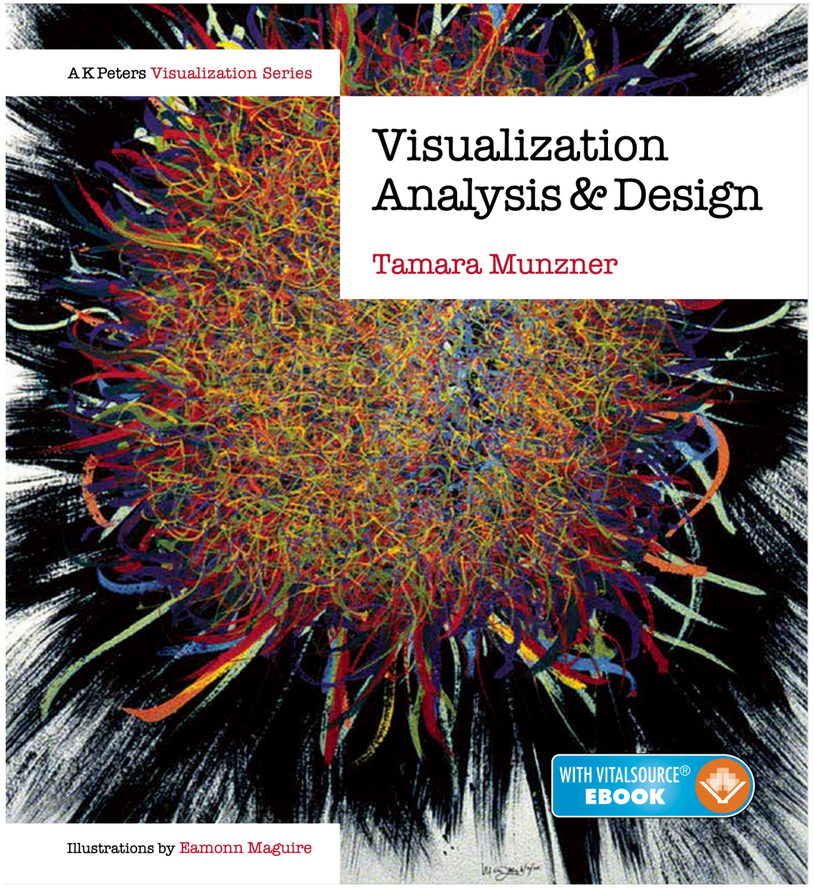
Visualization Analysis & Design
BMVC Tidbits



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University of British Columbia

UBC Biomedical Visualization and Communication
Oct 2025, virtual

https://www.cs.ubc.ca/~tmm/talks.html#bmvc25

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Defining visualization (vis)

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

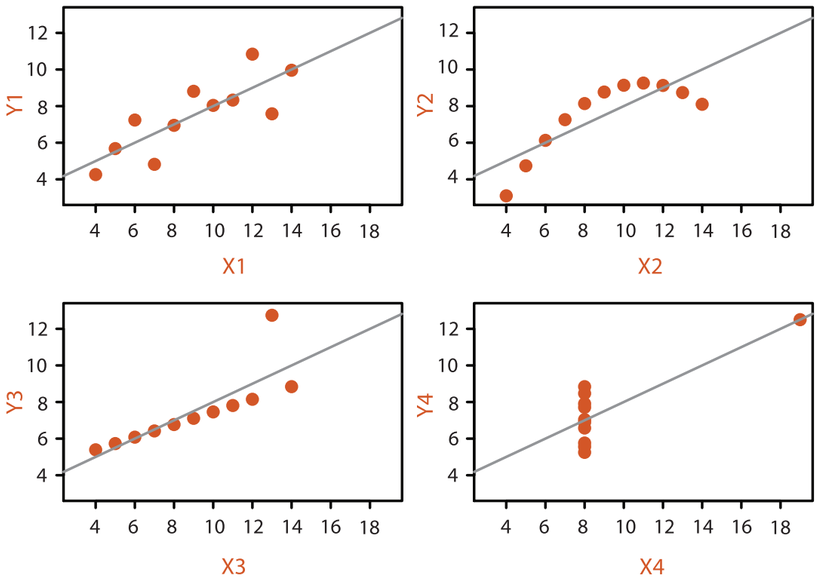
Why represent data visually?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

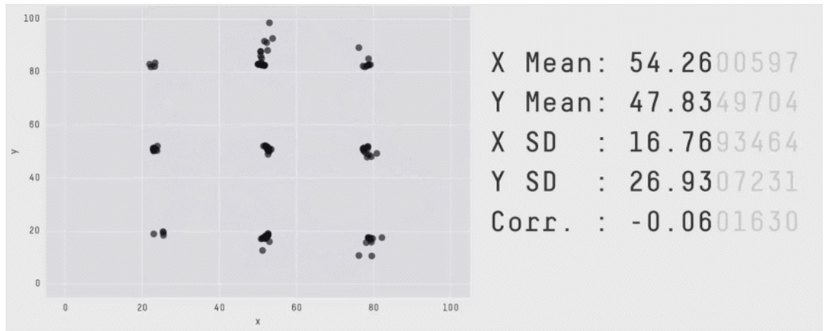
- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

Anscombe's Quartet

Identical statistics	
x mean	9
x variance	10
y mean	7.5
y variance	3.75
x/y correlation	0.816



Datasaurus Dozen



Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing. CHI 2017. Matejka & Fitzmaurice

Visualization analysis framework: Four levels, three questions

- *domain situation*
  - who are the target users?

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- *domain situation*
  - who are the target users?
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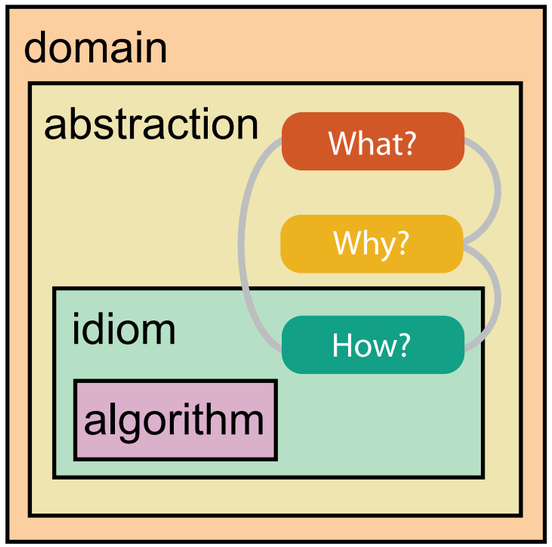
  - translate from specifics of domain to vocabulary of vis
    - **what** is shown? **data** abstraction
    - **why** is the user looking at it? **task** abstraction

[A Nested Model of Visualization Design and Validation. *Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).*]



[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

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- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate

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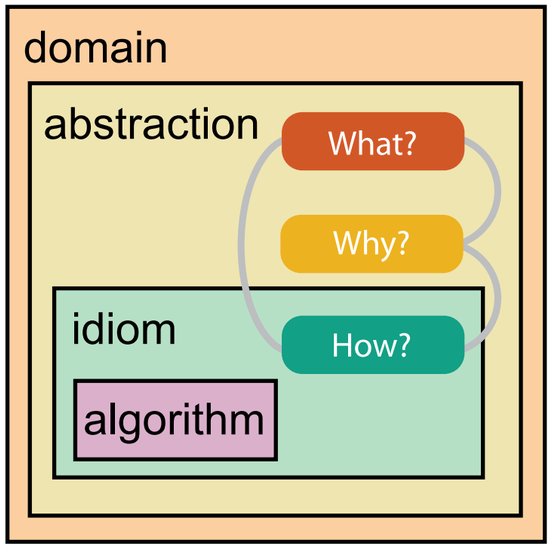

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- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate
- *algorithm*
  - efficient computation

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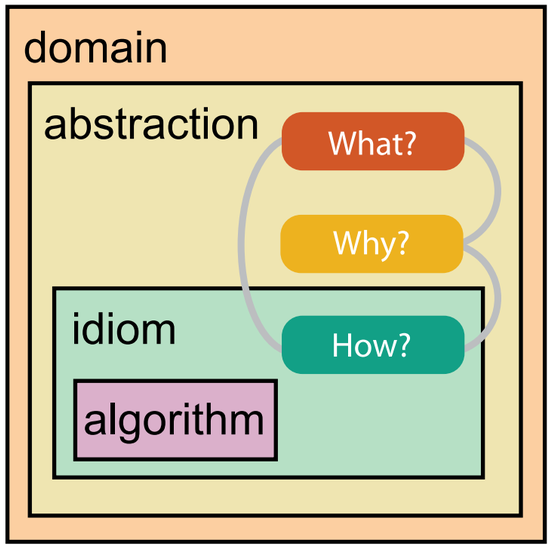

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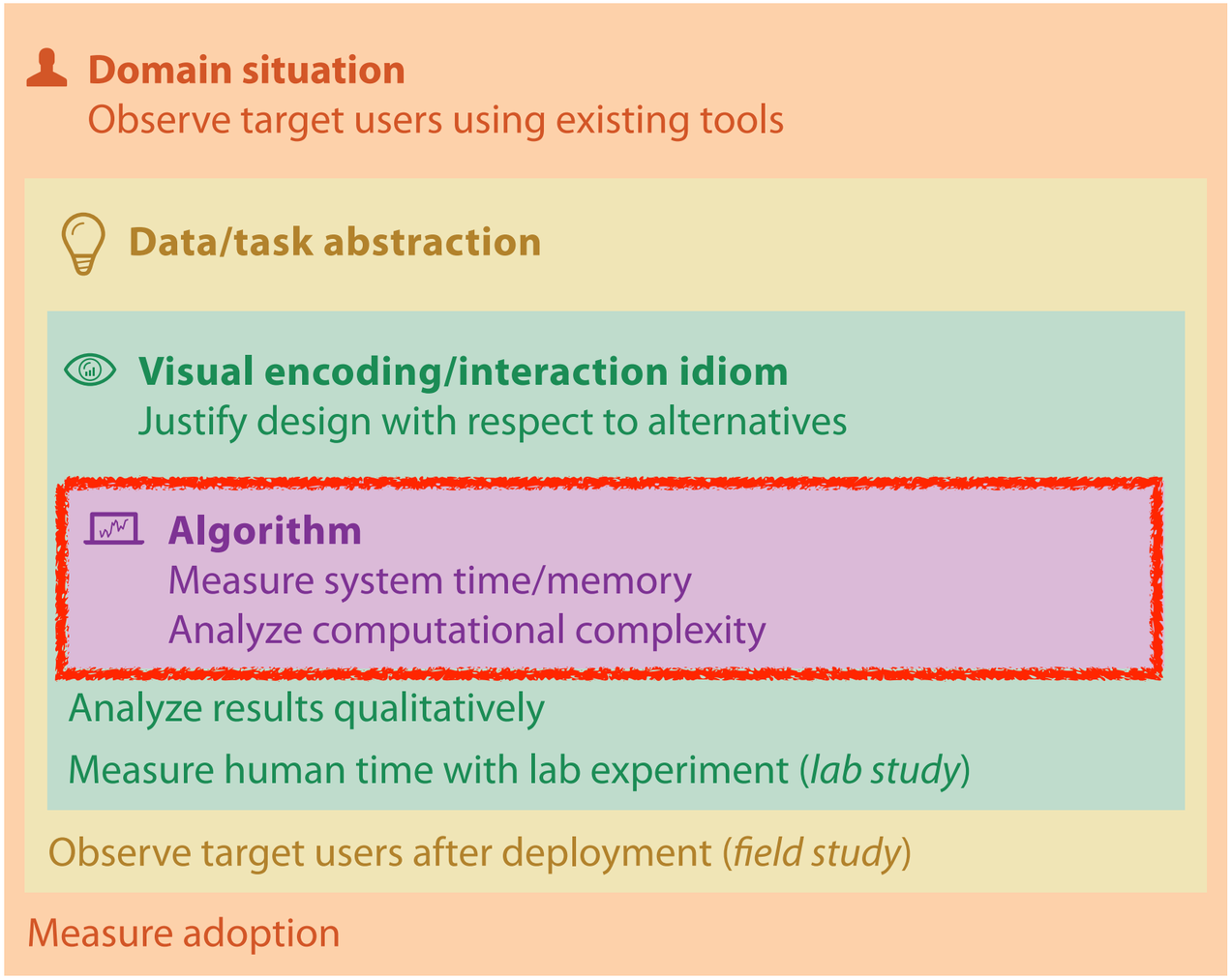
Why is validation difficult?

- different ways to get it wrong at each level

Why is validation difficult?

- solution: use methods from different fields at each level



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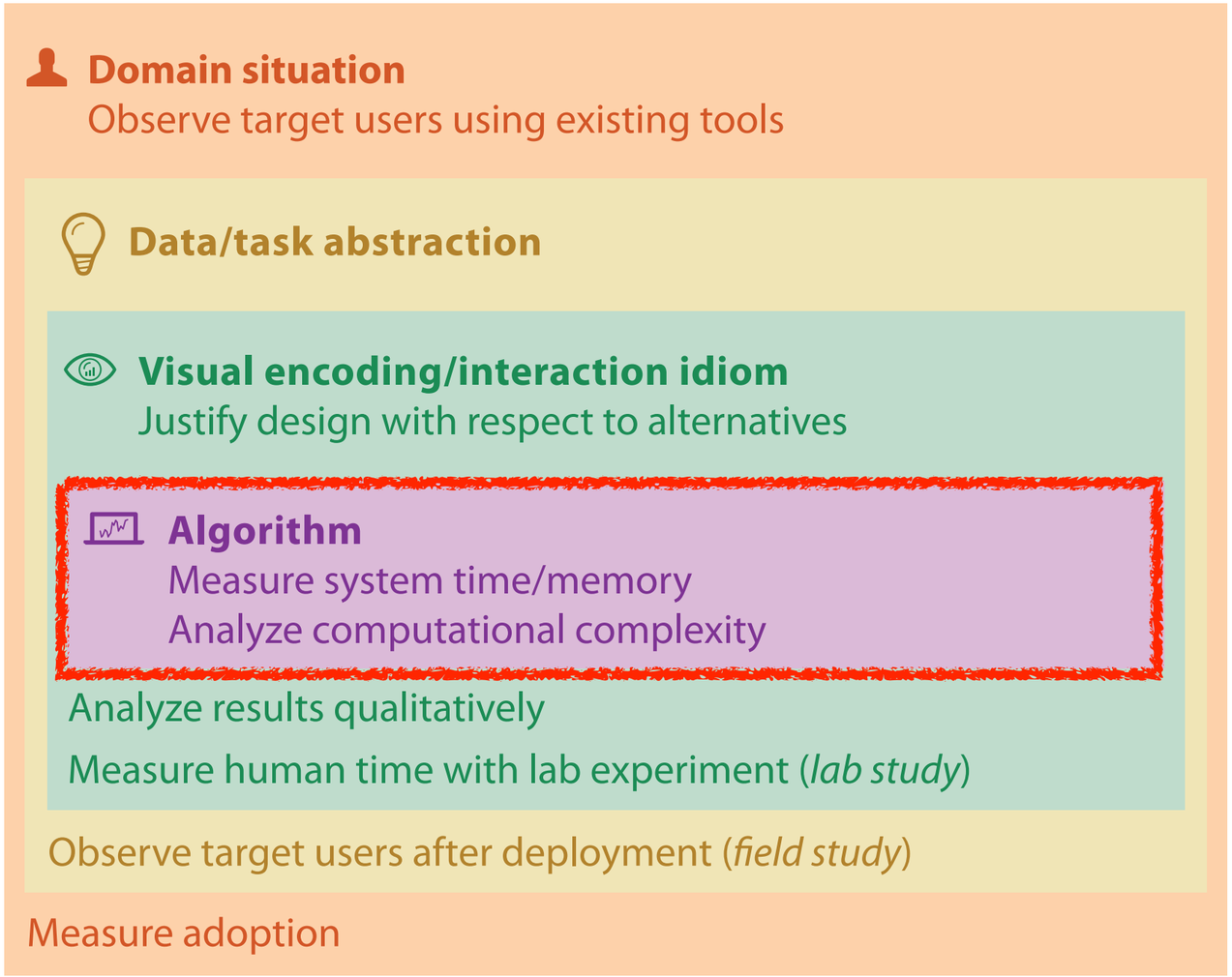
computer science



technique-driven work

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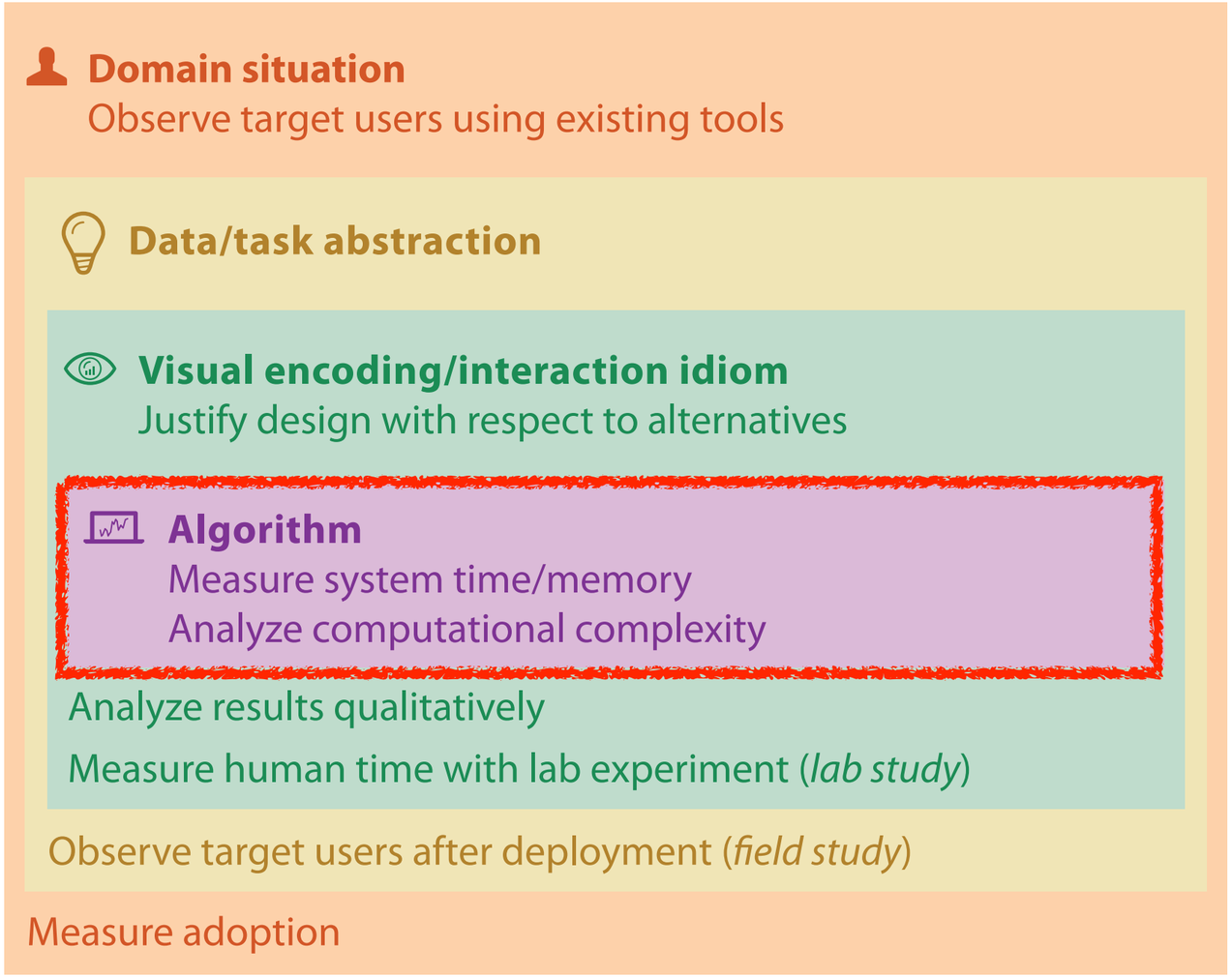

design

computer science

cognitive psychology

technique-driven work

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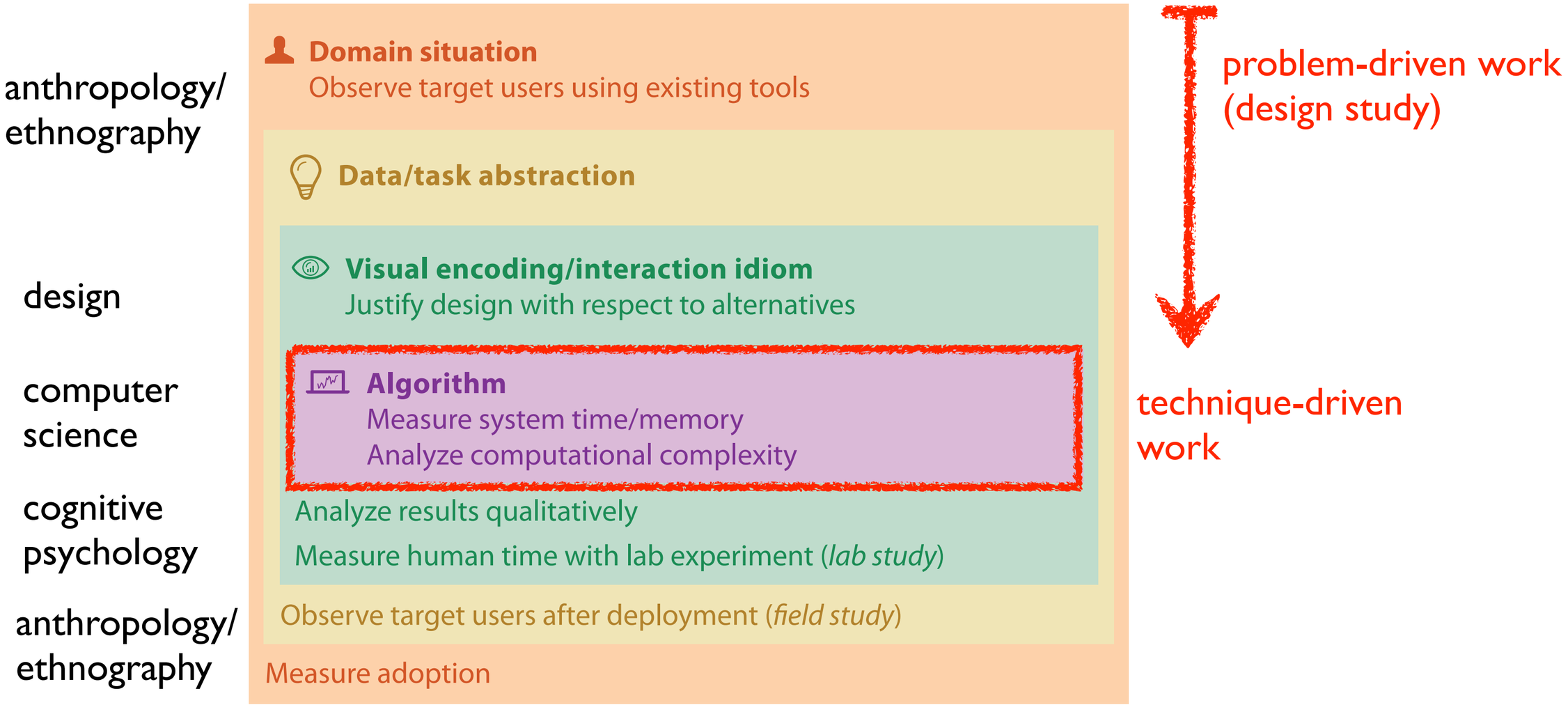

