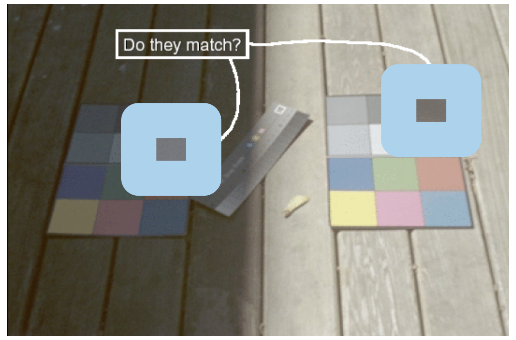

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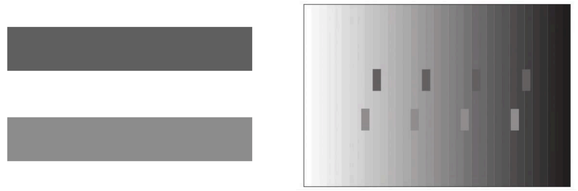
Contrast with background



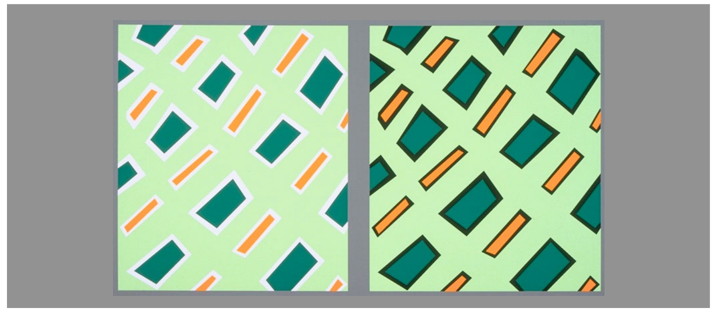
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

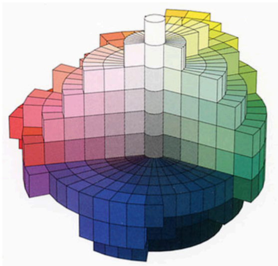
Bezold Effect: Outlines matter



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

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

http://www.thedoghousediaries.com/1406

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
  – …

Ordered color: Rainbow is poor default

- problems
  – perceptually unordered
  – perceptually nonlinear

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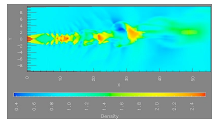
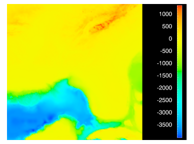
  – fine-grained structure visible and nameable



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



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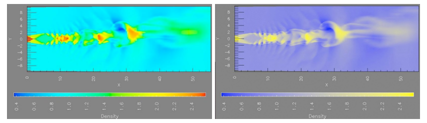
  – fine-grained structure visible and nameable
- alternatives
  – large-scale structure: fewer hues



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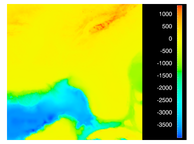

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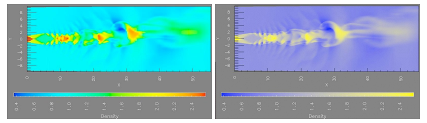
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis]



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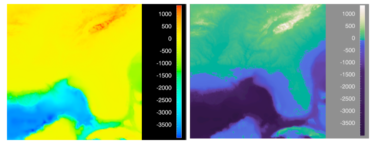

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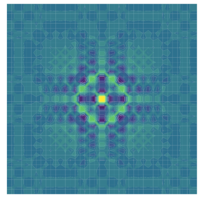
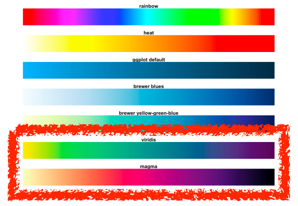
Viridis / Magma: sequential colormaps

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





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

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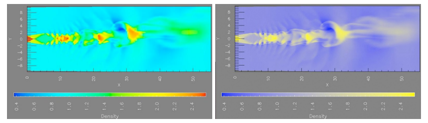
- benefits
  – fine-grained structure visible and nameable
- alternatives
  – large-scale structure: fewer hues
  – fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  – segmented saturated rainbow is good!



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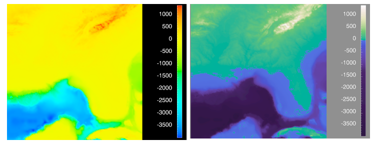

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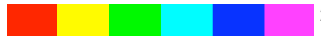
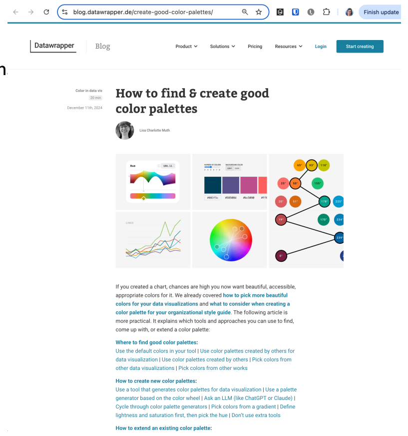


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

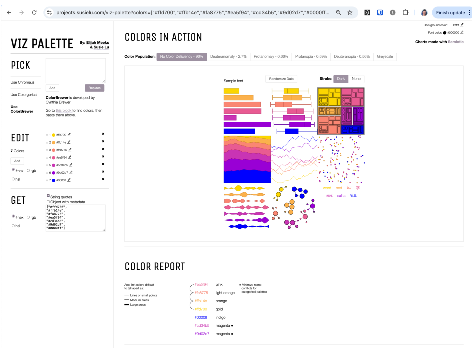
More color resources: Muth

- DataWrapper guidance on color palette creation by Lisa Charlotte Muth https://blog.datawrapper.de/create-good-color-palettes/
  – lots of practical advice, easy to understand



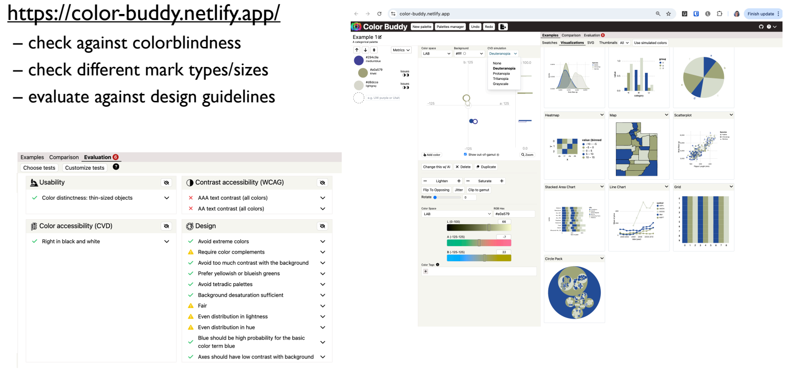
More color resources: Viz Palette

- Viz Palette, by Elijah Meeks and Susie Lu https://projects.susielu.com/viz-palette
  – colorblindness checks
  – examples for different mark sizes/types
  – report on distinguishability including names