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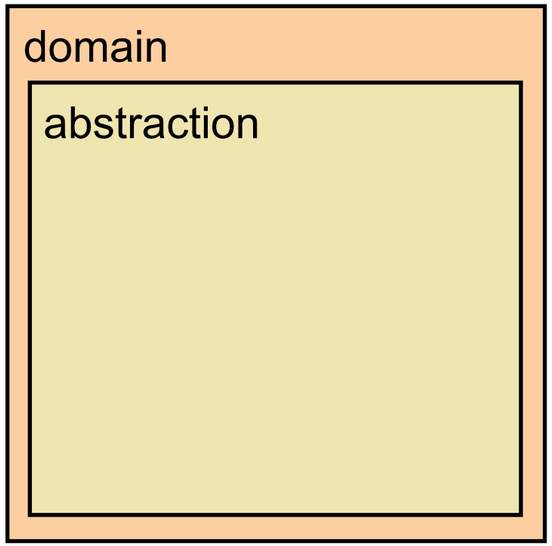
Abstractions

Abstraction: Data & task

- map *what* and *why* into generalized terms
  - identify tasks that users wish to perform, or already do
  - find data types that will support those tasks
    - possibly transform /derive if need be



Example: Find good movies

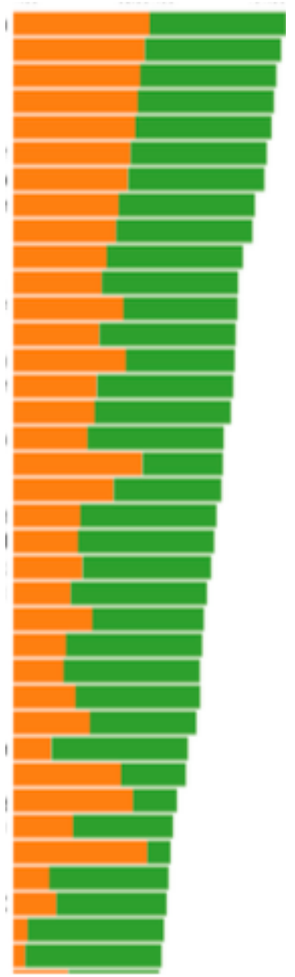
- identify good movies in genres I like
- domain:
  - general population, movie enthusiasts
- task: what is a good movie for me?
  - highly rated by critics?
  - highly rated by audiences?
  - successful at the box office?
  - similar to movies I liked?
  - matches specific genres?
- data: (is it available?)
  - yes! data sources IMDB, Rotten Tomatoes...

Example: Find good movies

- one possible choice for data and tasks, in domain language
  - data: combine audience ratings and critic ratings
  - task: find high-scoring movies for specific genre
- abstractions?
  - attribute: audience & critic ratings
    - ordinal
      - levels: 3 or 5 or 10...
  - attribute: genre
    - categorical
      - levels: < 20
  - items: movies
    - items: millions
  - task: find extreme (high) values

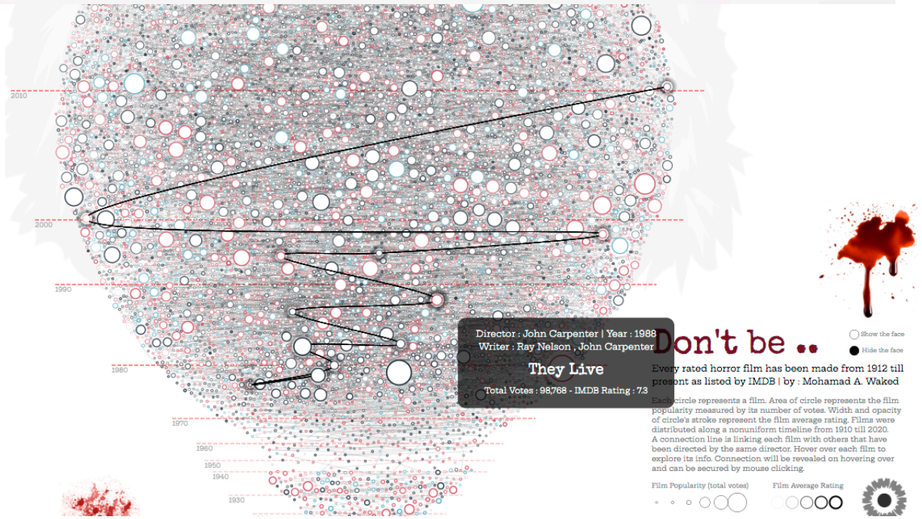
one possible idiom

- stacked bar chart for ratings



Example: Horrified

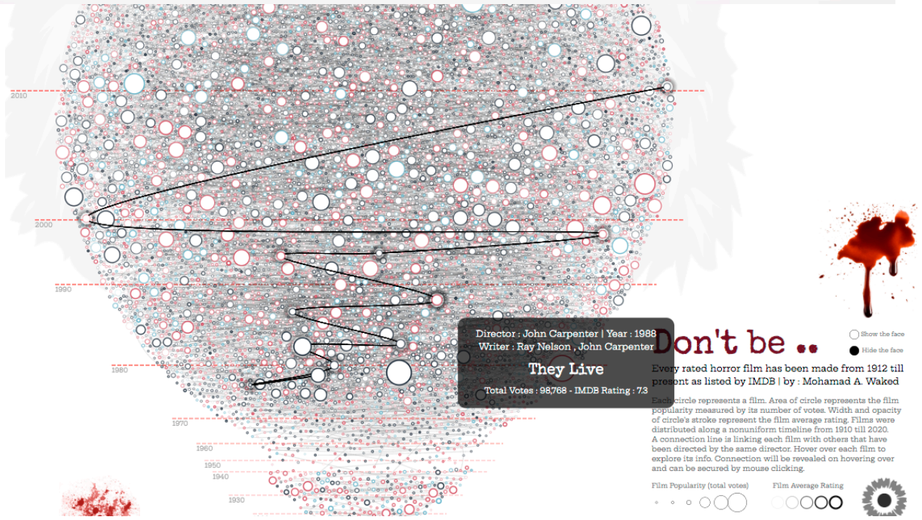
- same task: high-score movies
- slightly different data
  - 14K rated horror movies from IMDB



https://www.alhadaqa.com/wp-content/uploads/2020/04/horrified.html

Example: Horrified

- same task: high-score movies
- slightly different data
  - 14K rated horror movies from IMDB
- very different visual encoding idiom
  - circle per item (movie)
  - circle area = popularity
  - stroke width/opacity = avg rating
  - year made = vertical position
- interaction idiom
  - lines connect movies w/ same director, on mouseover



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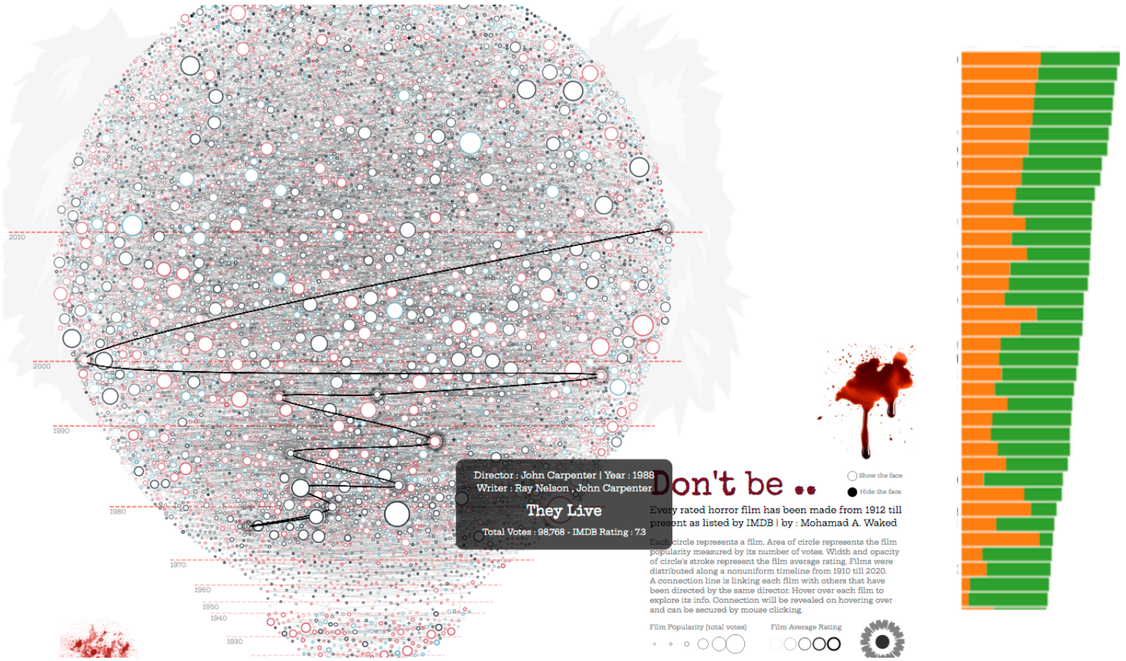
Example: Horrified vs stacked bars

- horrified: browse/explore
- stacked bars: locate/lookup

- which is better?
  - depends on goals / task
    - enjoy, social context, lots of time
    - find 2nd-best rated movie of all time
      - Jeopardy call, < 10 seconds to respond!



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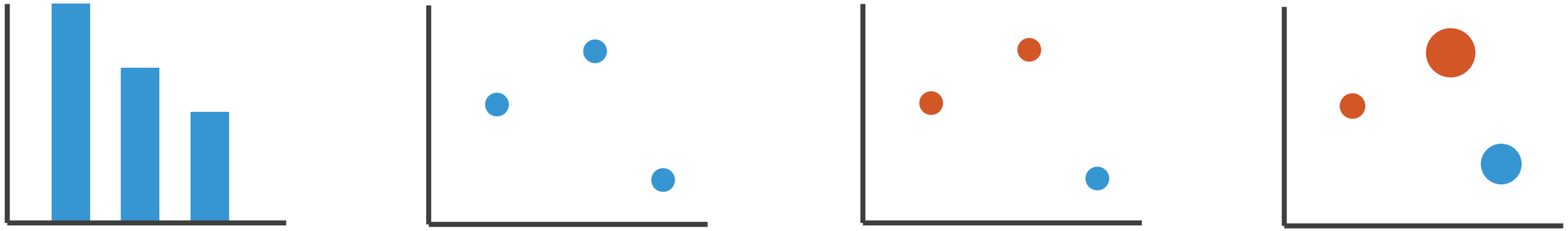
Visual Encoding Idioms

Visual encoding

- analyze idiom structure



Definitions: Marks and channels

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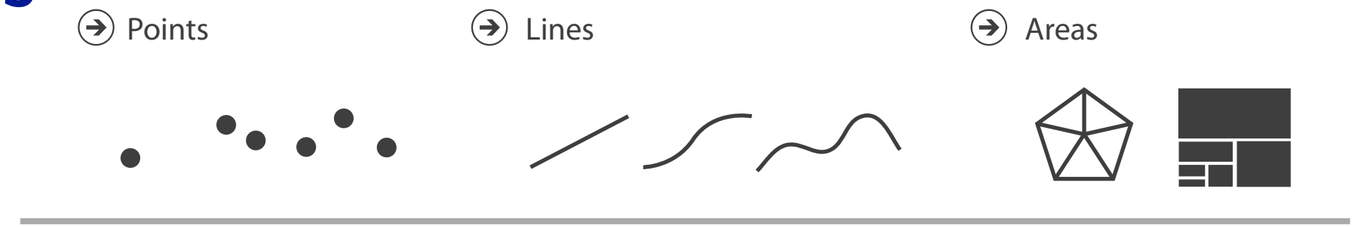
- marks
  - geometric primitives



Definitions: Marks and channels

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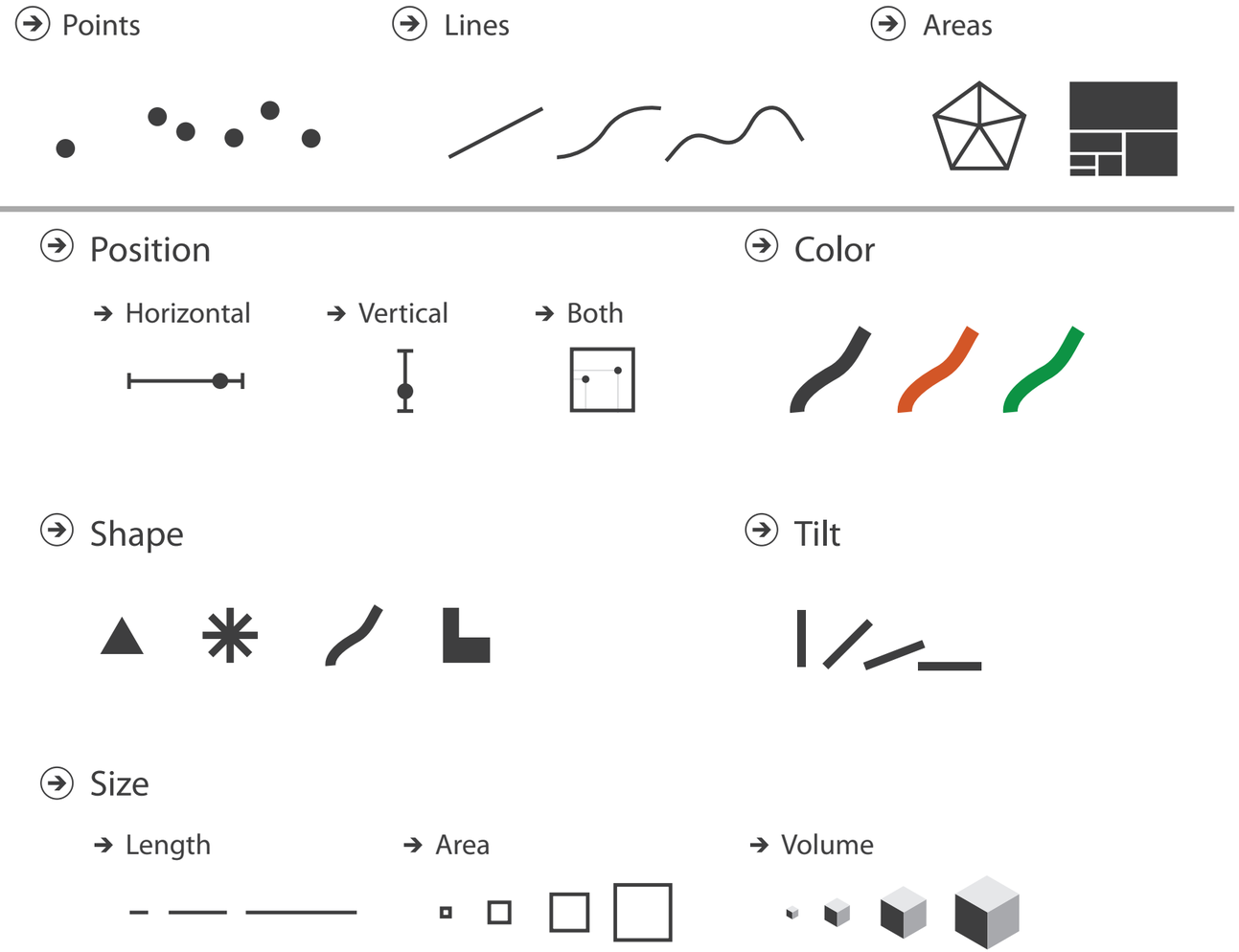
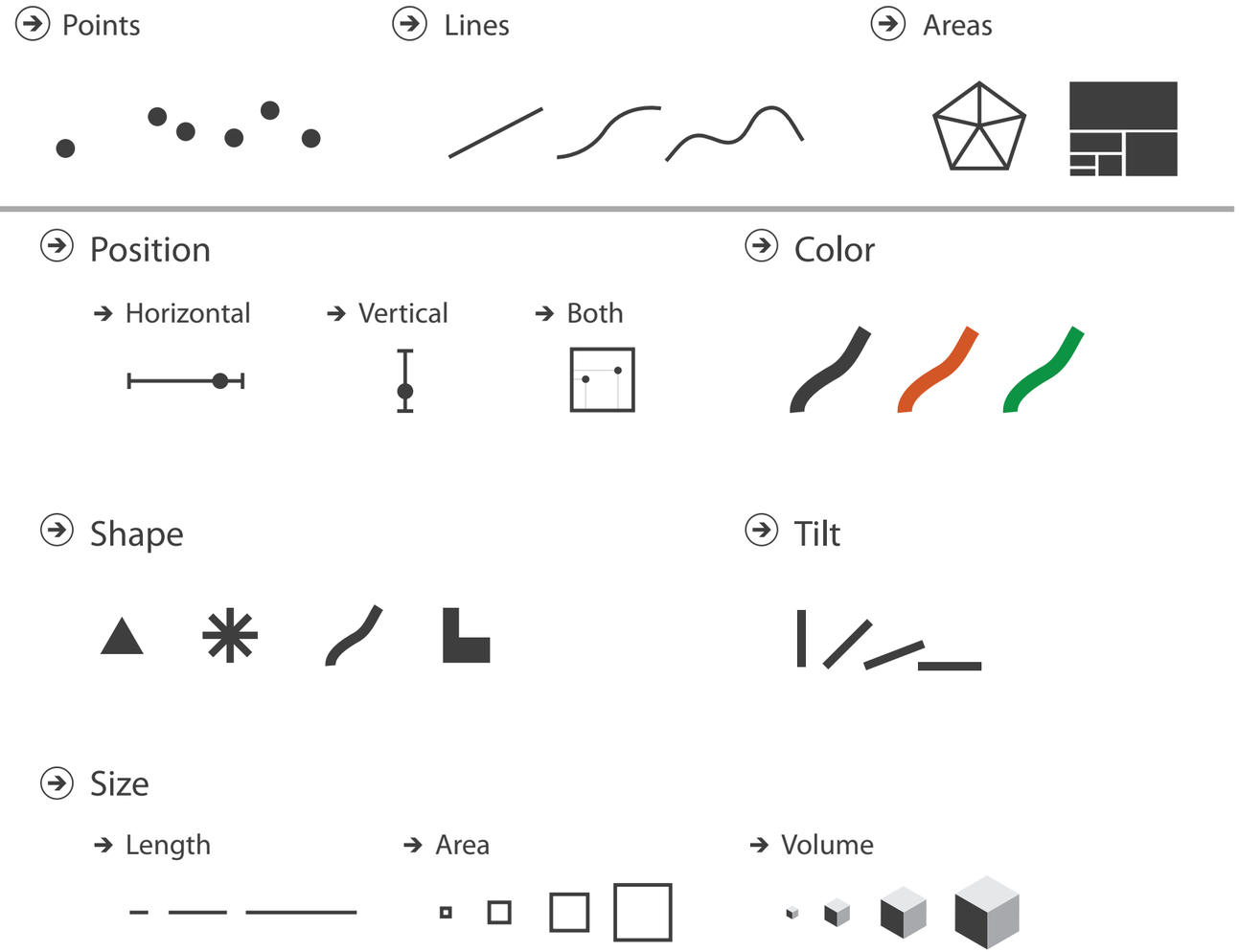


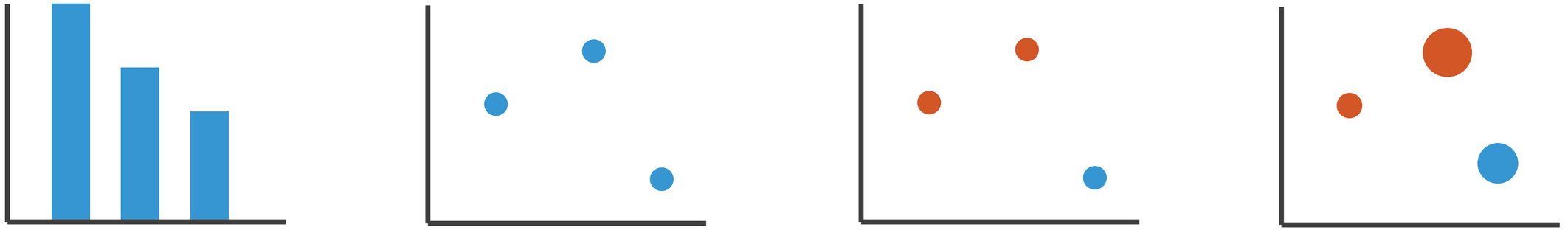
Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
    - type & amount of information that can be conveyed to human perceptual system



Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

mark: line

Visual encoding

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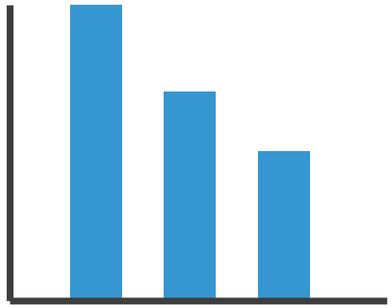

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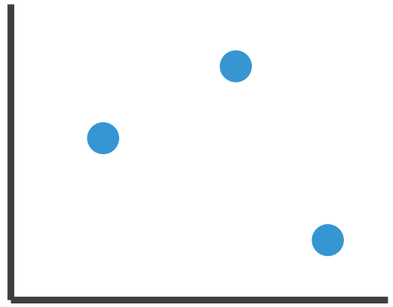
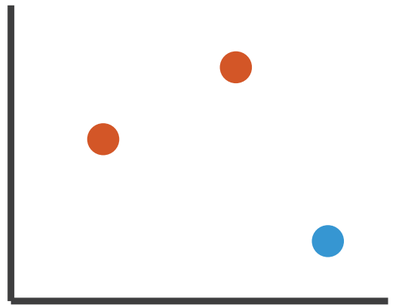
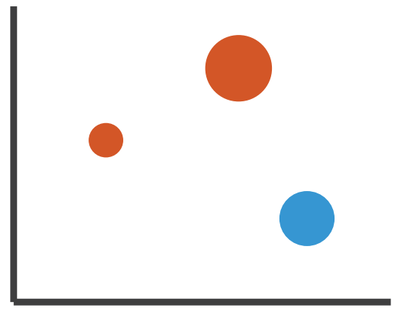
mark: line



2:
vertical position
horizontal position

mark: point





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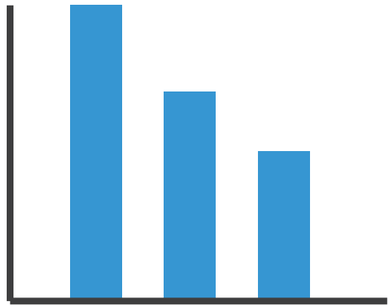

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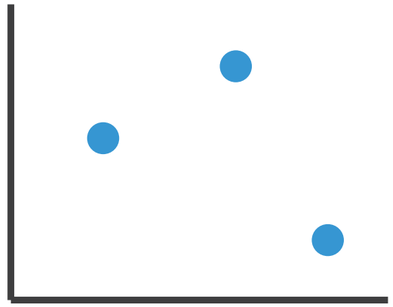

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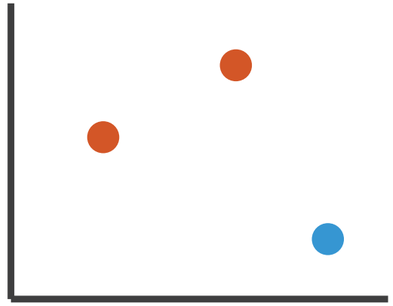
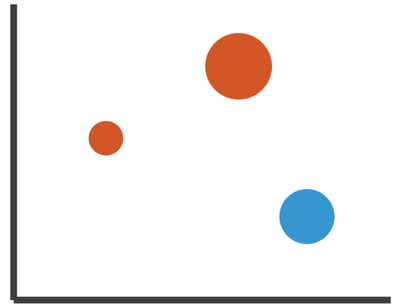


3:
vertical position
horizontal position
color hue

mark: point



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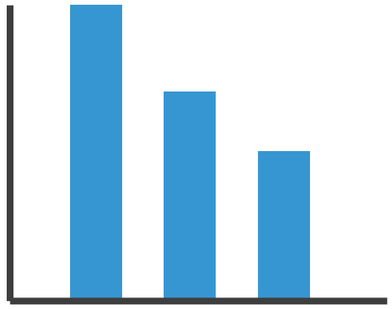

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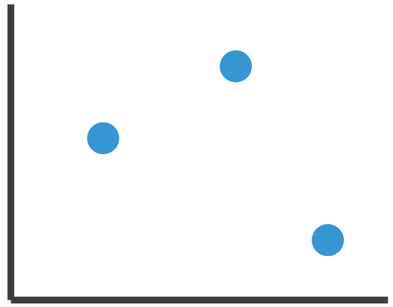

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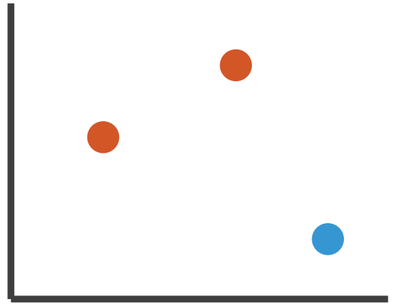

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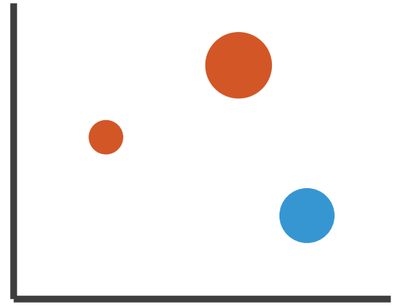


4:
vertical position
horizontal position
color hue
size (area)

mark: point

Channels: Rankings

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Spatial region

Color hue

Motion

Shape

Channels: Rankings

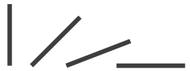
Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle



Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

Shape

- expressiveness
  - match channel and data characteristics

Channels: Rankings

Magnitude Channels: Ordered Attributes

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Position on unaligned scale

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Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

Shape

Attribute Types

→ Categorical

→ Ordered

→ *Ordinal*

→ *Quantitative*

- expressiveness
  - match channel and data characteristics
    - magnitude for ordered
      - how much? which rank?
    - identity for categorical
      - what?

Channels: Rankings

Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Best

Effectiveness

Least

Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

Shape

- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception

Channels: Rankings

Magnitude Channels: Ordered Attributes

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Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

Best

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Least

Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

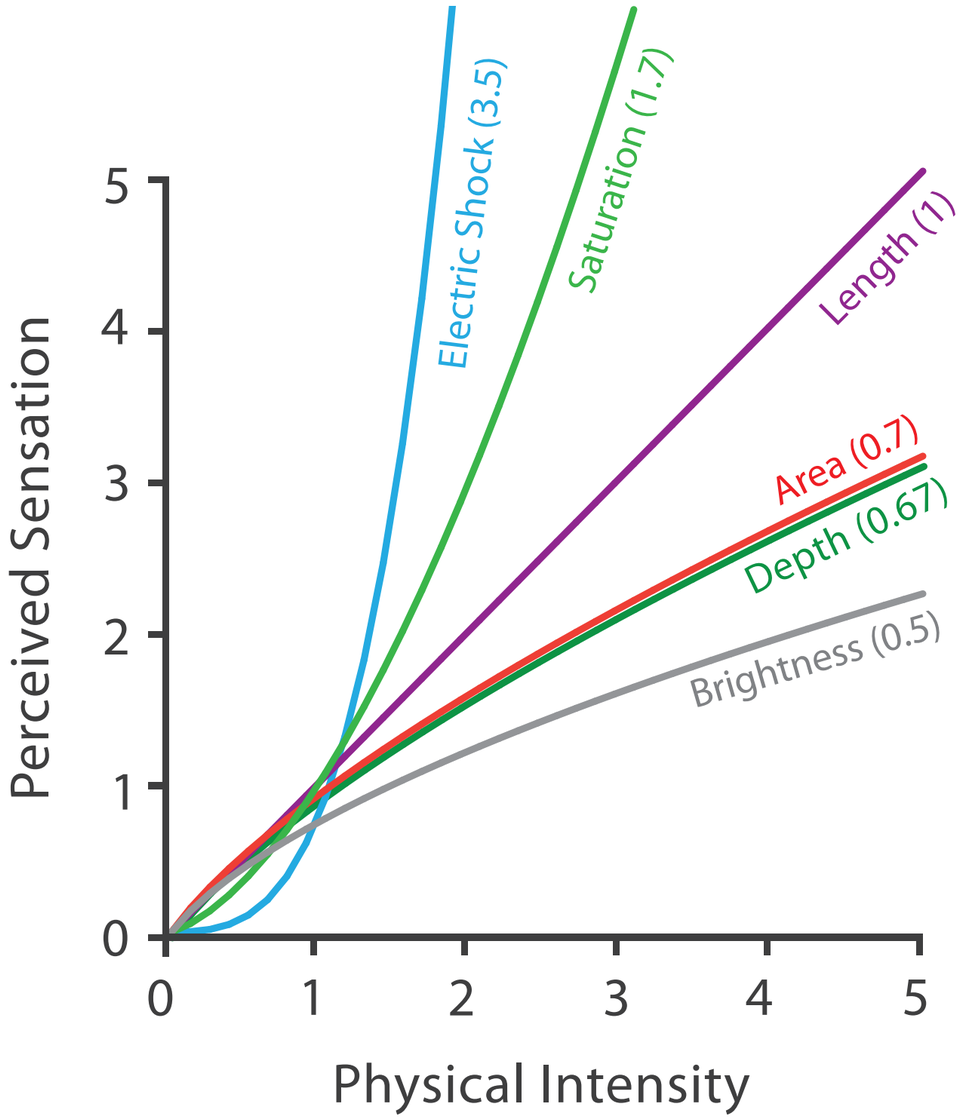
Shape

- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
  - spatial position ranks high for both

Accuracy: Fundamental theory

- length is accurate: linear
- others magnified or compressed
  - –exponent characterizes

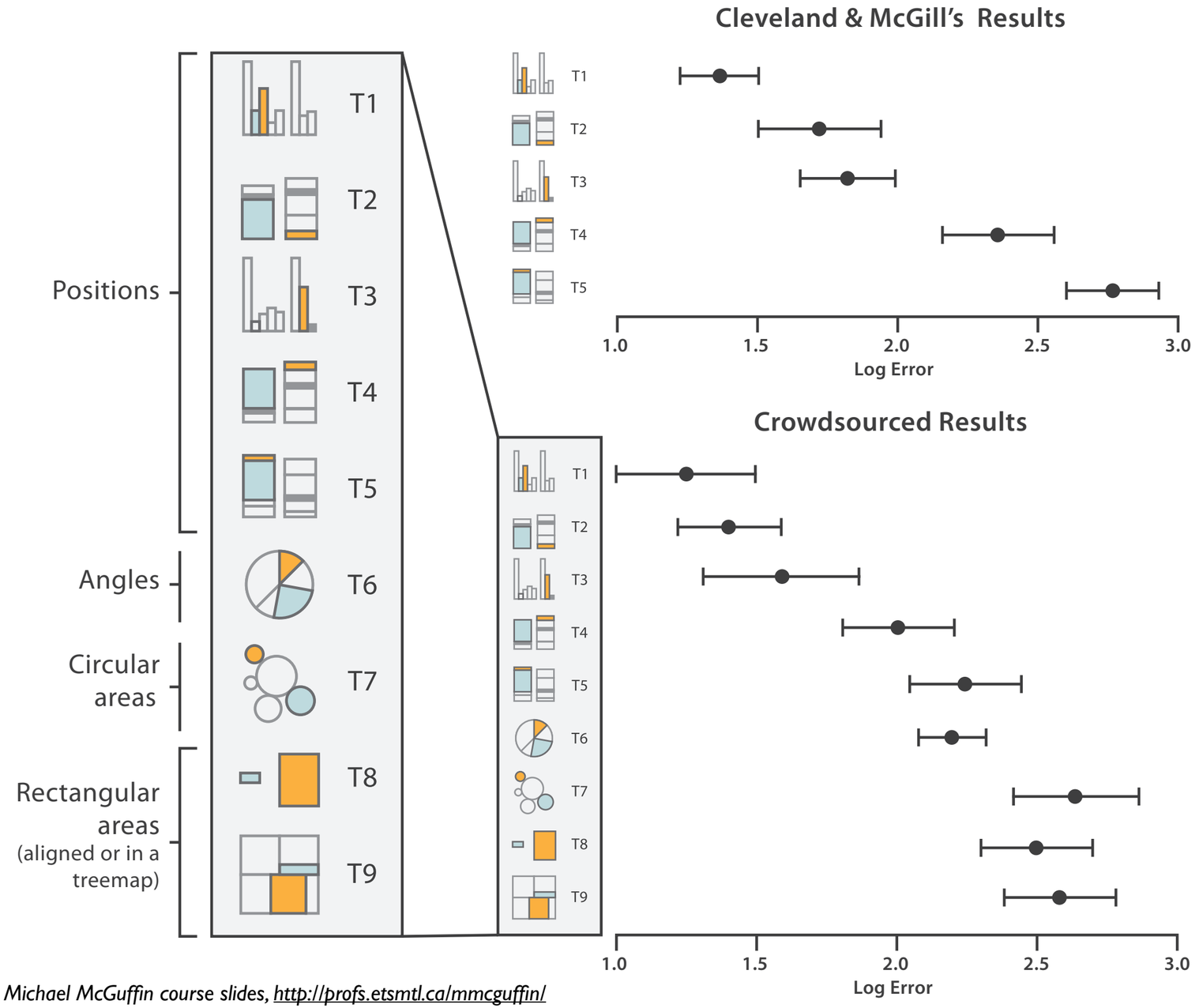
Steven's Psychophysical Power Law: $S = I^N$



S = sensation

I = intensity

Accuracy: Vis experiments

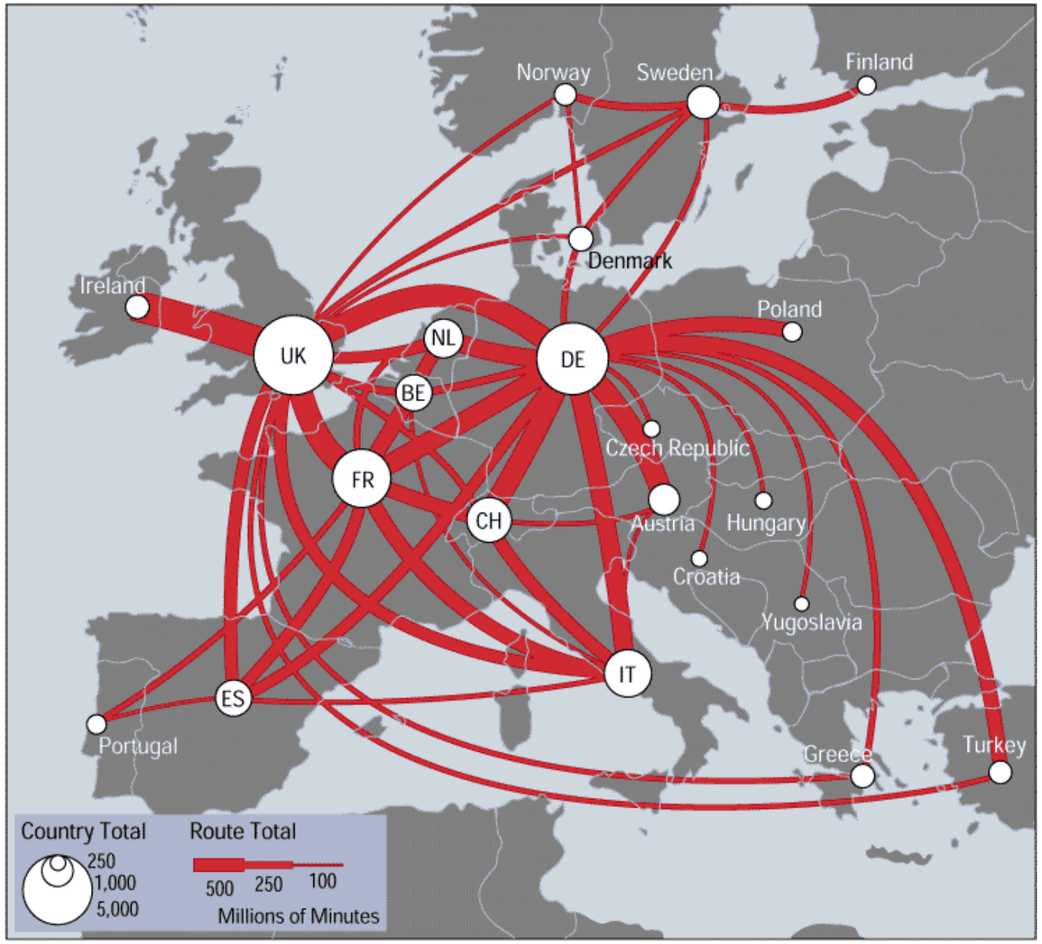


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

after Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/

Discriminability: How many usable steps?