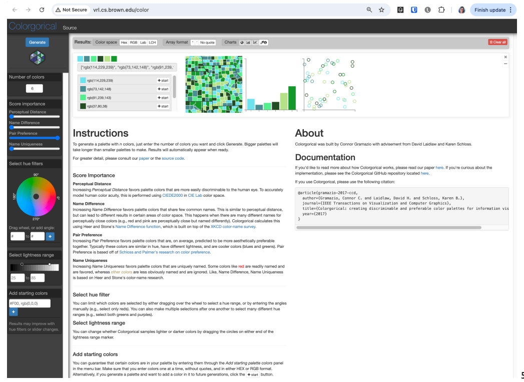
More color resources: Color Buddy

- Color Buddy, by Andrew McNutt and Maureen Stone
  https://color-buddy.netlify.app/
  - check against colorblindness
  - check different mark types/sizes
  - evaluate against design guidelines



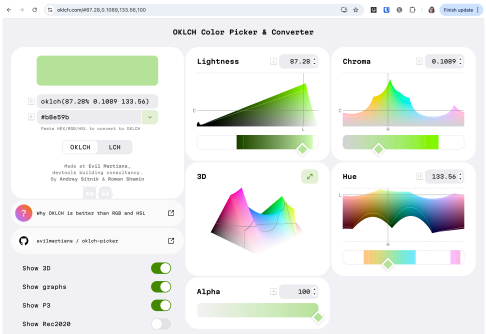
More color resources: Colorgorical

- Colorgorical, by Connor Gramazio
  http://vrl.cs.brown.edu/color
  - categorical color, including name



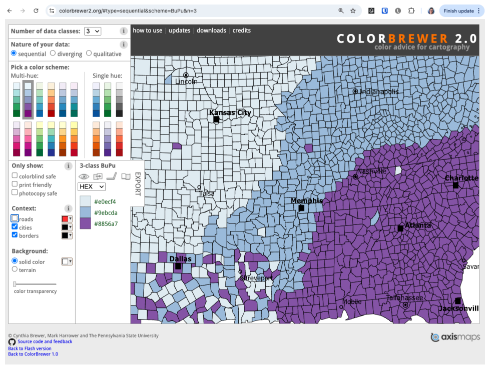
More color resources: oklch.com

- oklch perceptual space color picker/converter, by Andrey Sitnik & Roman Shamin (Evil Martians)
  https://oklch.com/
  - inspect color space itself



More color resources: ColorBrewer

- ColorBrewer, by Cynthia Brewer
  colorbrewer2.com



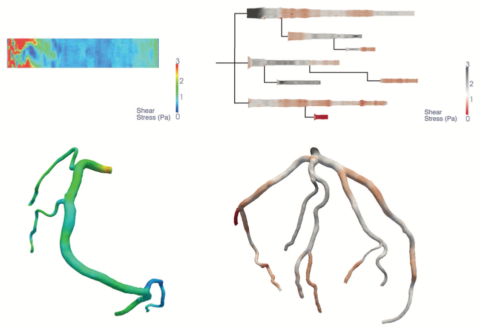
Breakouts

Break: 3:25-3:35

Artery Visualizations for Heart Disease Diagnosis

HemoViz: Design study + empirical evaluation

- C1 qual formative study with experts
  - task taxonomy
- C2 HemoViz design
- deploy attempt fails
  - experts balk: demand 3D and rainbows
- C3 quantitative user study
  - med students, real data
  - 91% with 2D/diverging vs 39% with 3D/rainbows
  - experts willing to use



[Fig 1. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]

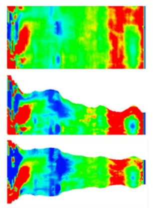
HemoVis tasks

- formative qual user study
- three projection alternatives
- result / contribution: (well justified) task taxonomy

cylindrical

circumference mapped to height

circumference mapped symmetrically

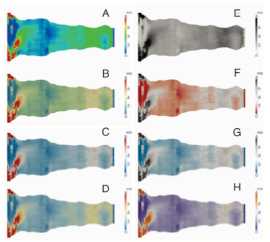


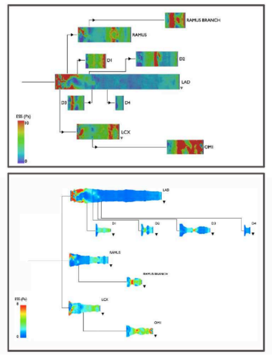
ID	Task	Clinical	Research
1	Identify stenosis or blockage	X	X
2	Identify regions of low ESS	X	X
3	View all ESS data for heterogeneous patterns	X	X
4	Study blood flow (velocity) patterns		X
5	Identify regions of blood recirculation		X
6	Investigate other physical variables of blood flow		X
7	Follow patient's disease progression	X	X

[Fig 2 & Table 1. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]

HemoVis design

- design evolution of tree layout
- color alternatives
  - A rainbow preferred
  - F red/black diverging
  - E greyscale misleading



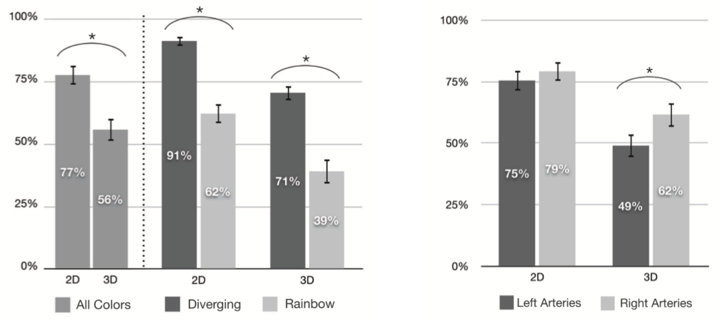


[Fig 3 & 4. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]

Deployment

- typical design study: deploy, then validate effectiveness with case studies
- this project: target audience refused to use it, what to do?
  - quant study as ammunition to change minds