- must be sufficient for number of attribute levels to show
  - linewidth: few bins



[mappa.mundi.net/maps/maps_014/telegeography.html]

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute

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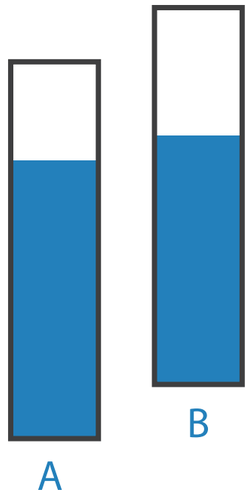
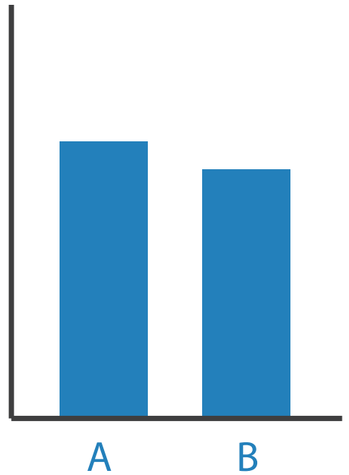
length



position along unaligned common scale



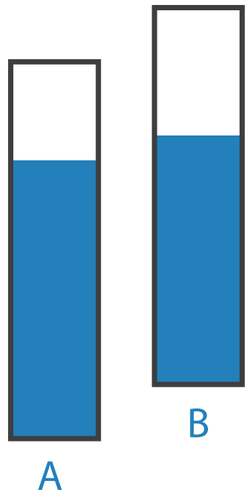
position along aligned scale

after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

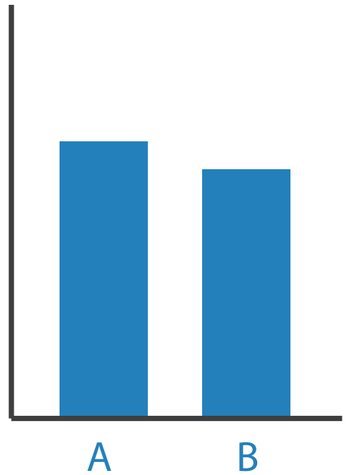
Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment
  - Weber's Law: ratio of increment to background is constant

length



position along unaligned common scale



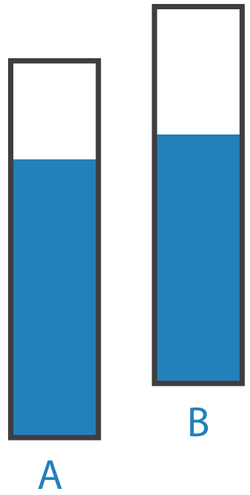
position along aligned scale

after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

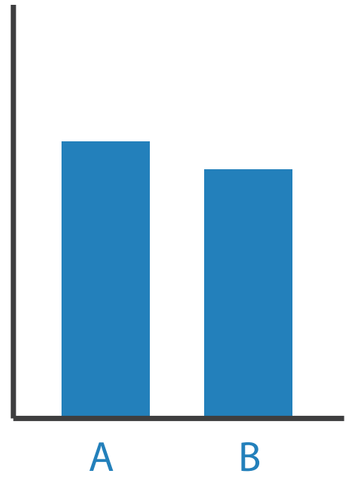
Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment
  - Weber's Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement

length



position along unaligned common scale



position along aligned scale

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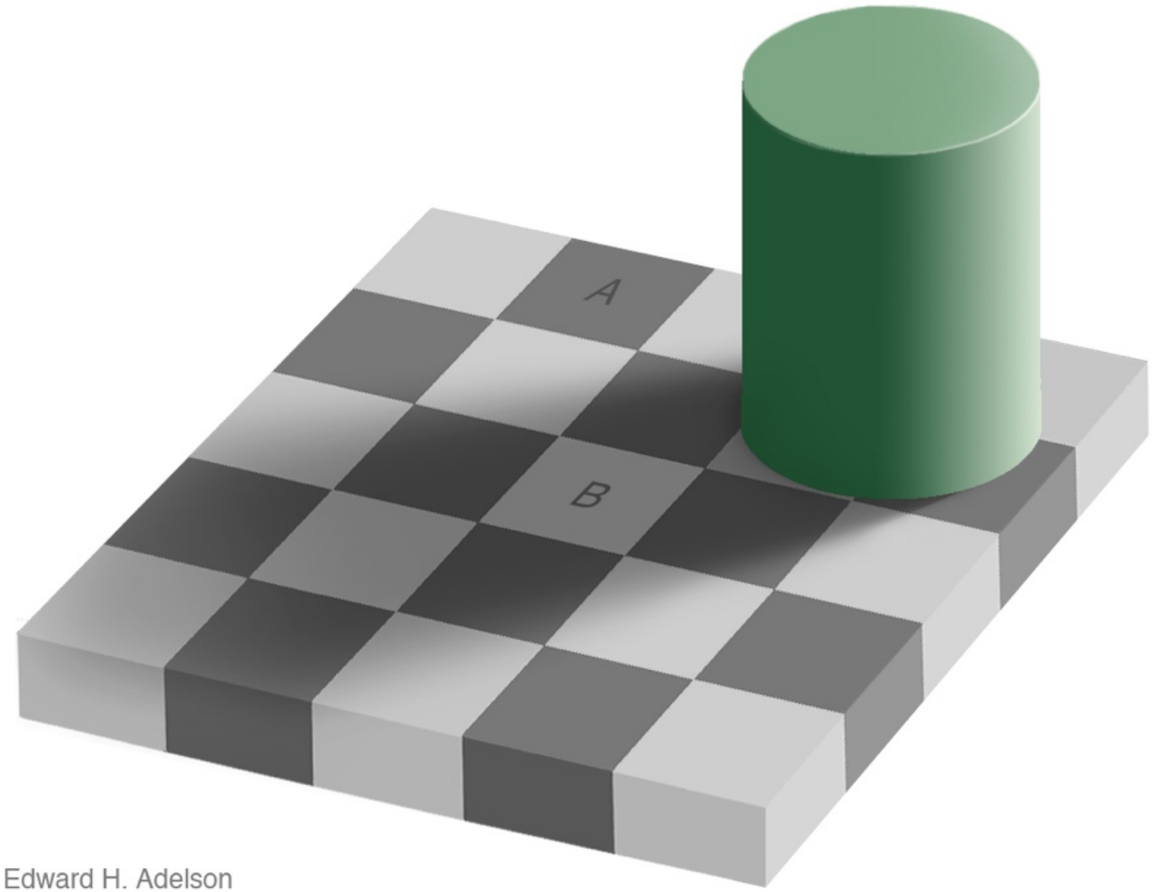
Relative luminance judgements

- perception of luminance is contextual based on contrast with surroundings



Edward H. Adelson

http://persci.mit.edu/gallery/checkershadow

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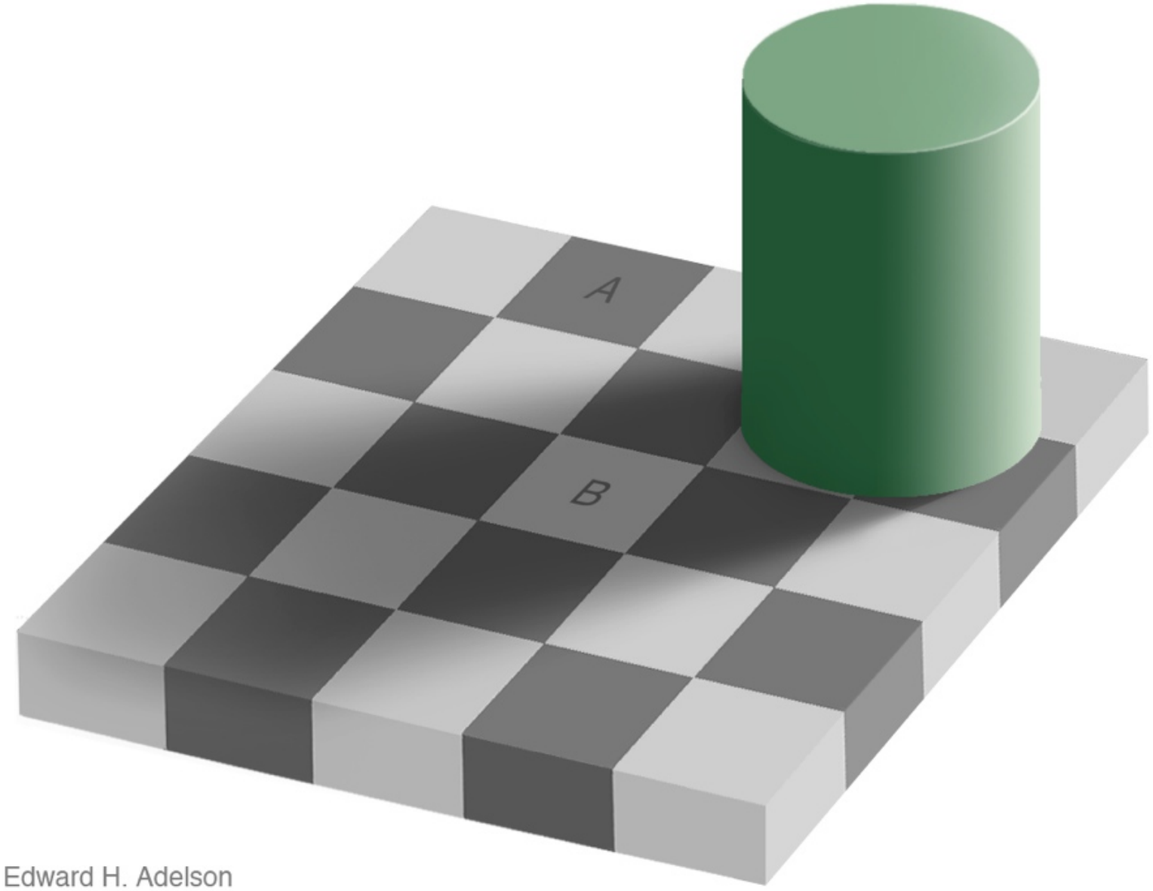
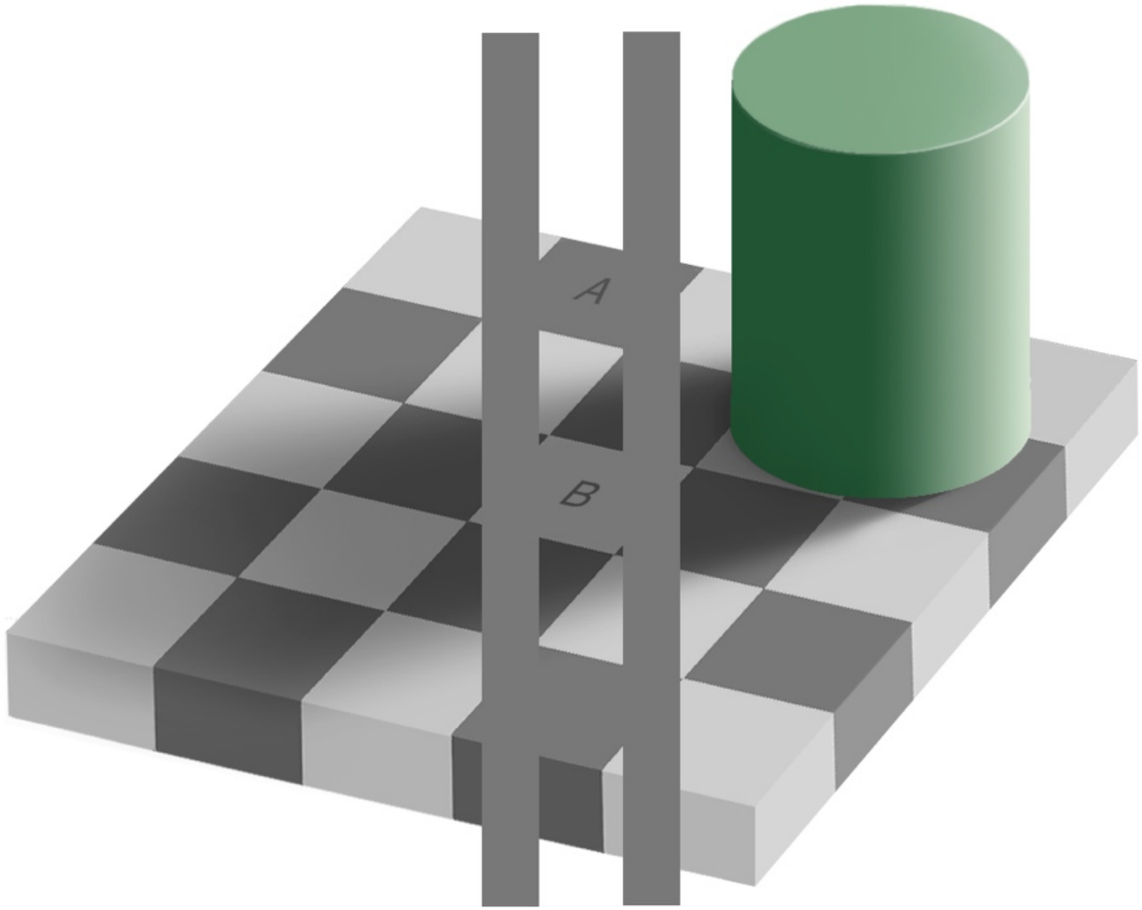


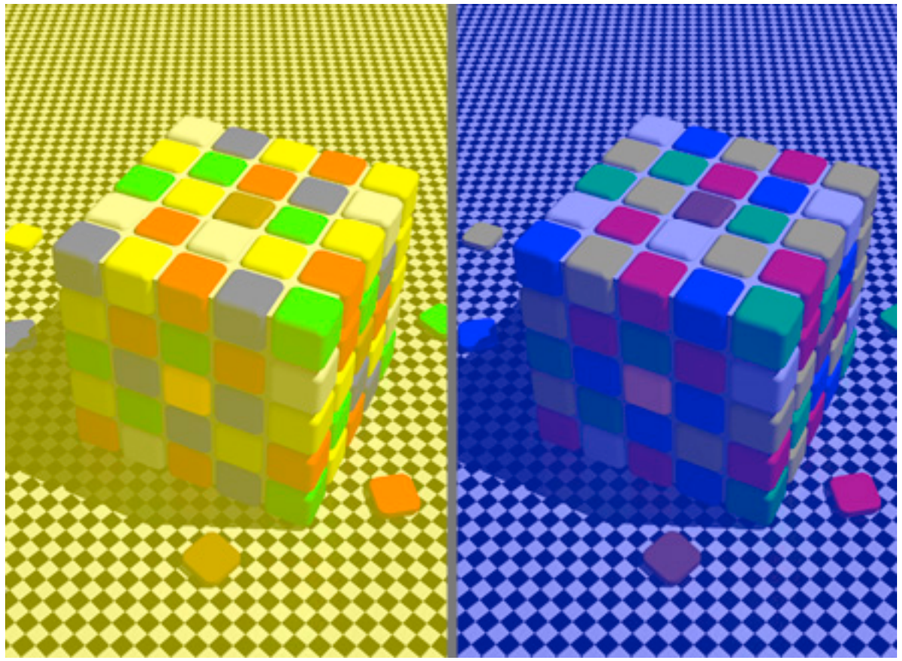
Edward H. Adelson



http://persci.mit.edu/gallery/checkershadow

Relative color judgements

- color constancy across broad range of illumination conditions



http://www.purveslab.net/seeforyourself/

Relative color judgements

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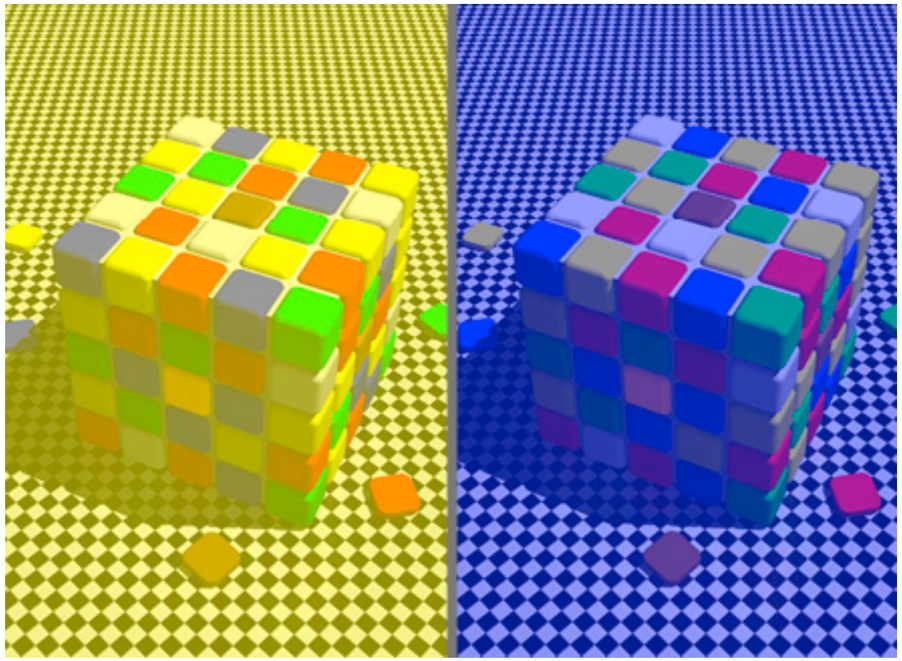
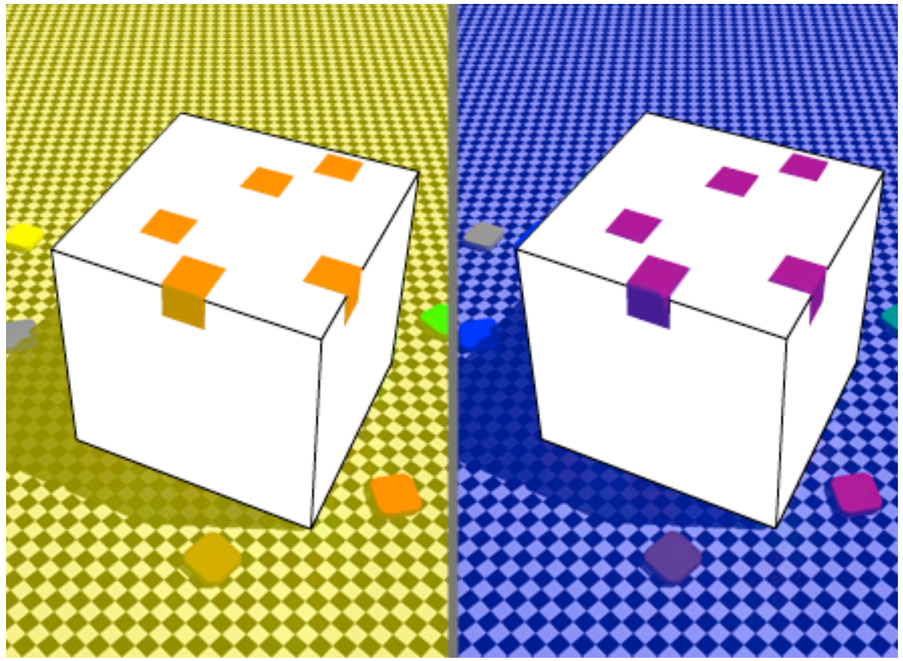




http://www.purveslab.net/seeforyourself/

Grouping

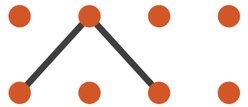
- containment
- connection

- proximity
  - same spatial region
- similarity
  - same values as other categorical channels

Marks as Links

➔ Containment

➔ Connection

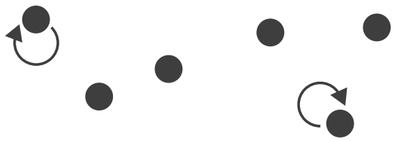


➔ Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion

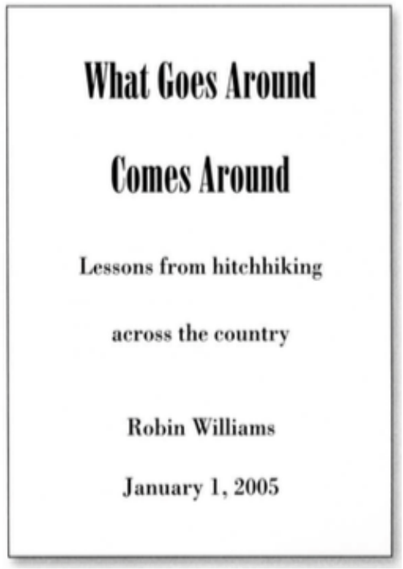


Shape

Graphic Design for Non-Designers

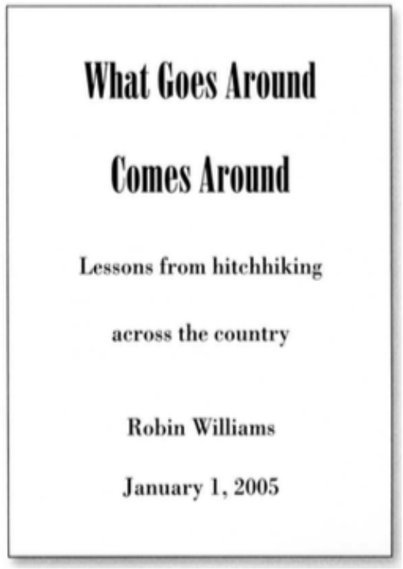
Form: Basic graphic design ideas

Form: Basic graphic design ideas



Form: Basic graphic design ideas

- proximity
  - do group related items together
  - avoid equal whitespace between unrelated



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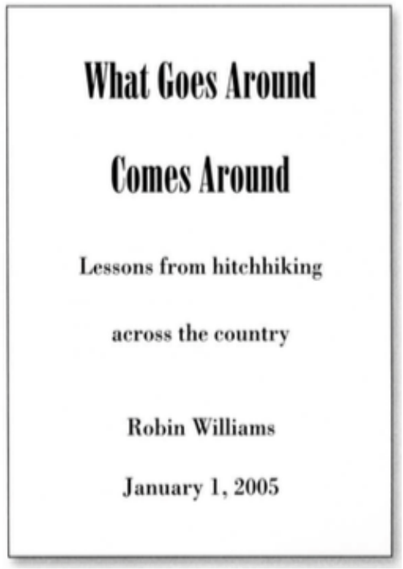

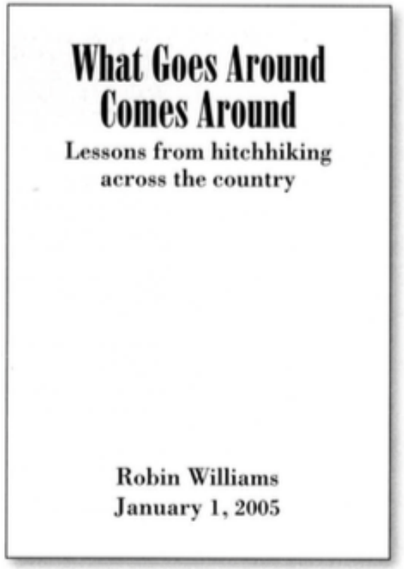

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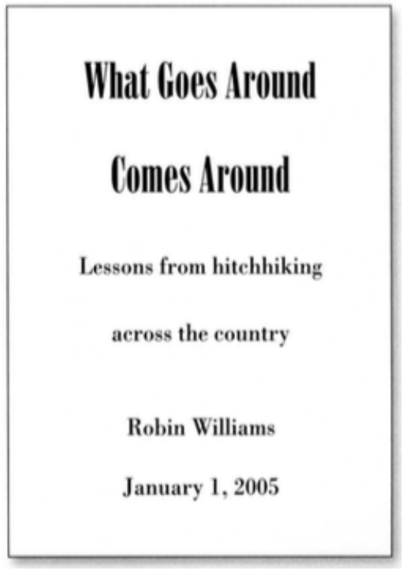

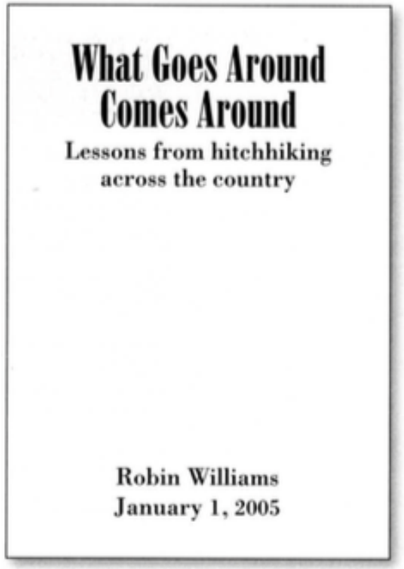

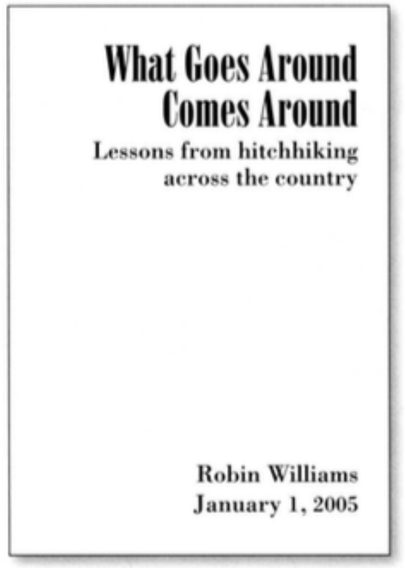

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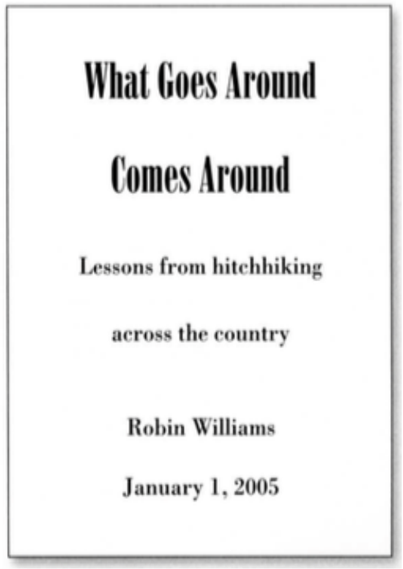

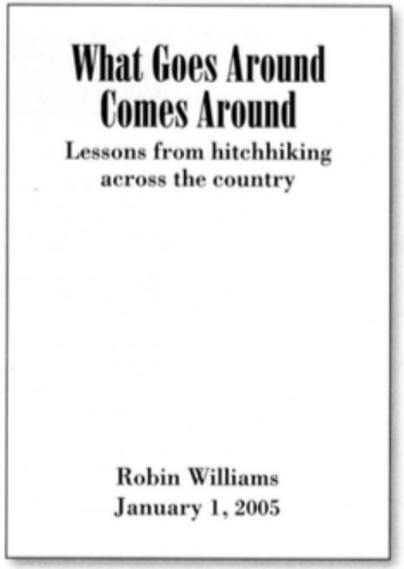

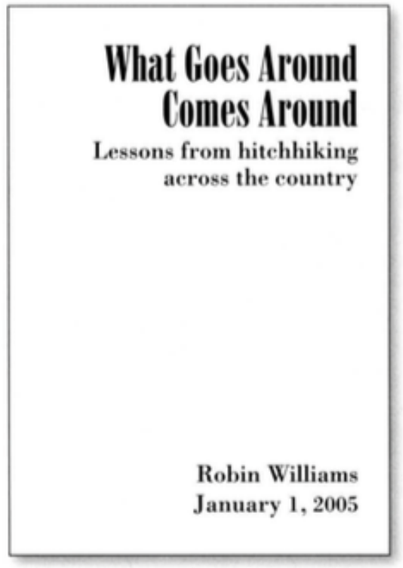

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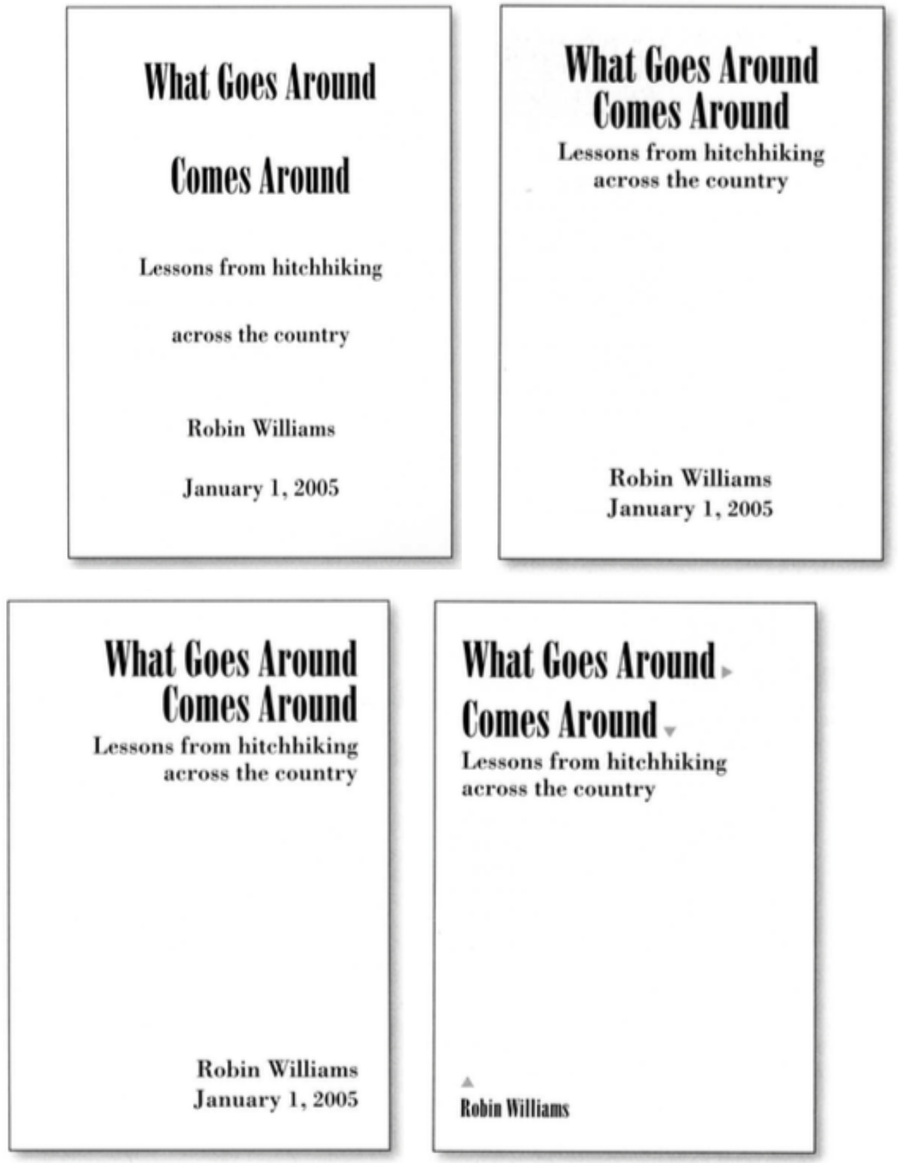

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  - if not identical, then very different
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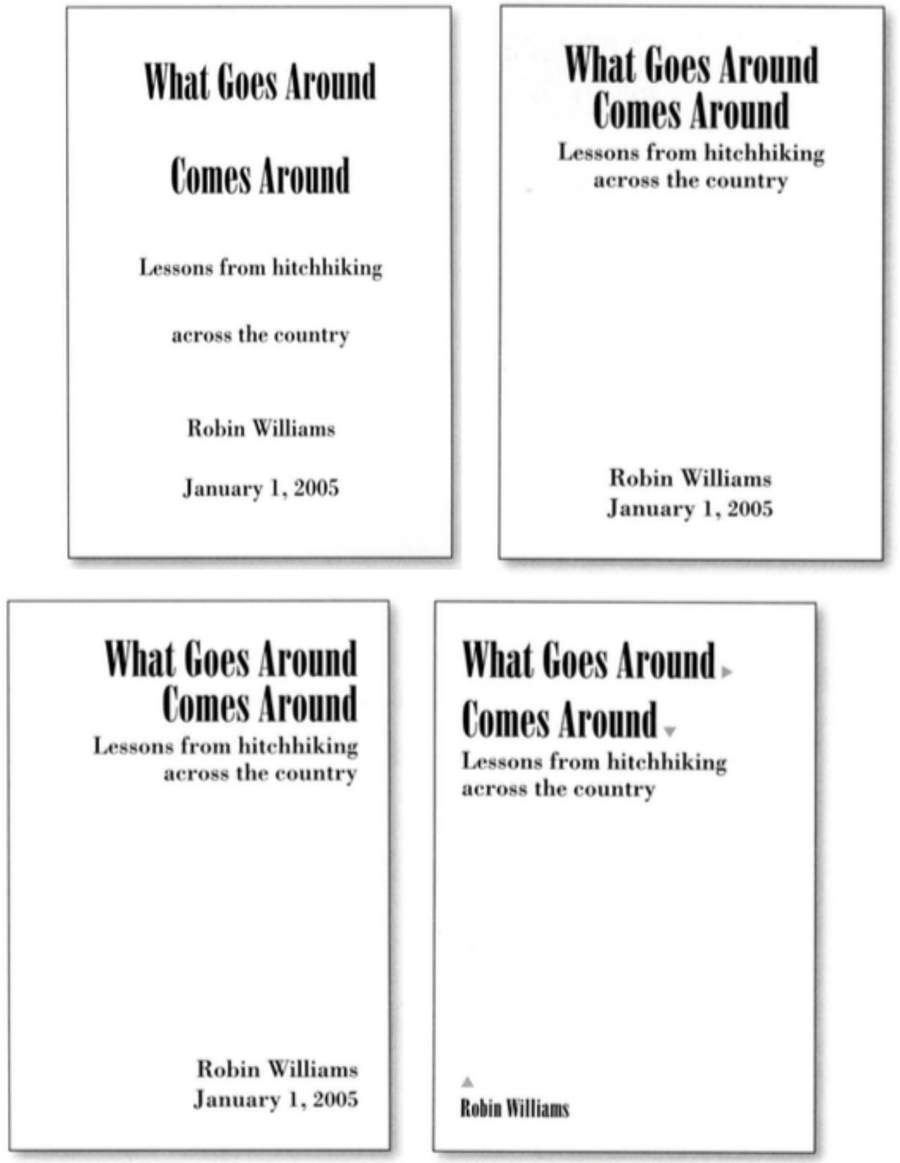

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- *The Non-Designer's Design Book, 4th ed. Robin Williams, Peachpit Press, 2015.*
  - fast read, very practical to work through whole thing

Function first, form next

- dangerous to start with aesthetics
  - usually impossible to add function retroactively
- start with focus on functionality
  - possible to improve aesthetics later on, as refinement
  - if no expertise in-house, find good graphic designer to work with
  - aesthetics do matter! another level of function
    - visual hierarchy, alignment, flow
    - Gestalt principles in action

Usability Testing

Guerilla/Discount Usability

- usability testing as formative evaluation: how could it improve?
  - vs summative evaluation: did it work?

- grab a few people and watch them use your interface
  - even 3-5 gives substantial coverage of major usability problems
  - agile/lean qualitative, vs formal quantitative user studies
    - goal is not statistical significance!
- think-aloud protocol
  - contextual inquiry (conversations back and forth) vs fly on the wall (you're silent)

Further reading, usability

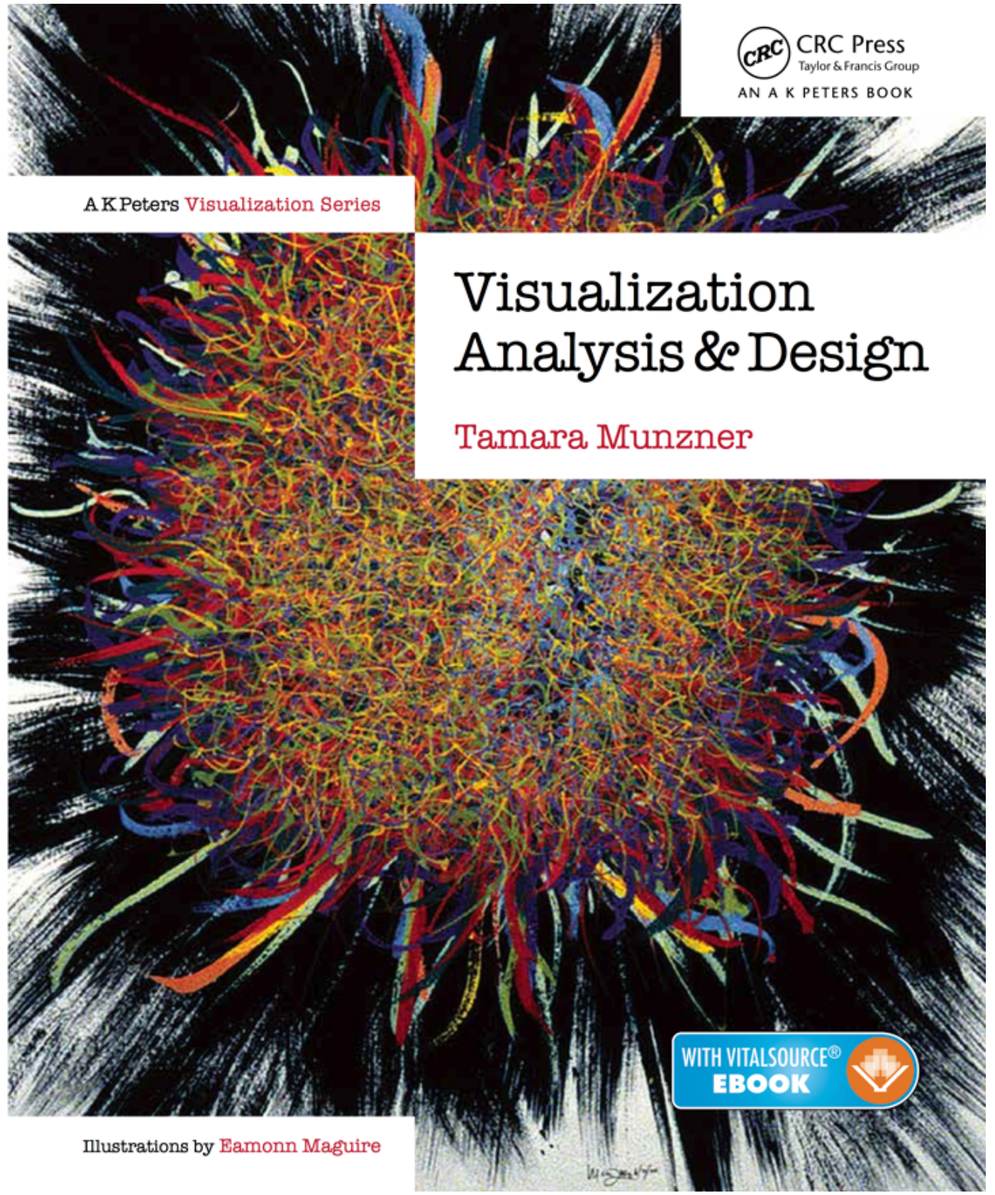
- 7 Step Guide to Guerrilla Usability Testing, Markus Piper
  - https://userbrain.net/blog/7-step-guide-guerrilla-usability-testing-diy-usability-testing-method
- Discount Usability: 20 Years, Jakob Nielsen
  - https://www.nngroup.com/articles/discount-usability-20-years/
- Interaction Design: Beyond Human-Computer Interaction
  - Preece, Sharp, Rogers. Wiley, 5th edition, 2019.
- About Face: The Essentials of Interaction Design
  - Cooper, Reimann, Cronin, Noessel. Wiley, 4th edition, 2014.
- Task-Centered User Interface Design. Lewis & Rieman, 1994
  - http://hcibib.org/tcuid/
- Designing with the Mind in Mind. Jeff Johnson. Morgan Kaufmann, 2nd, 2014.

More Resources: Books

Visualization Analysis and Design

- book from which these tidbits were drawn
  - illustration acknowledgement: Eamonn Maguire

- full courses, papers, videos, software, talks
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm

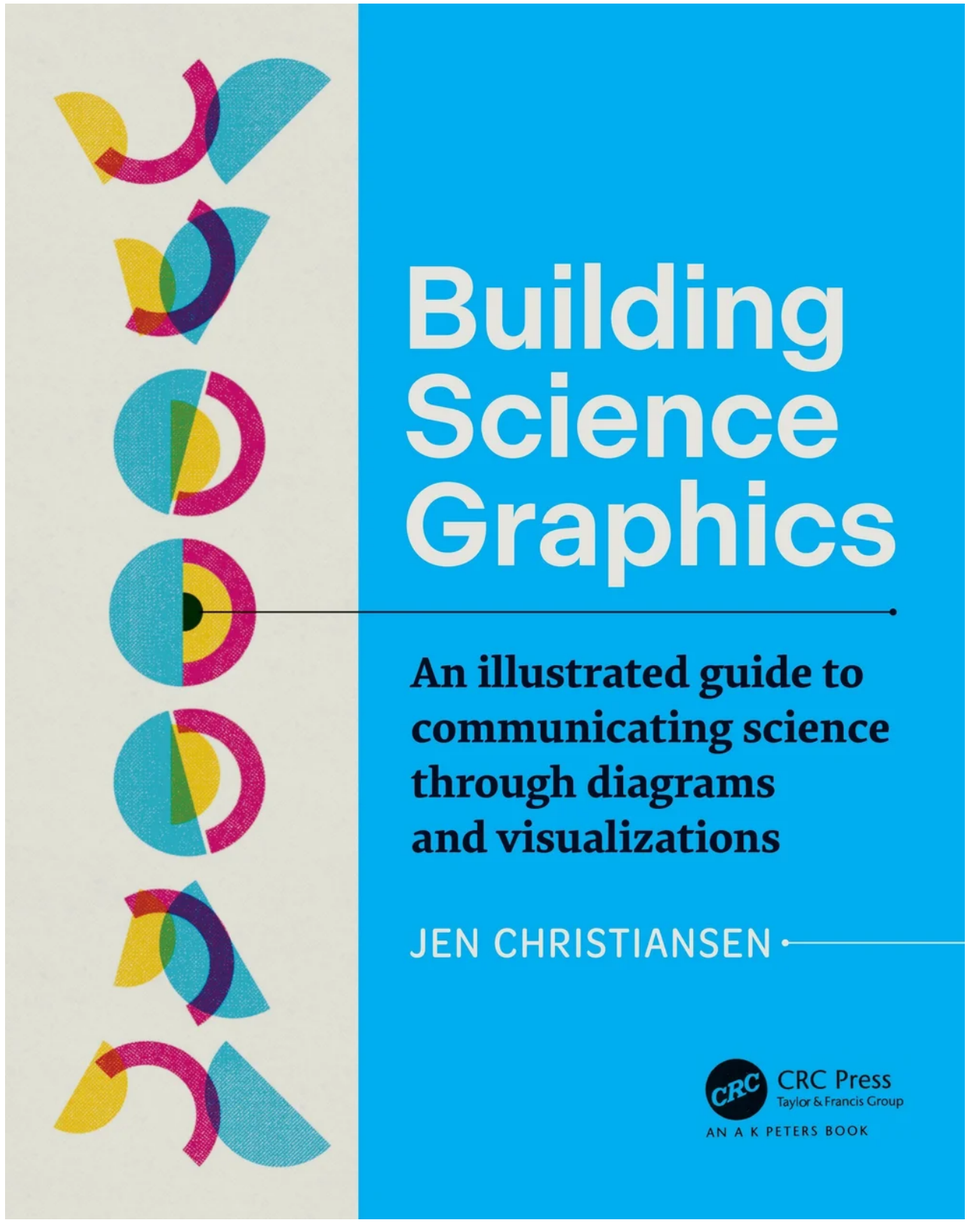


https://www.cs.ubc.ca/~tmm/vadbook

https://www.routledge.com/Visualization-Analysis-and-Design/Munzner/p/book/9781466508910