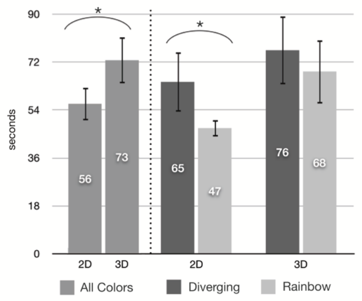
Study results: Accuracy



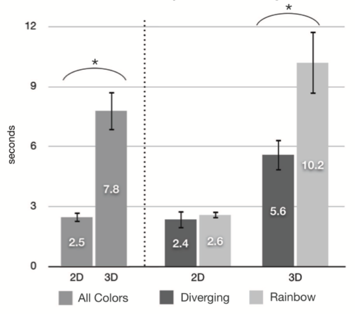
simple complex

Study results: Time

avg total time



time to identify low ESS region



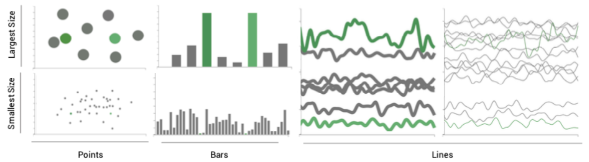
Critique

- many strengths
  - careful and well justified design, convincing human-subjects experiment
    - bringing visualization best practices to medical domain
- limitation
  - paper does not clearly communicate why colormap is diverging not sequential
    - answer by email
    - doctors care about extremely high and extremely low ESS (scalar) values
      - high values (top of scale, dark grey): extreme blood flow patterns may relate to heart malfunctions - but not imminently life threatening and don't indicate plaque locations
      - low values (bottom of scale, dark red): very diseased regions with lots of plaque, docs care a lot!
      - much debate from doctors on where is boundary between "normal" and "low" ESS values
        » most think below 3 Pa are indicative of disease but many argue other values in the 2-4 range
        » all docs agree that values below 2 Pa are increasingly dangerous disease levels
        » thus map has transition at 3 Pa for the diverging point and truly red below 2 Pa
    - why continuous not segmented?
      - doctors gain tremendous insight by seeing the subtle patterning of the ESS values
      - particularly varying values in red region - patterns help them understand disease progression and severity
        » especially useful for deciding what types of interventions to prescribe for the patient

Color Diff

Modeling Color Difference for Visualization Design

- evaluation paper: very careful quant study
  - factors (independent variables): mark size, color difference, colourspace axis (L*a*b*)
  - dependent measure: discriminability rate (proportion where diff correctly recognized)
  - vision science methodology: JNDs, binary forced-choice
  - model includes mark type and size



Challenges for vision science vs visualization

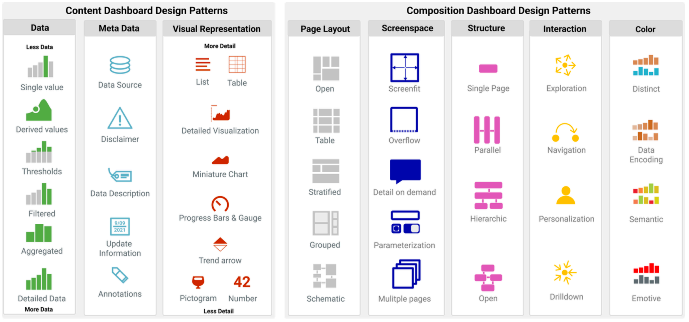
- Simple World Assumption
  - most pw: perfect viewing conditions
  - here: real-world / anywhere, via crowdsourcing
- Isolation Assumption
  - pw: one or two isolated color patches
  - here: visually complex, including distractor marks
- Geometric Assumption
  - pw: all patches same size/shape
  - here: disparate sizes & shapes, varying systematically

- result: models that take size & mark type into account

Dashboard Design Patterns

Dashboard design patterns

- Dashboard Design Patterns. Bach, Freeman, Abdul-Rahman, Turkay, Khan, Fan, and Chen. IEEE TVCG (Proc. VIS 2022) 29(1):342-352, 2023

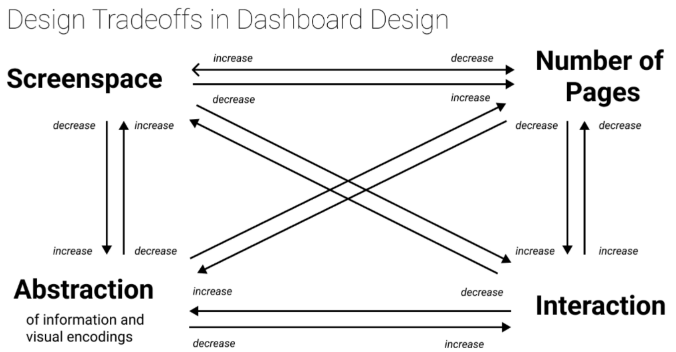


[Fig 1. Bach et al, Dashboard Design Patterns, IEEE VIS 2022, (TVCG 2023)]

Methods

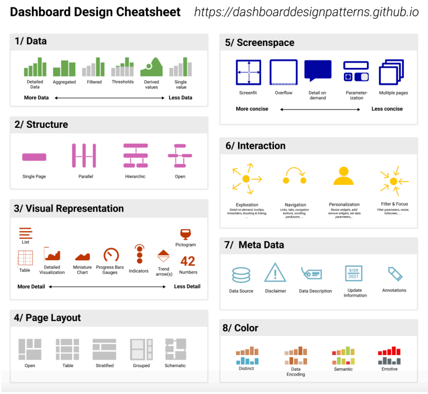
- design space through qualitative analysis
  - systematic review of corpus (144 dashboards)
    - open coding from 3 authors independently
    - refined through iteration with other 3 authors
    - (fewer methods details than some other design space papers)
  - 42 patterns grouped into 8 categories
  - 6 genres
  - design tradeoffs between 4 parameters
  - guidelines (20 & 8)
- evaluation
  - design workshops with 23 participants
  - author experience creating 7000 dashboards

Design tradeoffs



Supplemental materials

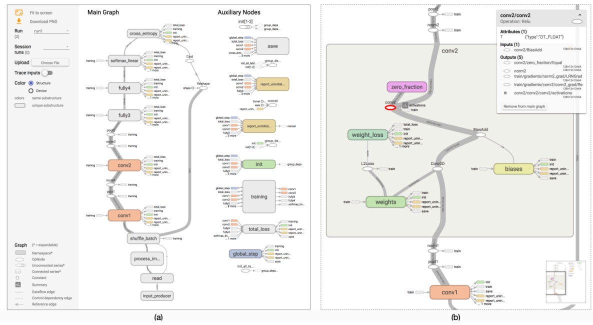
- power of rich supplemental materials
  https://dashboarddesignpatterns.github.io/
- many design space papers now have browsable interfaces
  - Timelines Revisited
  - Multiscale Vis



TensorFlow

TensorFlow

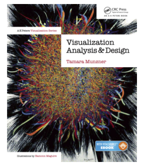
- design study: ML explainability
- embed



[Visualizing Dataflow Graphs of Deep Learning Models in TensorFlow. Wongsuphasawat, Smilkov, Wexler, Wilson, Mané, Fritz, Krishnan, Viégas, and Wattenberg. IEEE TVCG (Proc. VAST 2017) 24(1):1-12, 2018.]