Building Science Graphics

- Building Science Graphics: An illustrated guide to communicating science through diagrams and visualizations
  - Jen Christiansen

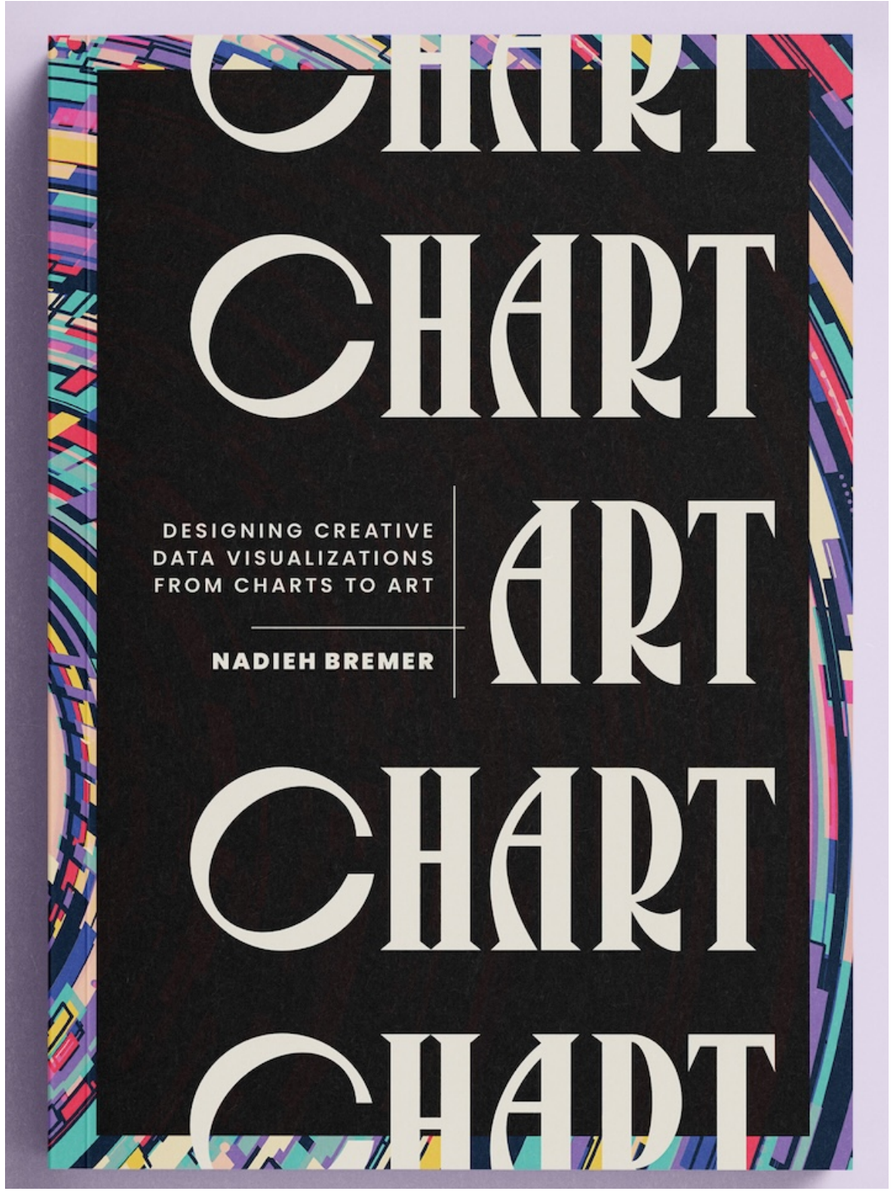


https://www.buildingsciencegraphics.com/

https://www.routledge.com/Building-Science-Graphics-An-Illustrated-Guide-to-Communicating-Science-through-Diagrams-and-Visualizations/Christiansen/p/book/9781032106748

CHART

- CHART: Designing Creative Data Visualizations from Charts to Art
  - Nadieh Bremer

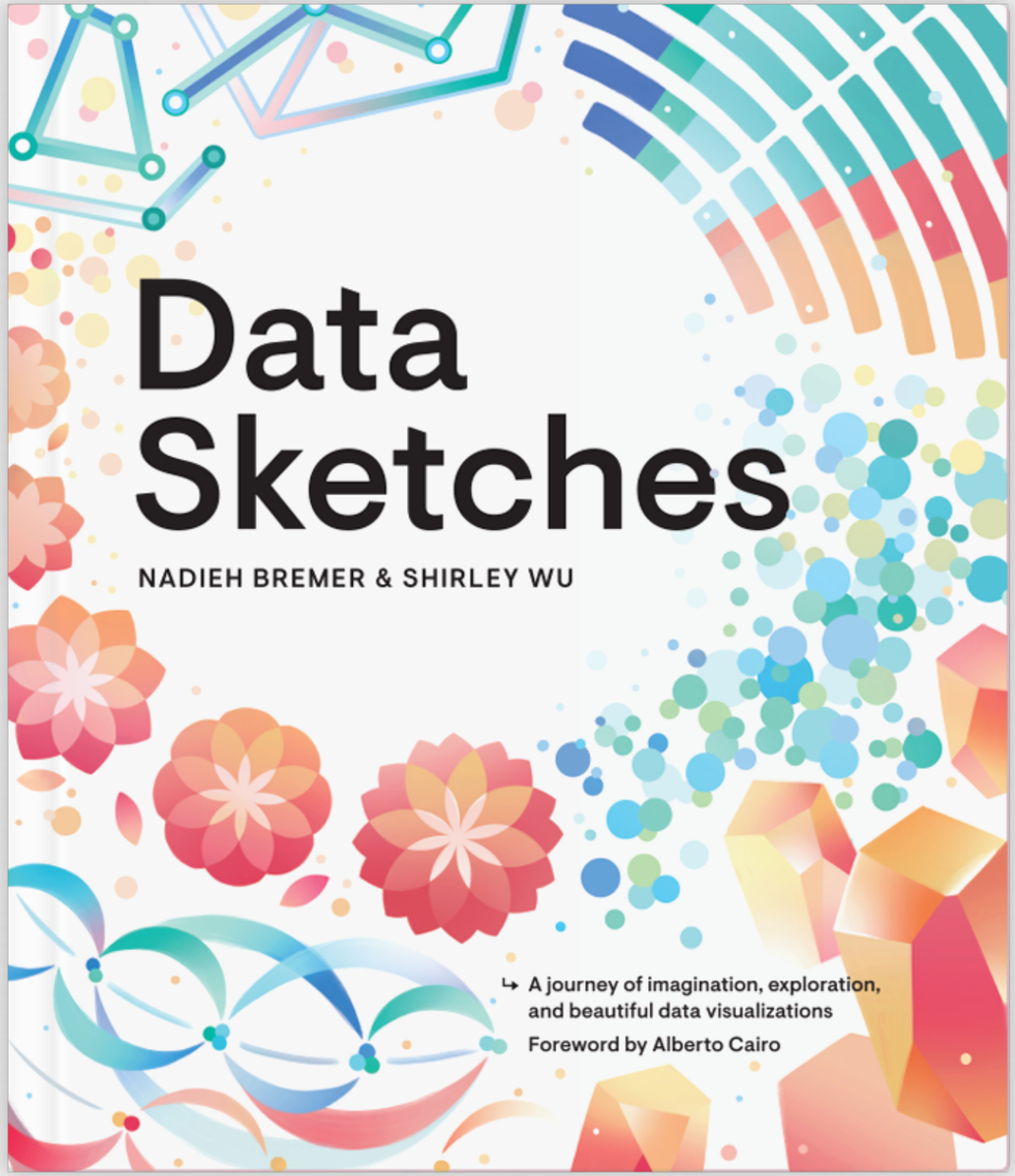


https://www.visualcinnamon.com/chart/

https://www.routledge.com/CHART-Designing-Creative-Data-Visualizations-from-Charts-to-Art/Bremer/p/book/9781032797755

Data Sketches

- Data Sketches:
  A journey of imagination, exploration, and beautiful data visualizations
  - Nadieh Bremer & Shirley Wu

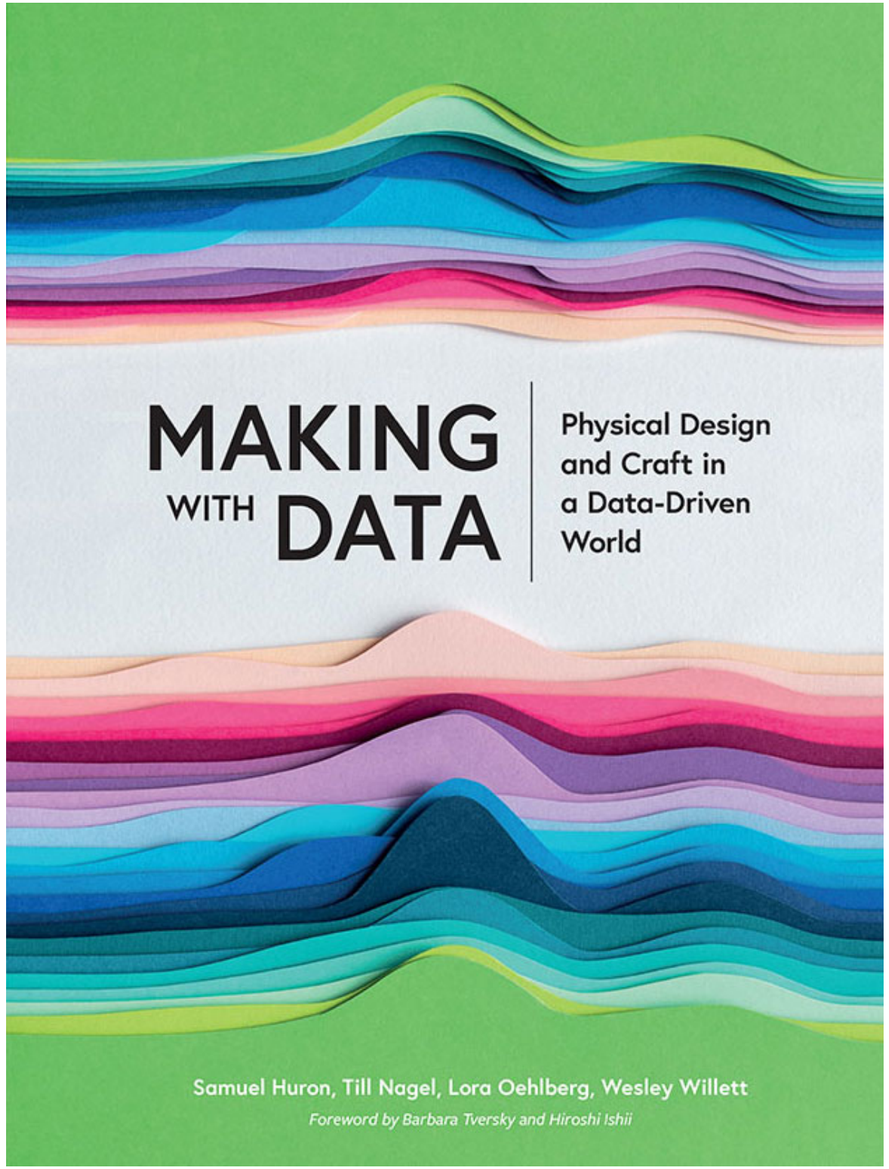


https://www.datasketch.es/book

https://www.routledge.com/Data-Sketches-A-journey-of-imagination-exploration-and-beautiful-data-visualizations/Bremer-Wu/p/book/9780367000080

Making with Data

- Making with Data: Physical Design and Craft in a Data-Driven World
  - editors:
    Samuel Huron, Till Nagel,
    Lora Oehlberg, Wesley Willett



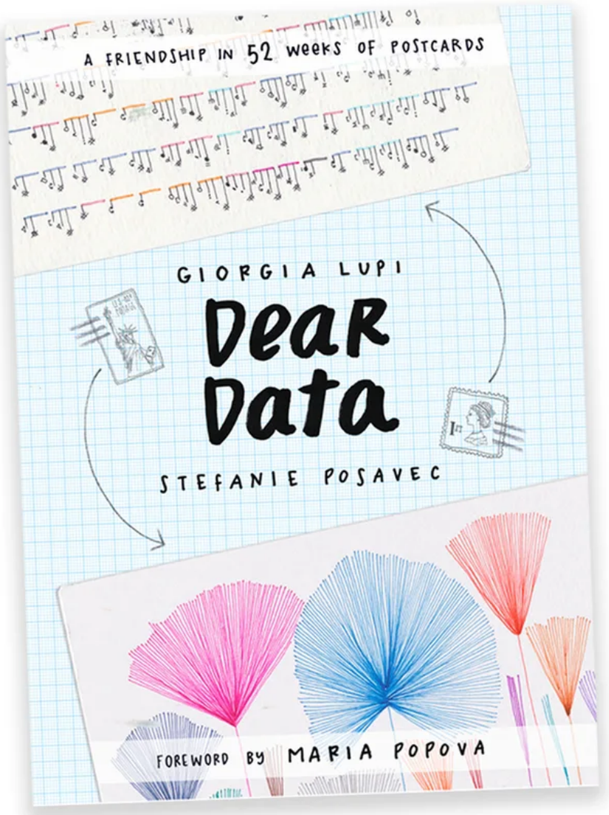
https://makingwithdata.org/

https://www.routledge.com/Making-with-Data-Physical-Design-and-Craft-in-a-Data-Driven-World/Huron-Nagel-Oehlberg-Willett/p/book/9781032182223

Dear Data: A Friendship in 52 Weeks of Postcards

- inspiring celebration of data humanism

Giorgia Lupi and
Stefanie Posavec



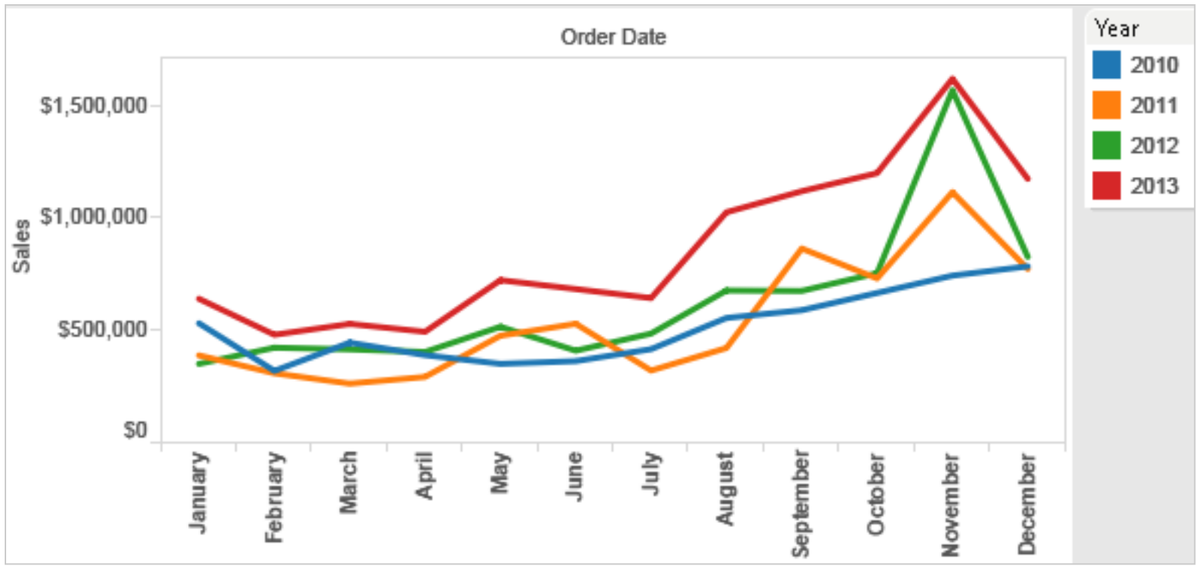
http://www.dear-data.com/by-week/

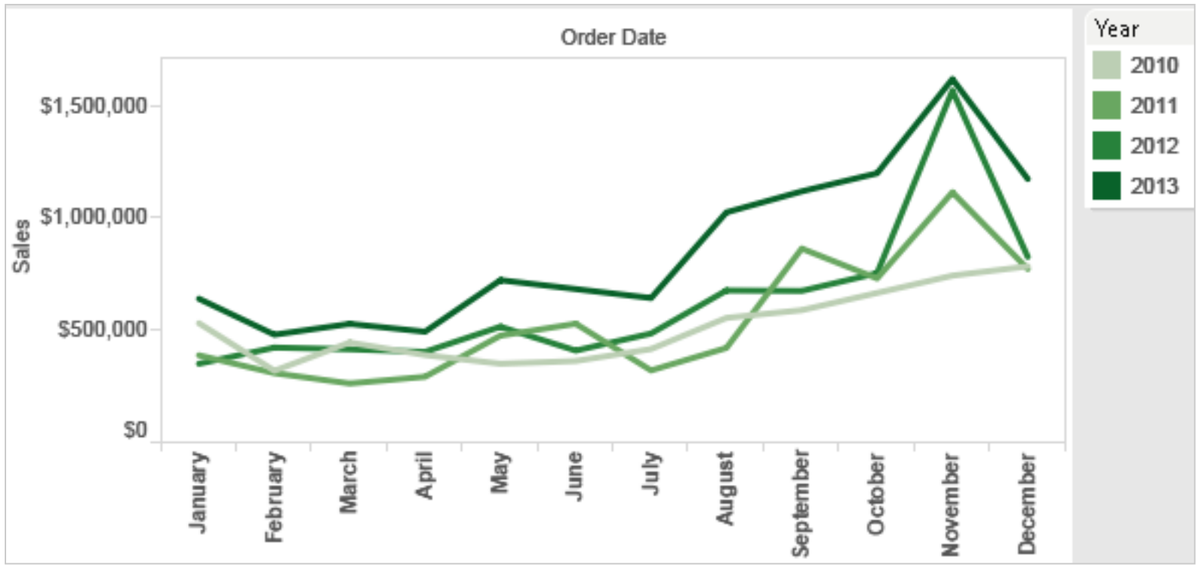
https://giorgialupi.com/dear-data

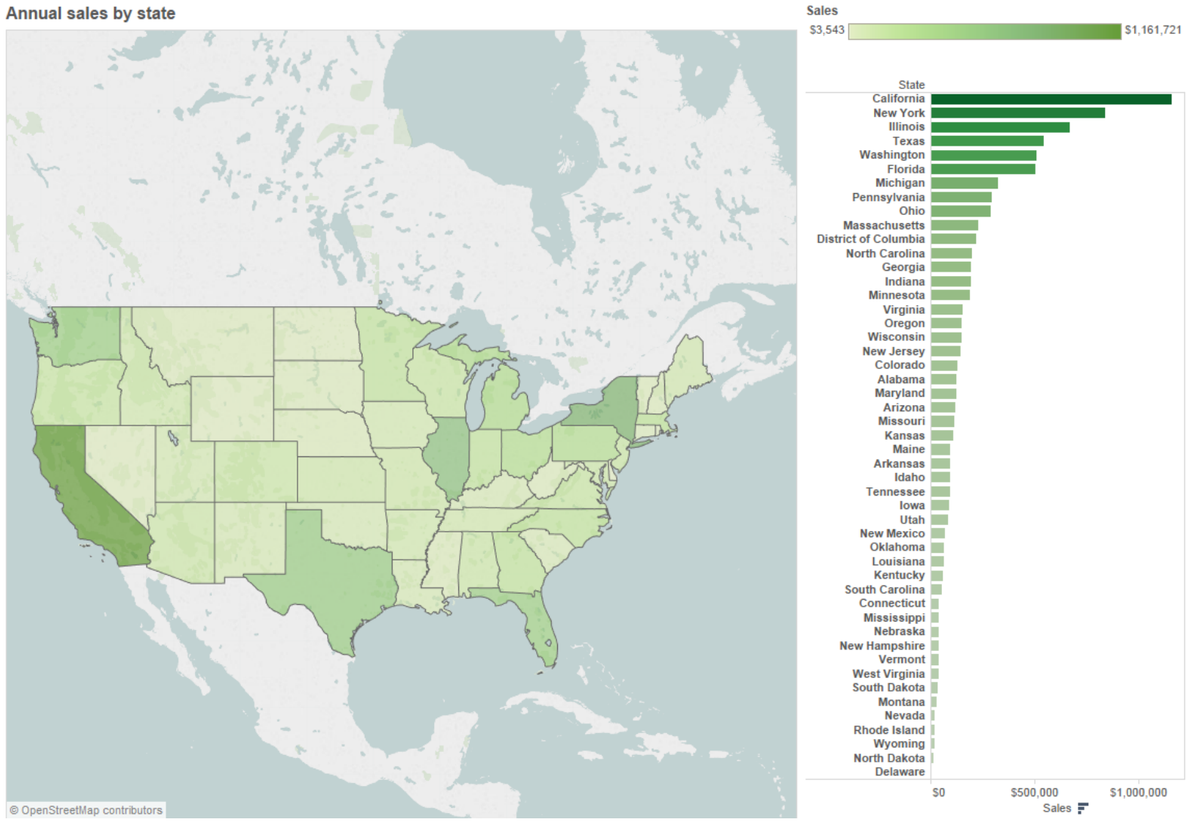
https://www.stefanieposavec.com/dear-data

Color

Categorical vs ordered color





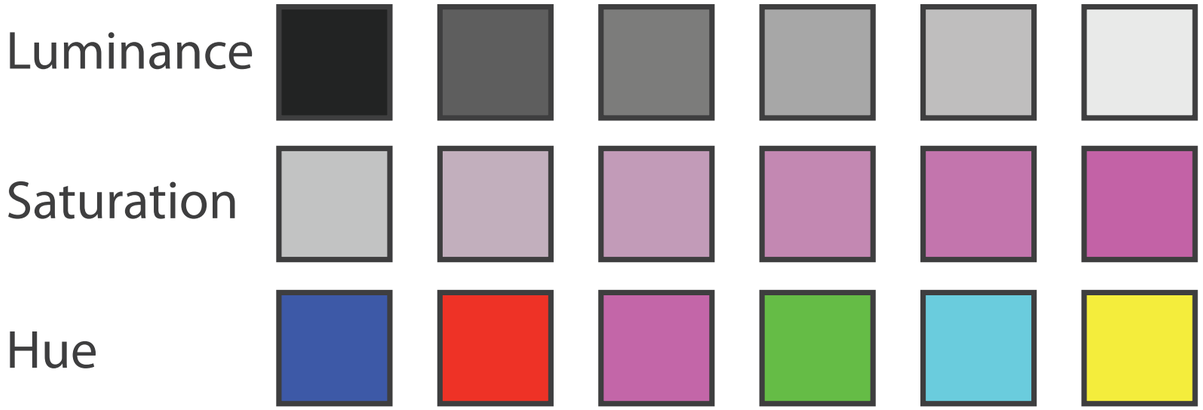


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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?