Q&A / Backup Slides

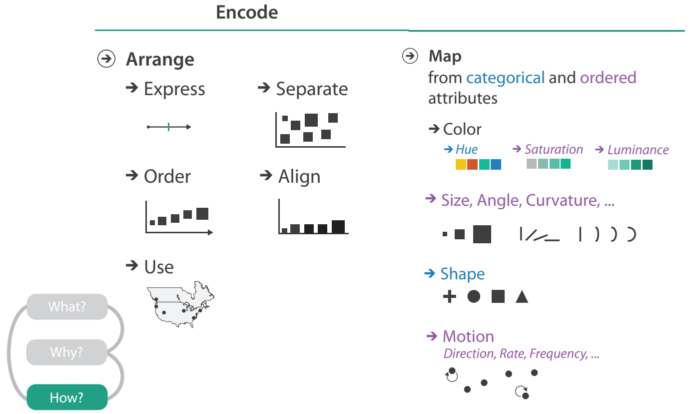
Visualization Analysis & Design



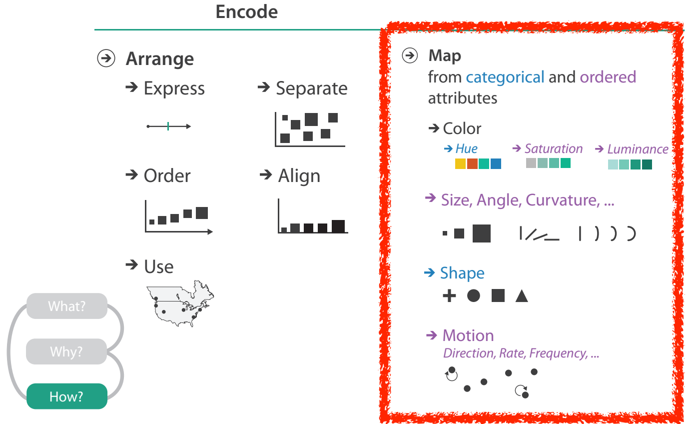
Color (Ch 10)

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

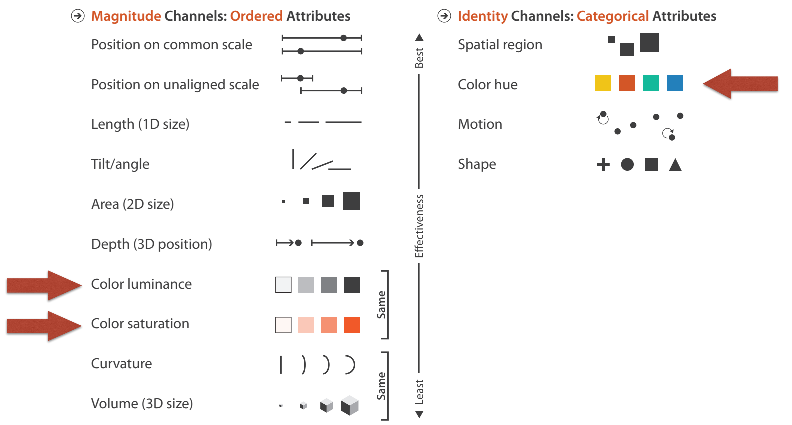
Idiom design choices: Visual encoding



Idiom design choices: Beyond spatial arrangement



Channels: What's up with color?



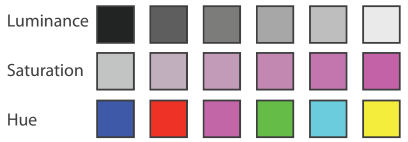
Decomposing color

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



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  - color is confusing if treated as monolithic
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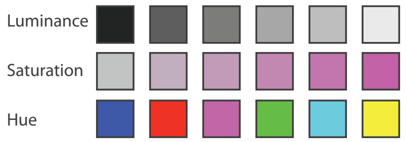
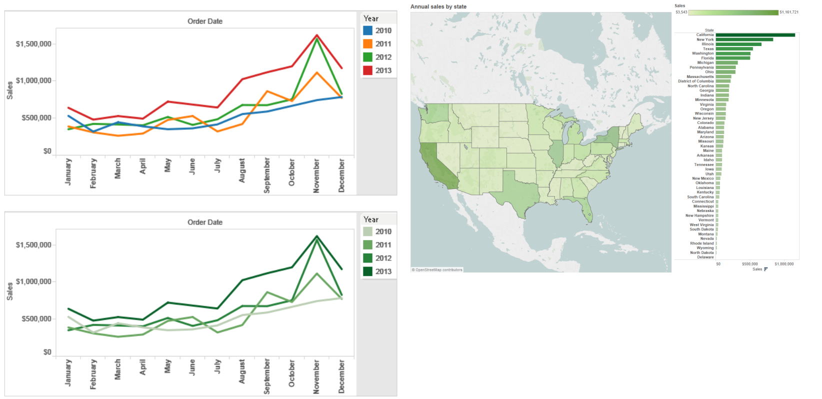
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable 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

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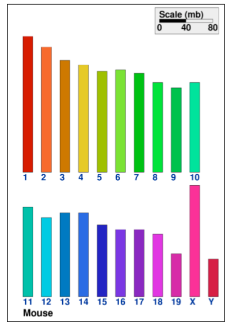
  - great if color contiguous



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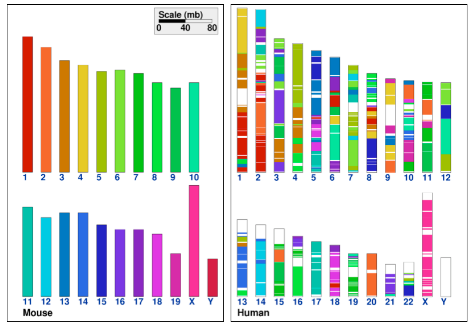

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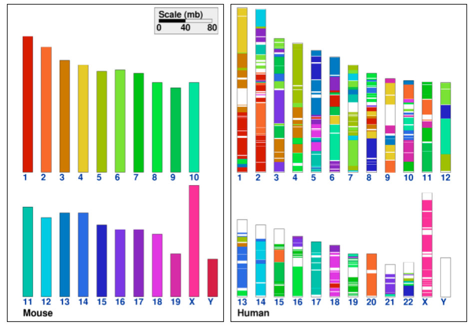
Categorical color: limited number of discriminable bins

- 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



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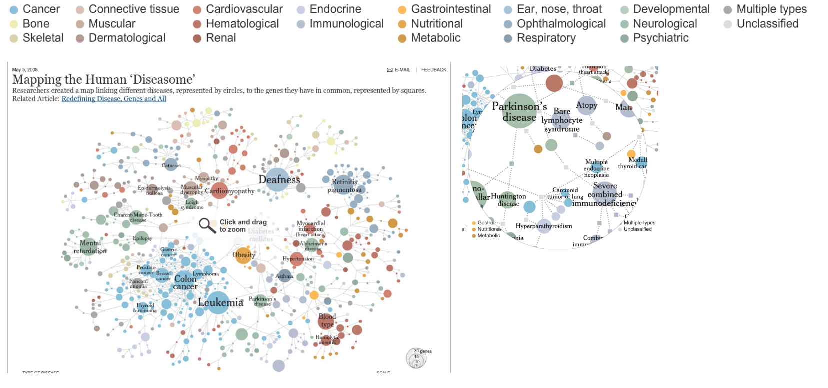
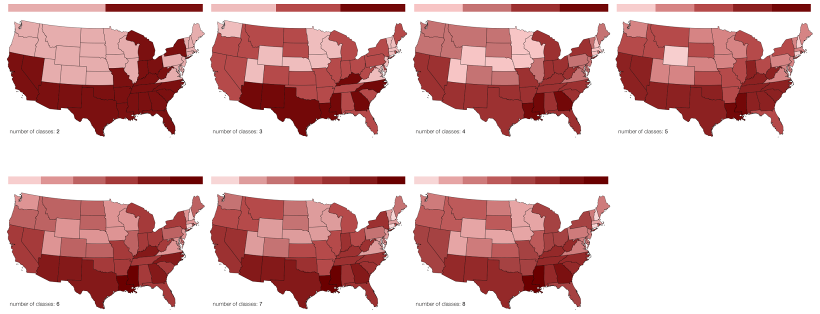


https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

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

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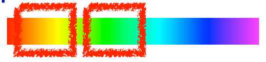

Ordered color: Rainbow is poor default

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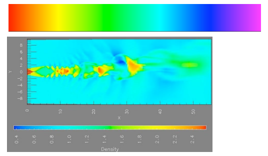
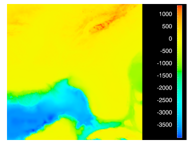
- benefits
  - fine-grained structure visible and nameable



[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]

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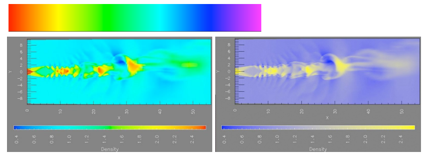
  - large-scale structure: fewer hues



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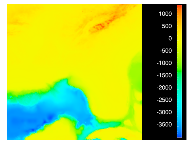

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  - fine-grained structure visible and nameable
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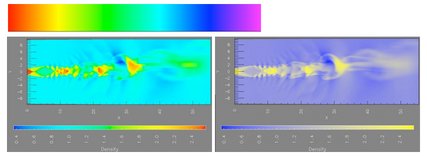
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]



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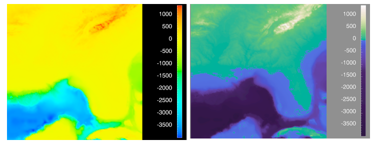
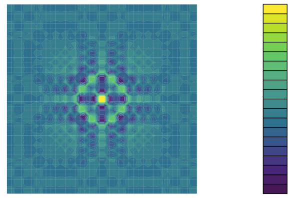
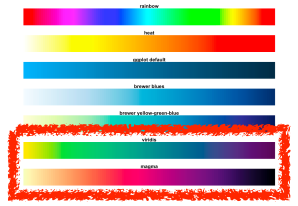


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

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- problems
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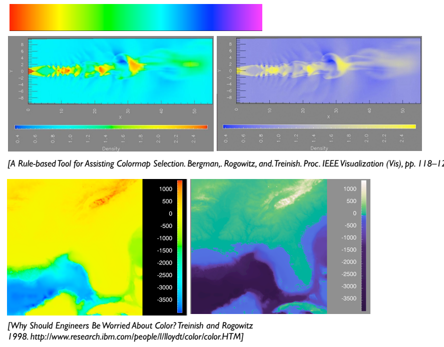
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented saturated rainbow is good!



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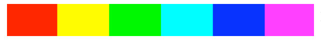
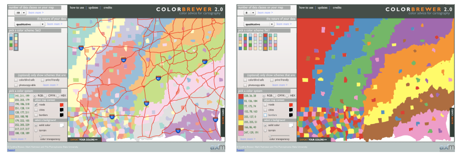


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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/

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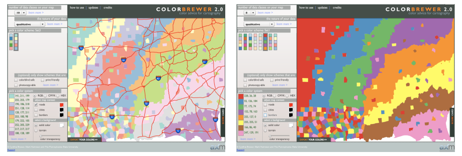
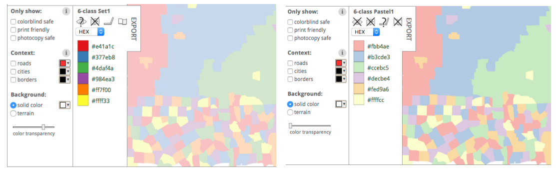
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency





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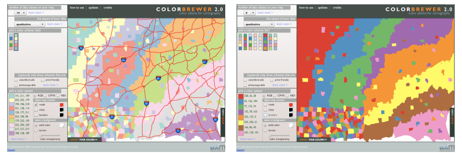
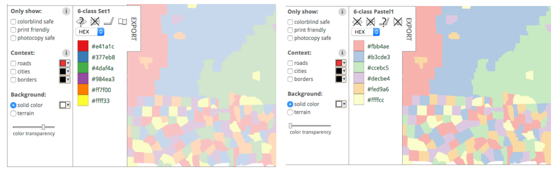
- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency
  - small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max
  - contiguous regions: many bins (use only one of these channels)





http://colorbrewer2.org/

Color Palettes

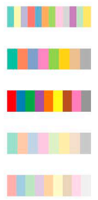
Color palettes: univariate

→ Categorical

Categorical

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

categorical



after [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*

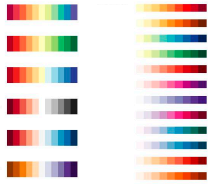
Categorical

Diverging −1 0 +1

Sequential 3 2 1

- 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 sequential



after [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

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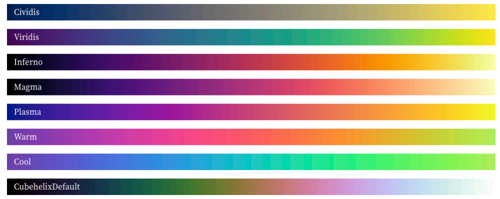
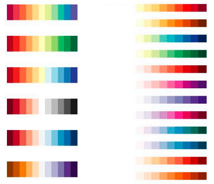


Diverging −1 0 +1

Sequential 3 2 1

- 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 sequential



after [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*

→ Cyclic

cyclic multihue

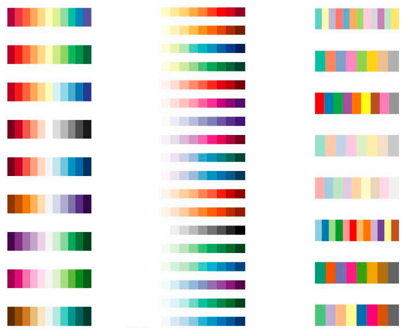
https://github.com/d3/d3-scale-chromatic

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

Color palette design considerations: univariate

segmented

diverging sequential categorical



continuous

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?