Luminance

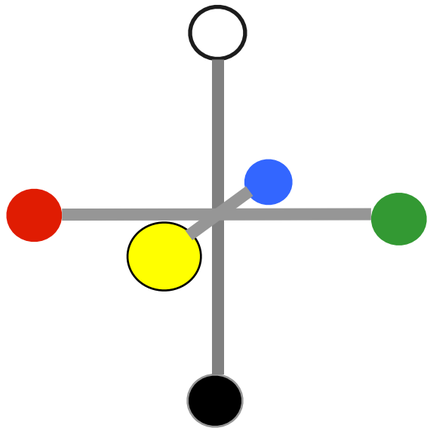
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!

- intrinsic perceptual ordering

[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*)
- "color blind": one axis has degraded acuity
  - 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.]

Color spaces

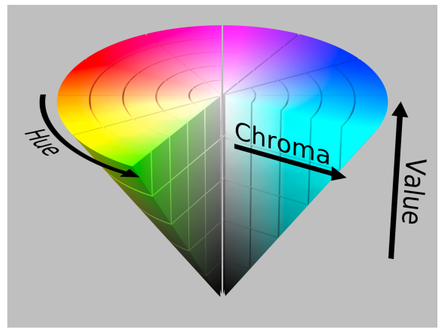
- CIE L*a*b*: good for computation
  - L* intuitive: perceptually linear luminance
  - a*b* axes: perceptually linear but nonintuitive
- RGB: good for display hardware
  - poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!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

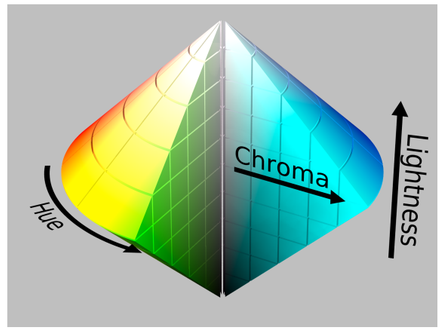
Corners of the RGB color cube

L from HLS
All the same

Luminance values

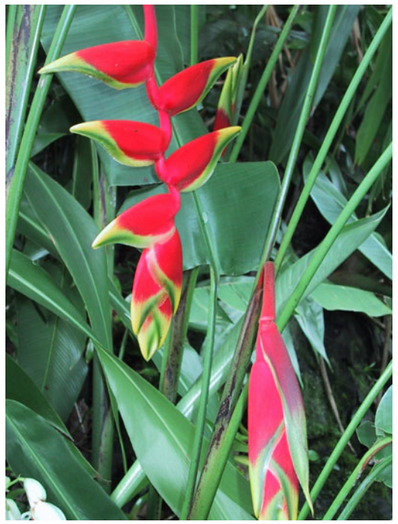
L* values



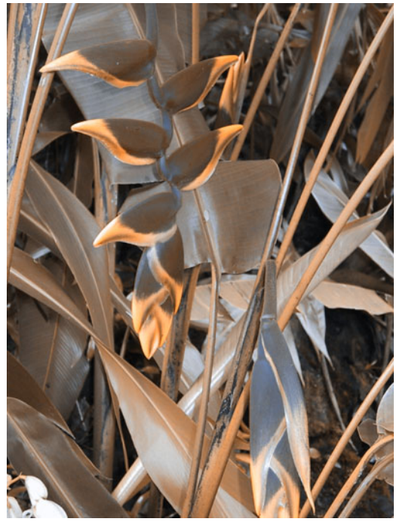


[https://en.wikipedia.org/wiki/HSL_and_HSV]

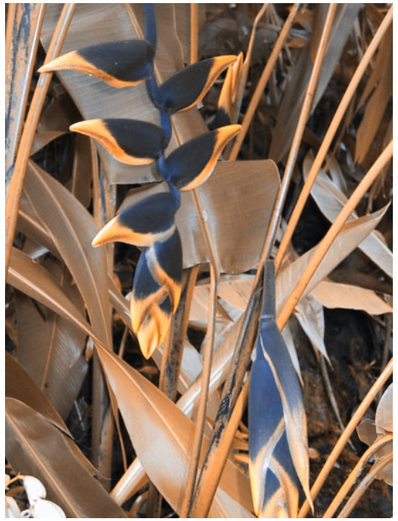
Designing for color deficiency: Check with simulator



Normal vision



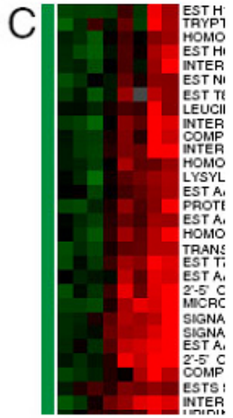
Deuteranope

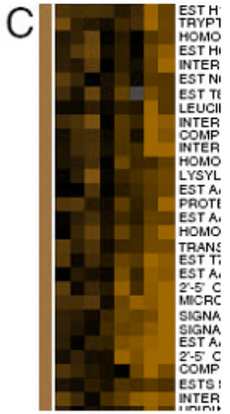


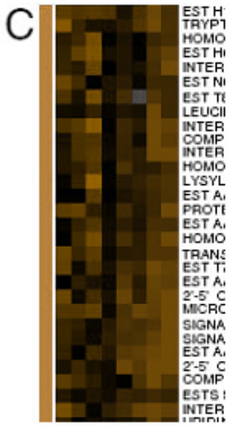
Protanope

Tritanope

http://rehue.net



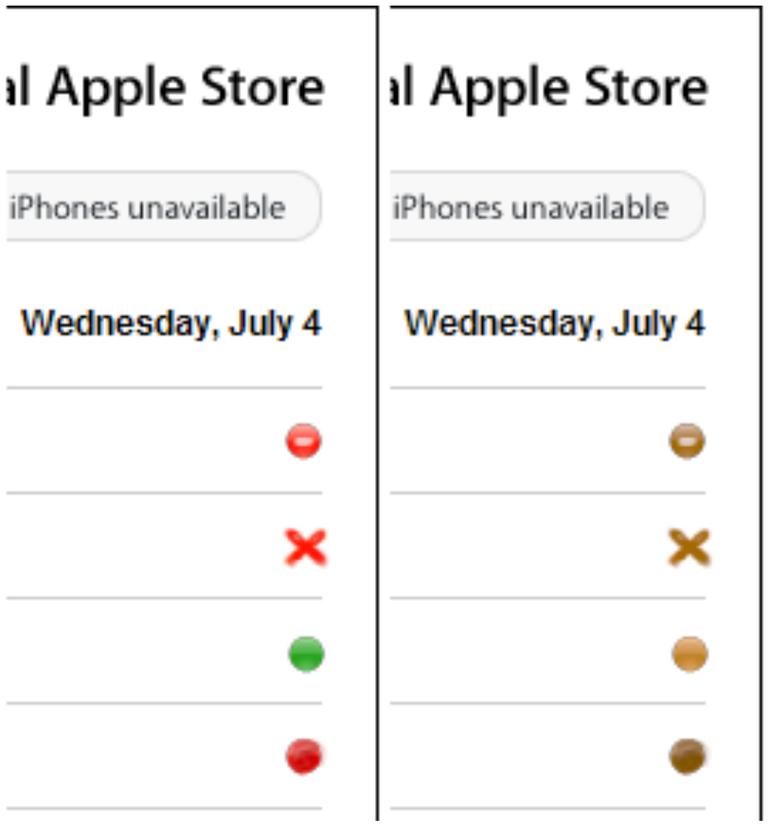


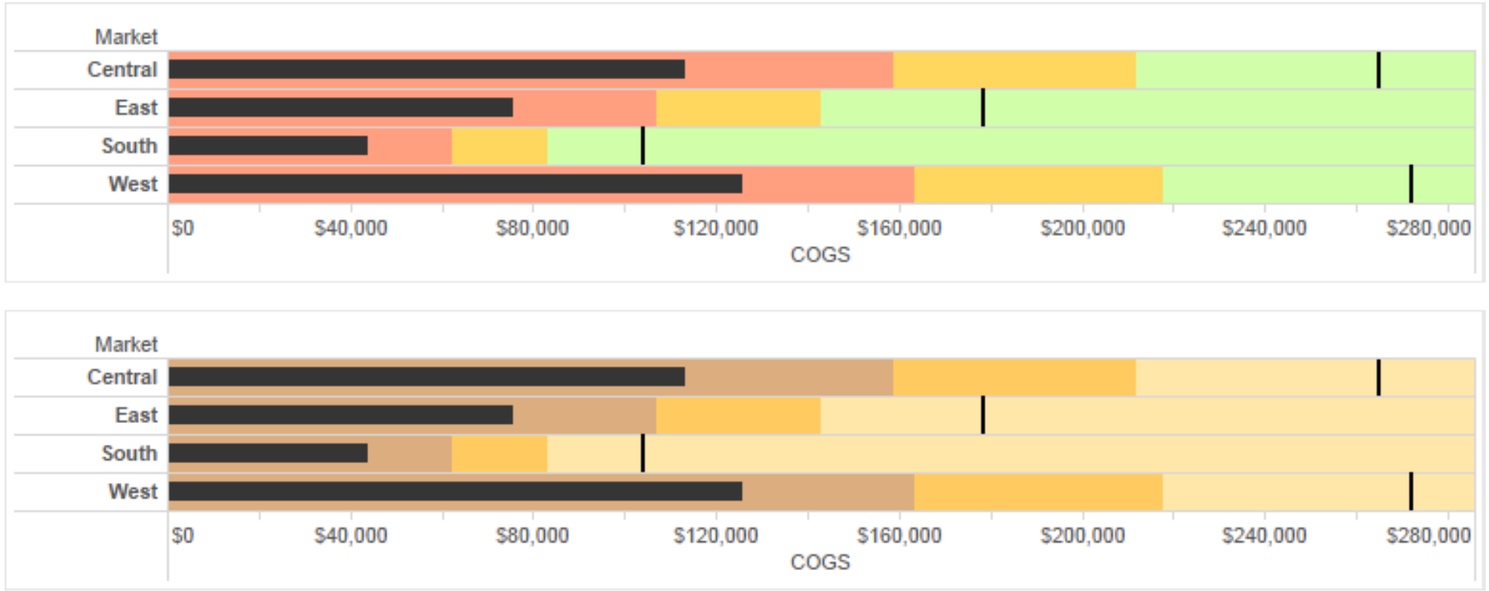


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape





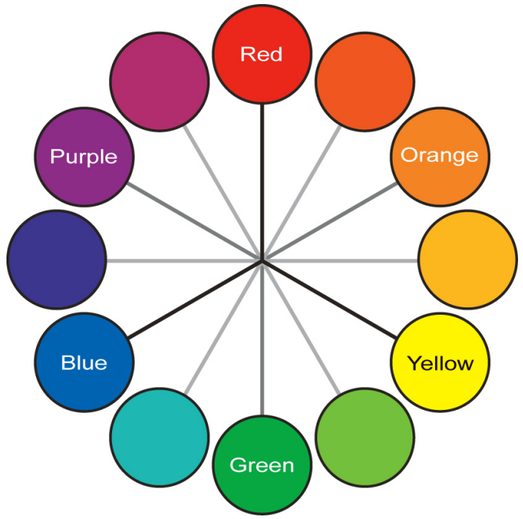
Deuteranope simulation

Change the shape

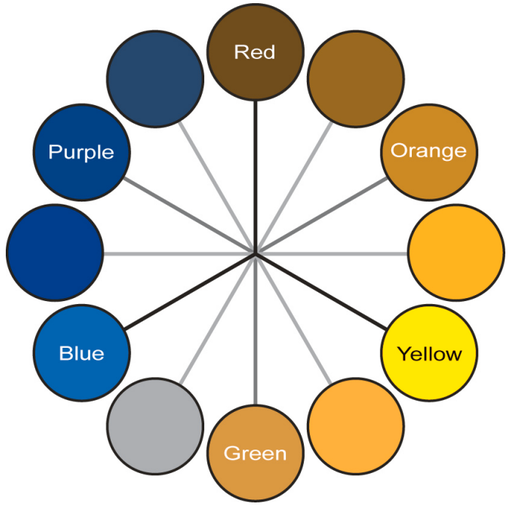
Vary luminance

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

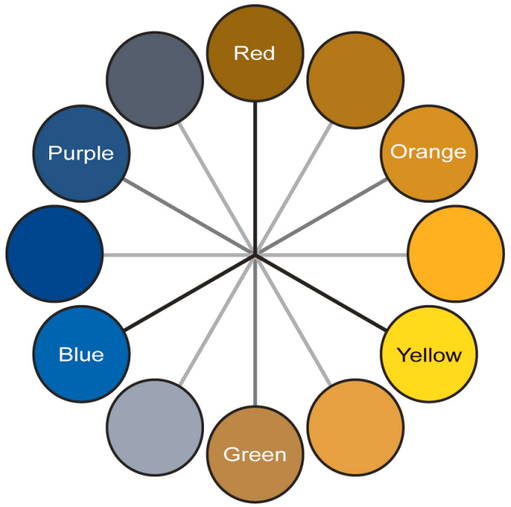
Color deficiency: Reduces color to 2 dimensions



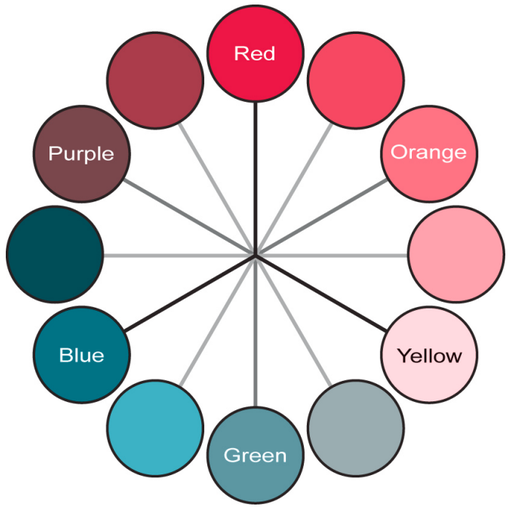
Normal



Protanope



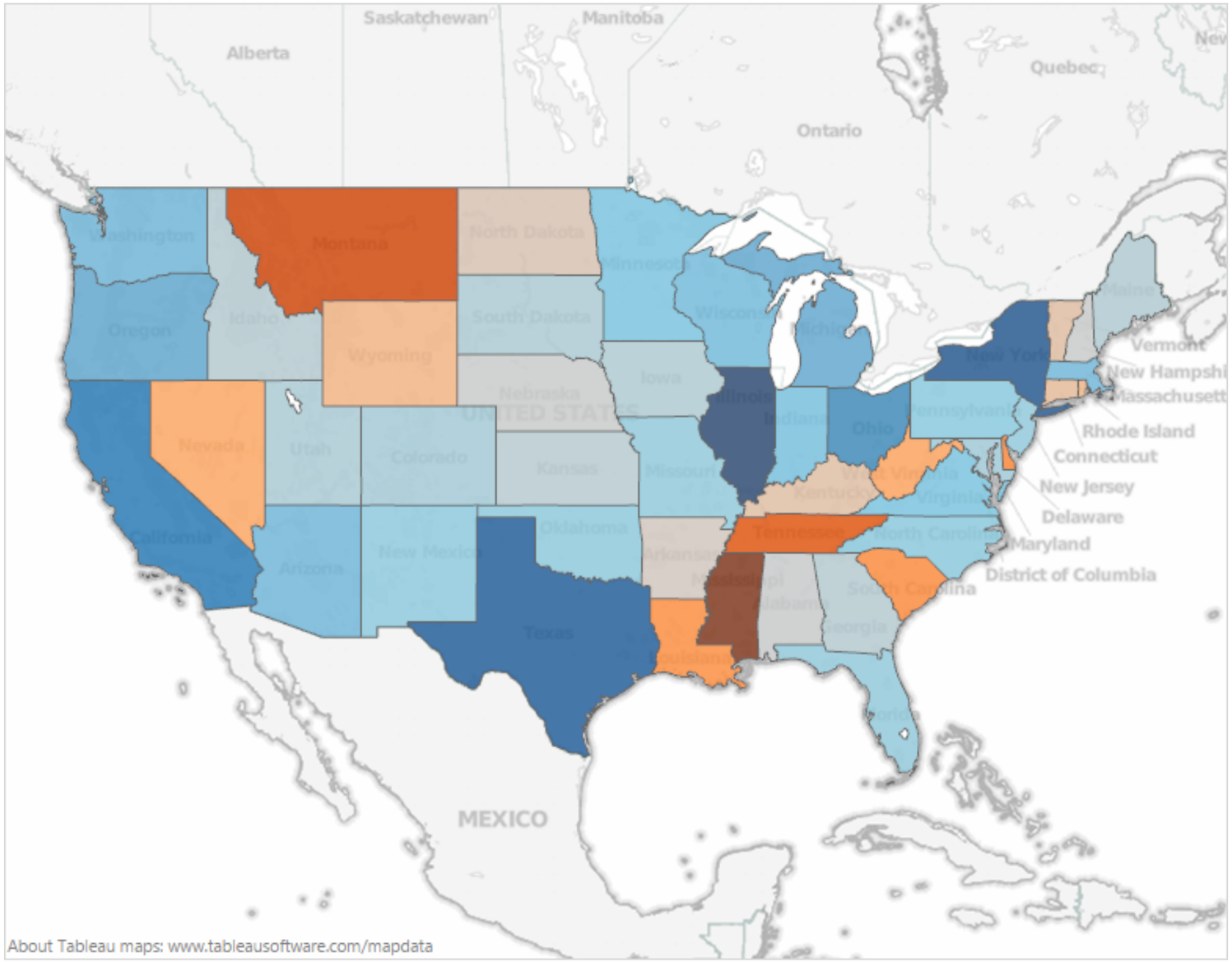
Deuteranope



Tritanope

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

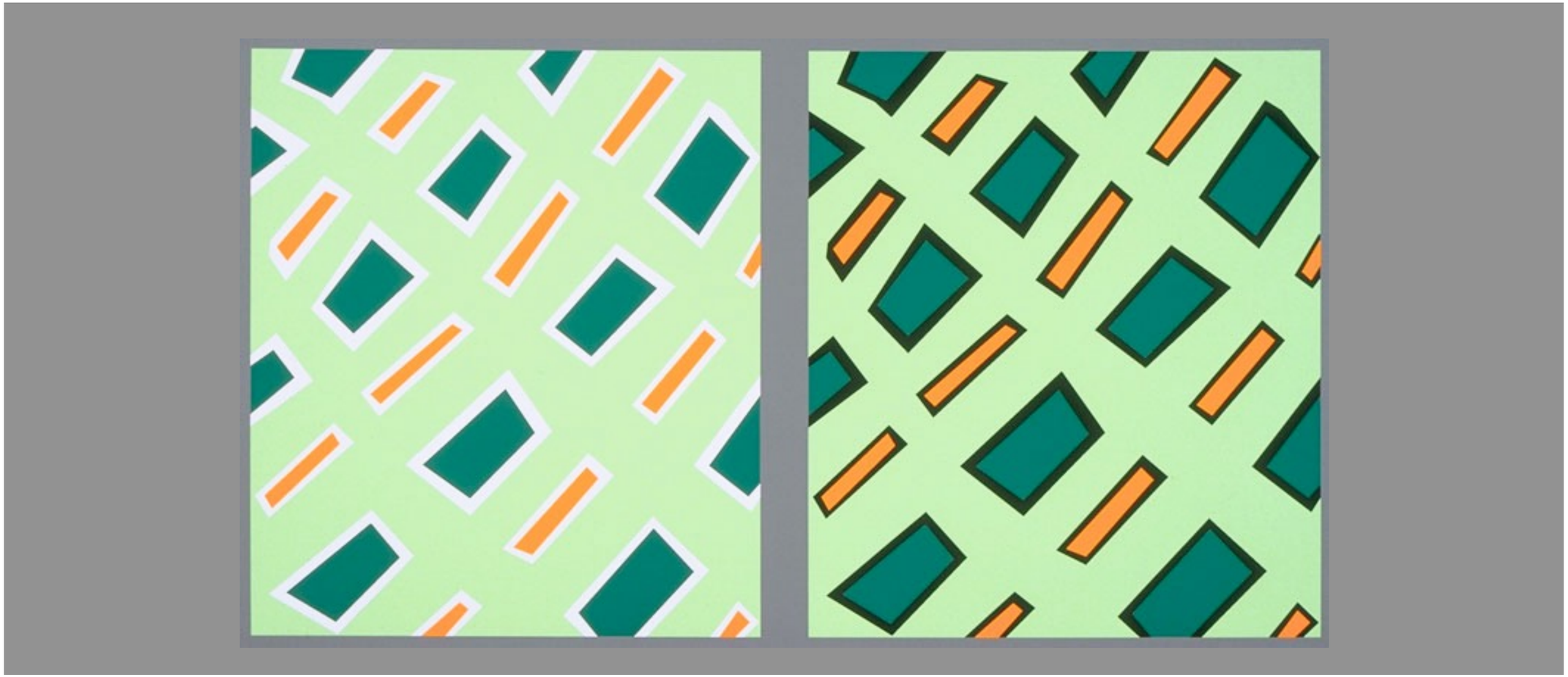
Designing for color deficiency: Blue-Orange is safe