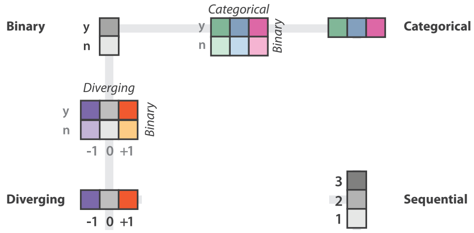
[A Study of Colormaps in Network Visualization. Karim et al. Appl. Sci. **2019**, 9, 4228; doi:10.3390/app9204228] https://github.com/d3/d3-scale-chromatic

Colormaps: bivariate

→ Categorical

→ Ordered
→ *Sequential* → *Diverging*

→ Bivariate



- bivariate best case
  - binary in one of the directions

d3.schemePaired <>

binary saturation

categorical hue

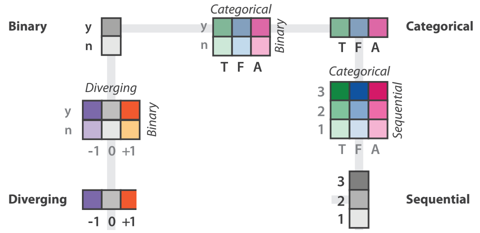
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps: bivariate

→ Categorical

→ Ordered
→ *Sequential* → *Diverging*

→ Bivariate



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

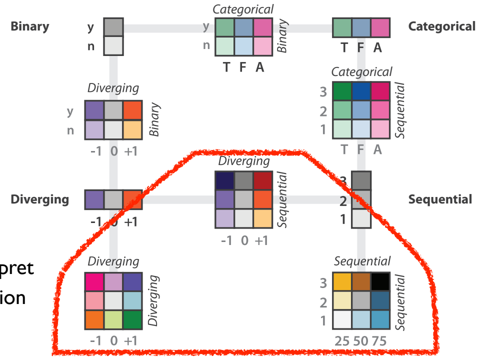
Colormaps

→ Categorical

→ Ordered
→ *Sequential* → *Diverging*

→ Bivariate

use with care!

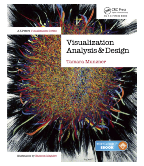


- bivariate can be very difficult to interpret
  - when multiple levels in each direction

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

Visualization Analysis & Design

Color (Ch 10) II



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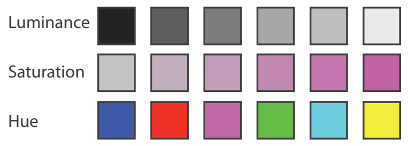
Decomposing color

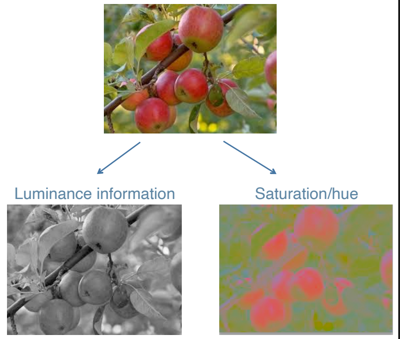
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



Color Deficiency

Luminance

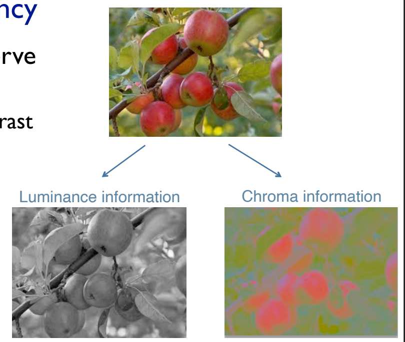
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!



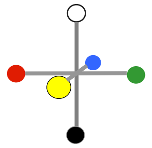
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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*)

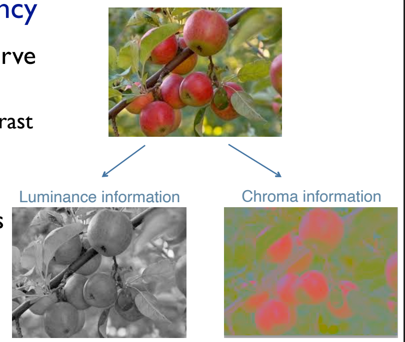


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

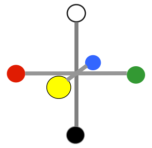


Opponent color and color deficiency

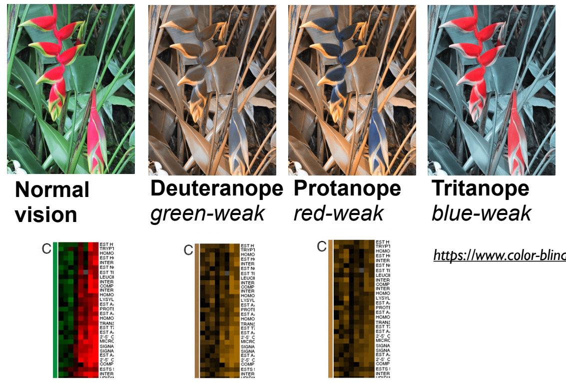
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- "colorblind": degraded acuity, one axis
  - 8% of men are red/green color deficient
  - blue/yellow is rare



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



Designing for color deficiency: Check with simulator

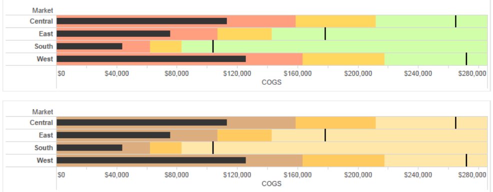


https://www.color-blindness.com/coblis-color-blindness-simulator/

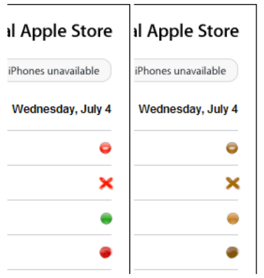
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape



Deuteranope simulation

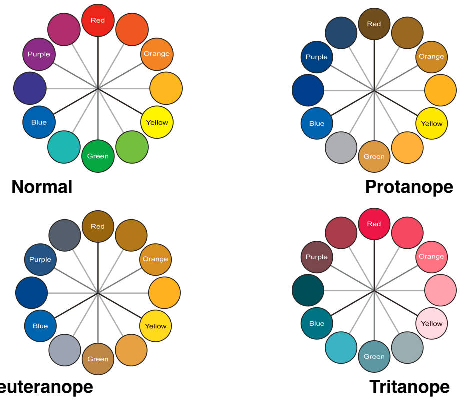


Change the shape

Vary luminance

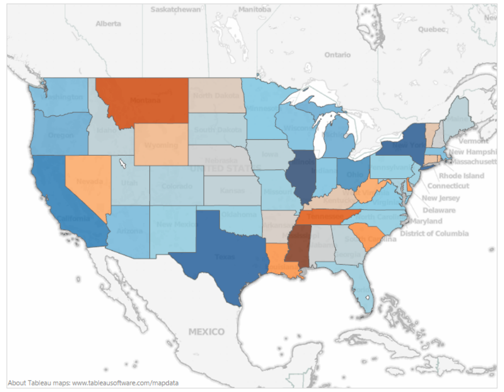
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions



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

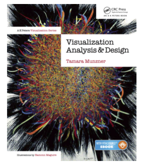
Designing for color deficiency: Blue-Orange is safe



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

Visualization Analysis & Design

Color (Ch 10) III



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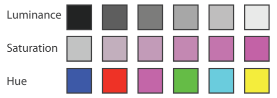
Color Spaces

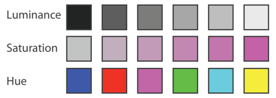
Many color spaces

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



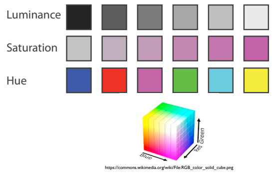
Many color spaces

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



Many color spaces

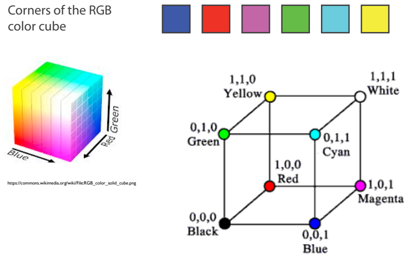
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware



RGB

- RGB: good for display hardware

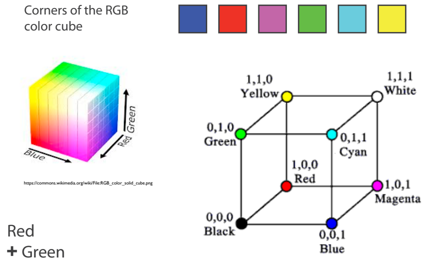
Corners of the RGB color cube



RGB

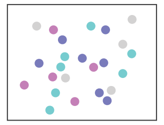
- RGB: good for display hardware

Corners of the RGB color cube



  - poor for encoding & interpolation

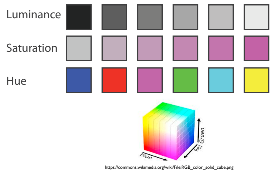
Red + Green



Major interference

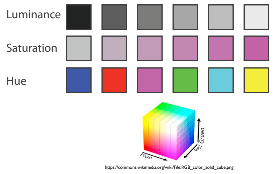
Many color spaces

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



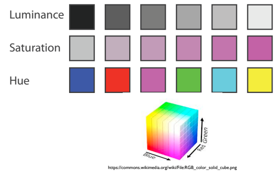
Many color spaces

- 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



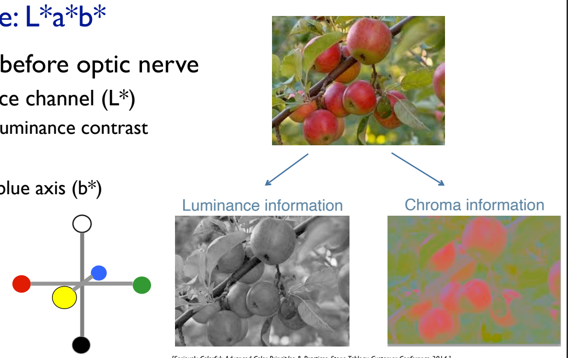
Many color spaces

- 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*

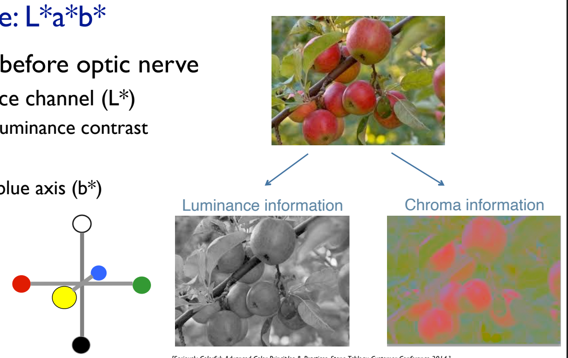
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)



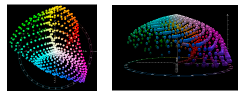
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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



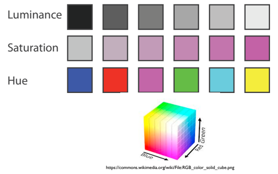
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]



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

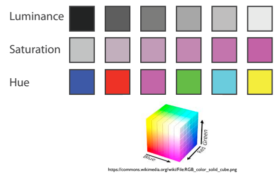
Many color spaces

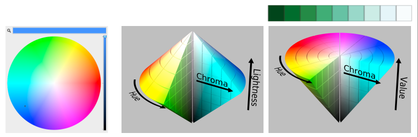
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding



Many color spaces

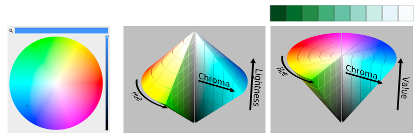
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding

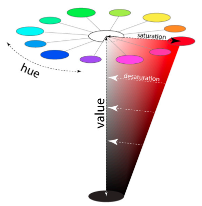




HSL/HSV

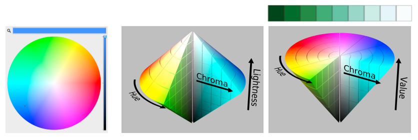
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
-

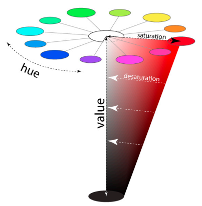


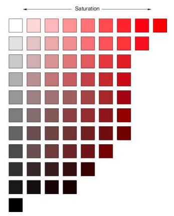


HSL/HSV

- 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

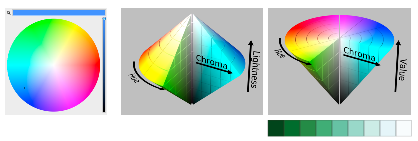






HSL/HSV: Pseudo-perceptual colorspace

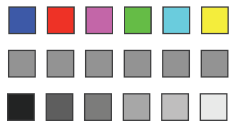
- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance



Corners of the RGB color cube

L from HLS
All the same

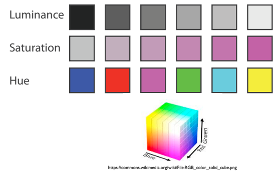
Luminance values

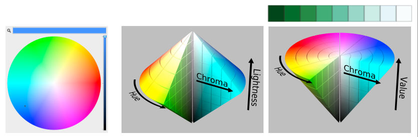


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Many color spaces

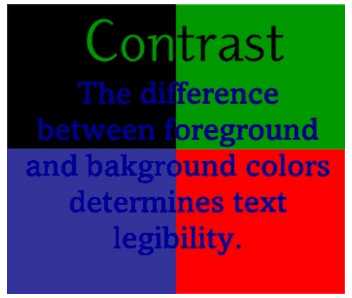
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)

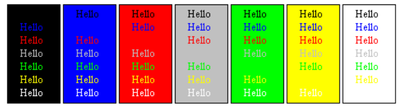




Color Constrast & Naming

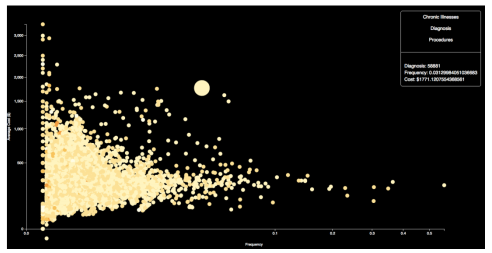
Interaction with the background





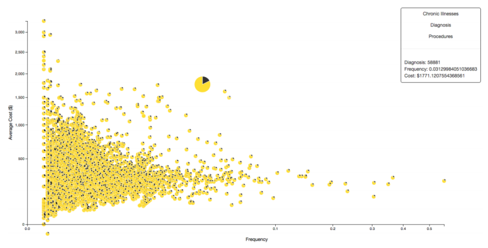
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



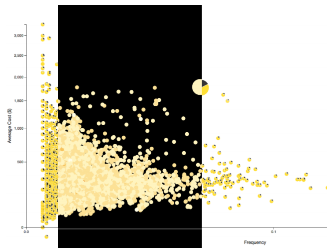
Interaction with the background: tweaking yellow for visibility

- 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

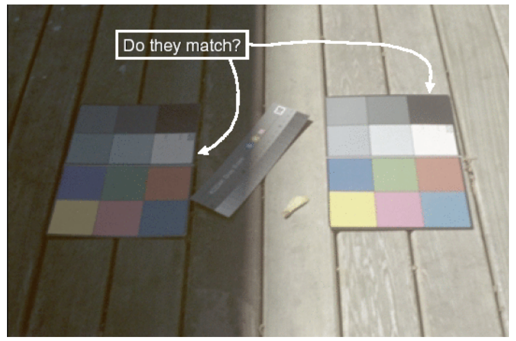


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

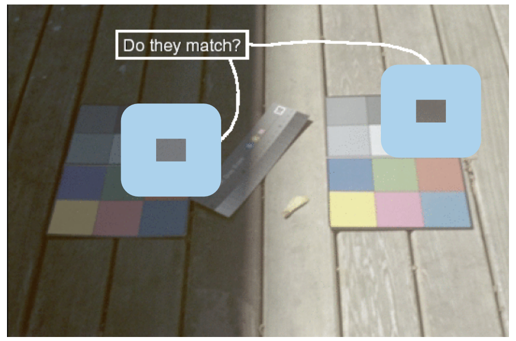
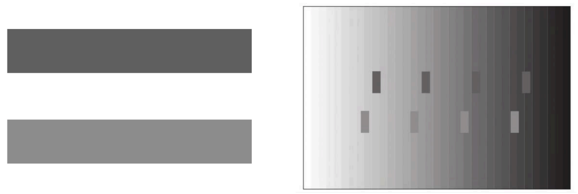


Image courtesy of John McCann via Maureen Stone

Contrast with background



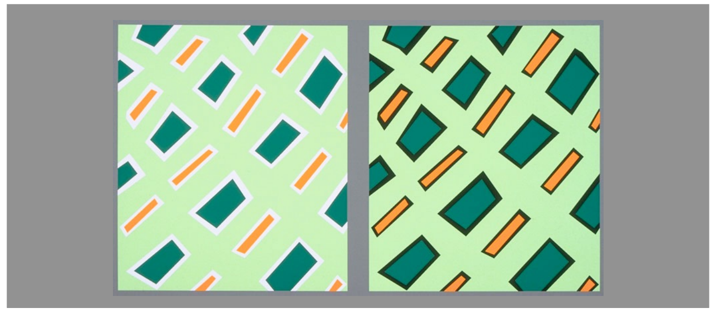
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

Bezold Effect: Outlines matter

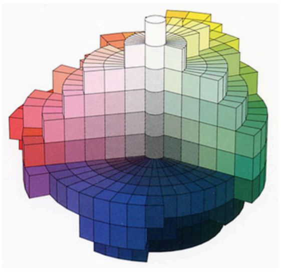


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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

http://www.thedoghousediaries.com/1406

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/

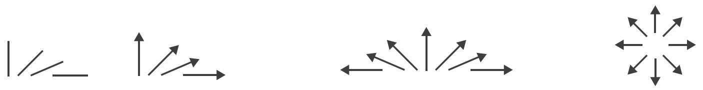
Color is just part of vision system

- 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

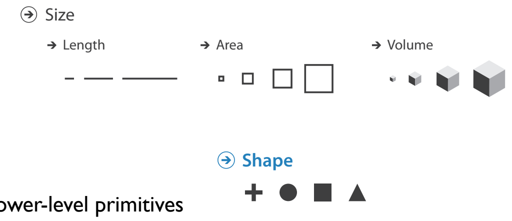
- nonlinear accuracy
  - high: exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (eg 37 vs 38 degrees)

Map other channels

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

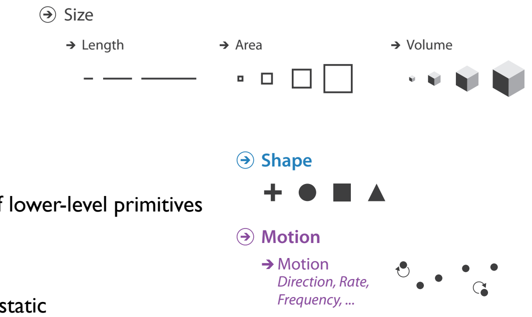
Map other channels

- 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



Spectral sensitivity to luminance