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

Bezold Effect: Outlines matter

- color constancy: simultaneous contrast effect



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

Relative judgements: Color & illumination

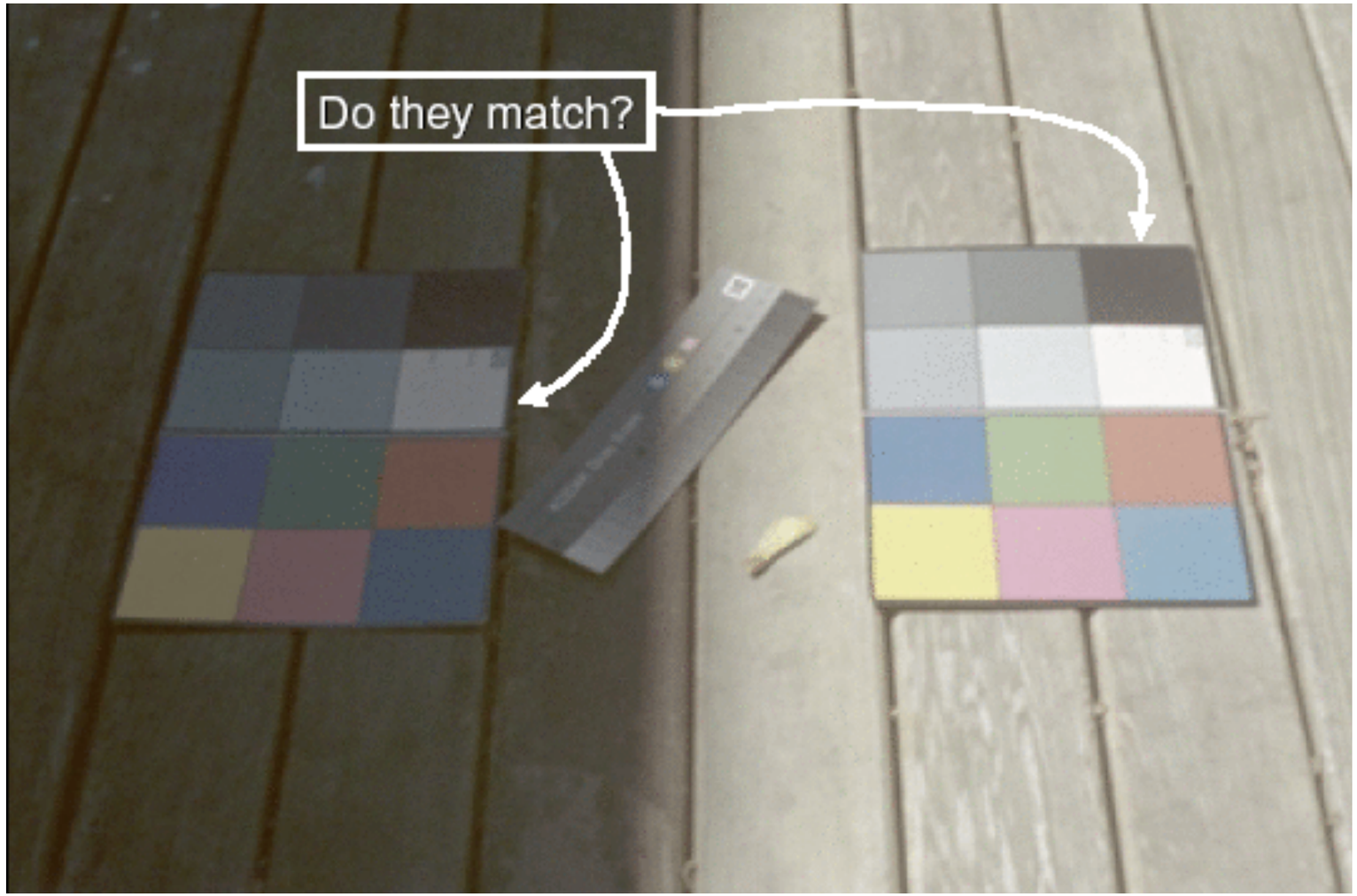


Image courtesy of John McCann

Relative judgements: Color & illumination

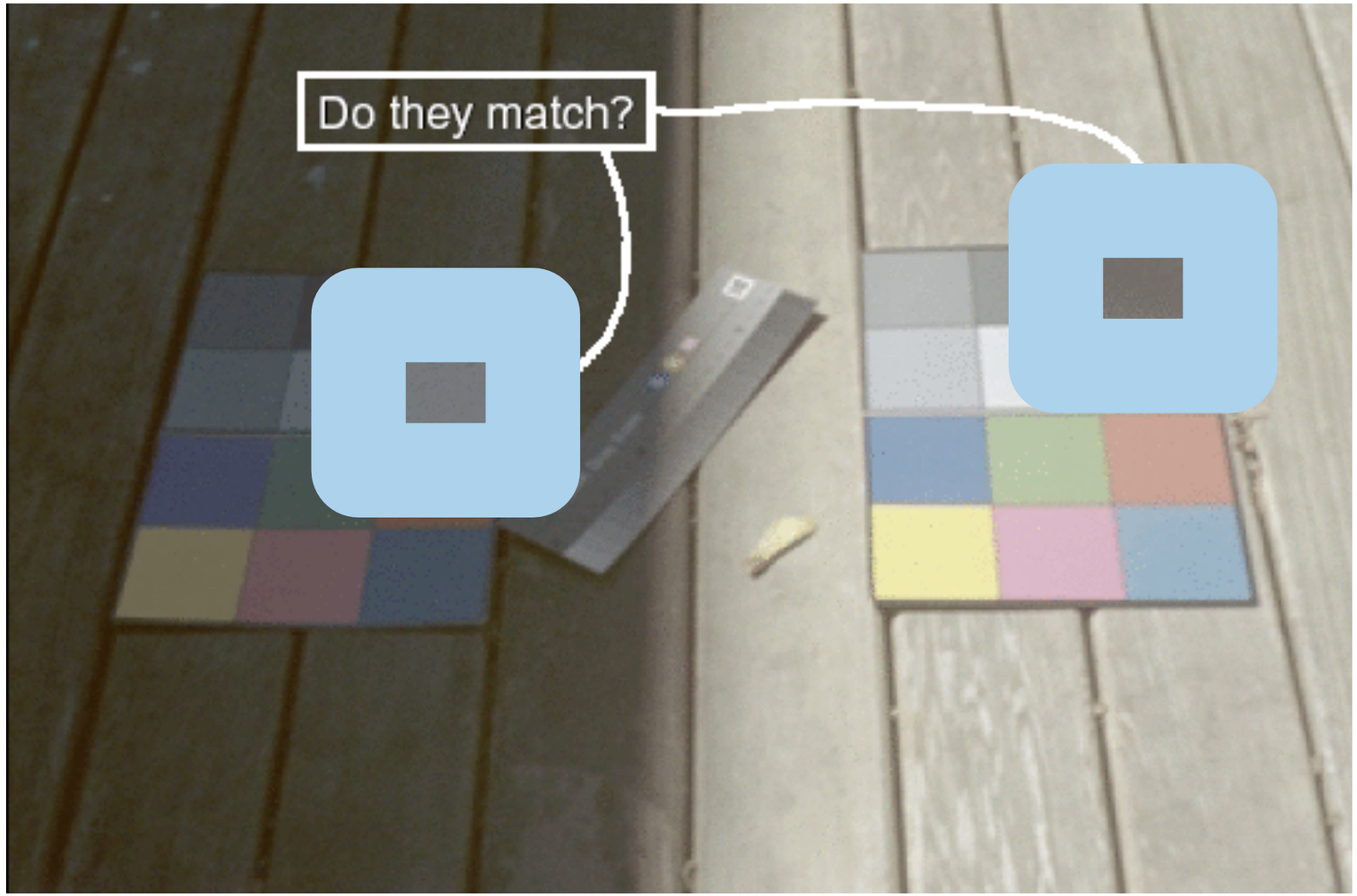
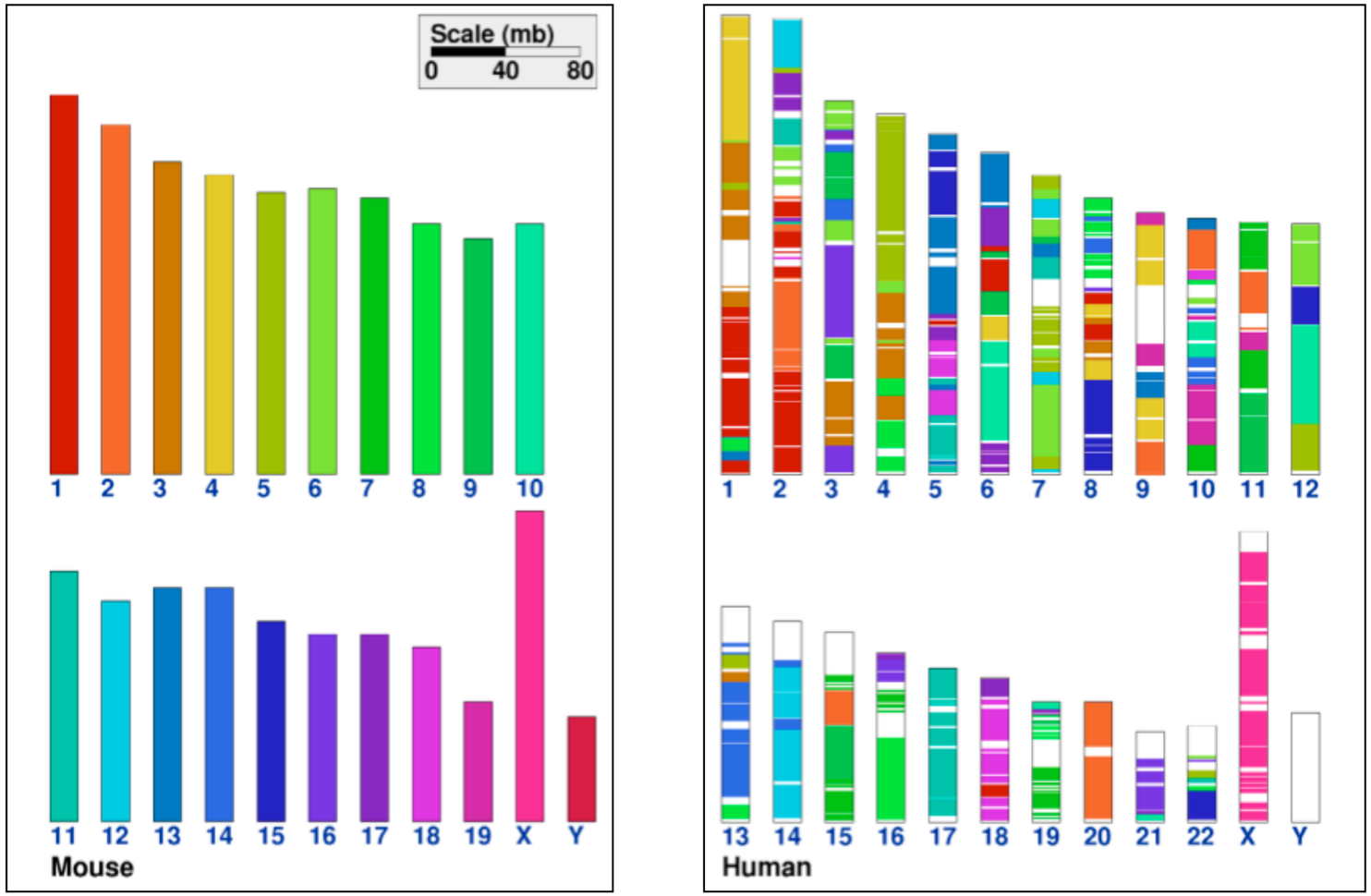


Image courtesy of John McCann via Maureen Stone

Categorical color: limited number of discriminable bins

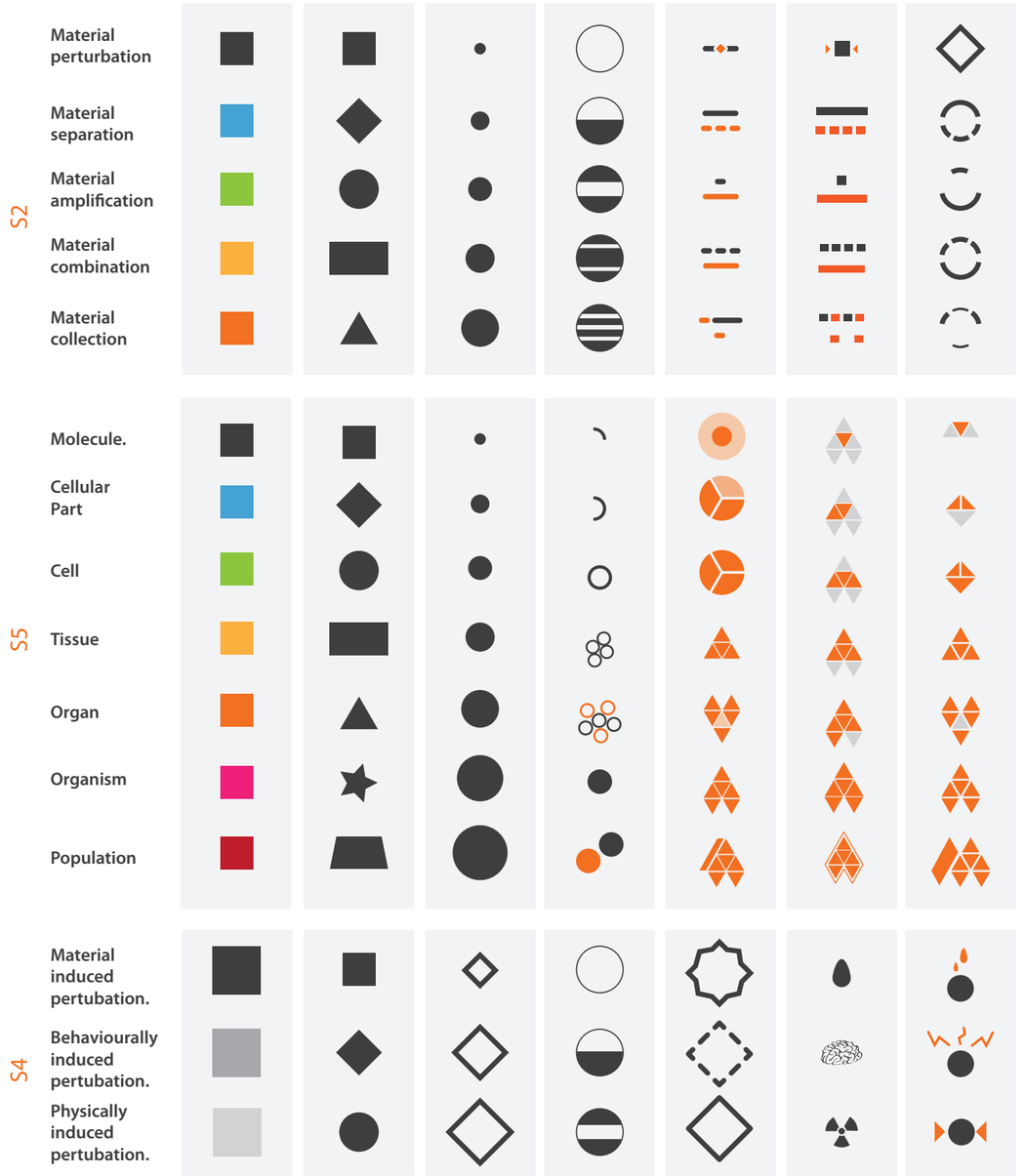
- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights



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

Glyphs

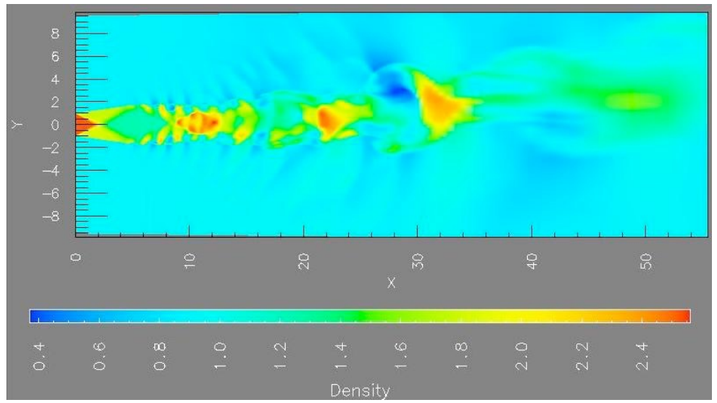
- glyphs: composite objects
  - internal structure with multiple marks
- alternative to color coding
  - or coding with any single channel



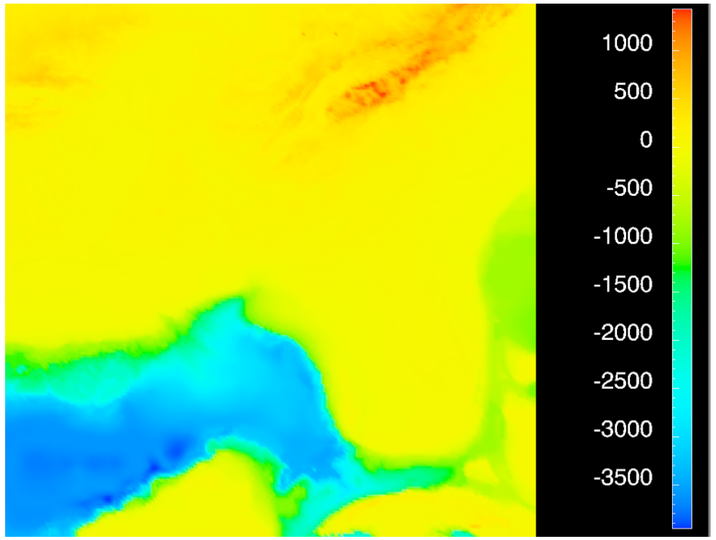
[Fig 5. Taxonomy-Based Glyph Design - with a Case Study on Visualizing Workflows of Biological Experiments. Maguire, Rocca-Serra, Sansone, Davies, and Chen. IEEE Trans. Visualization and Computer Graphics 18:12:2603-2612 (Proc. InfoVis 12).]

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]

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

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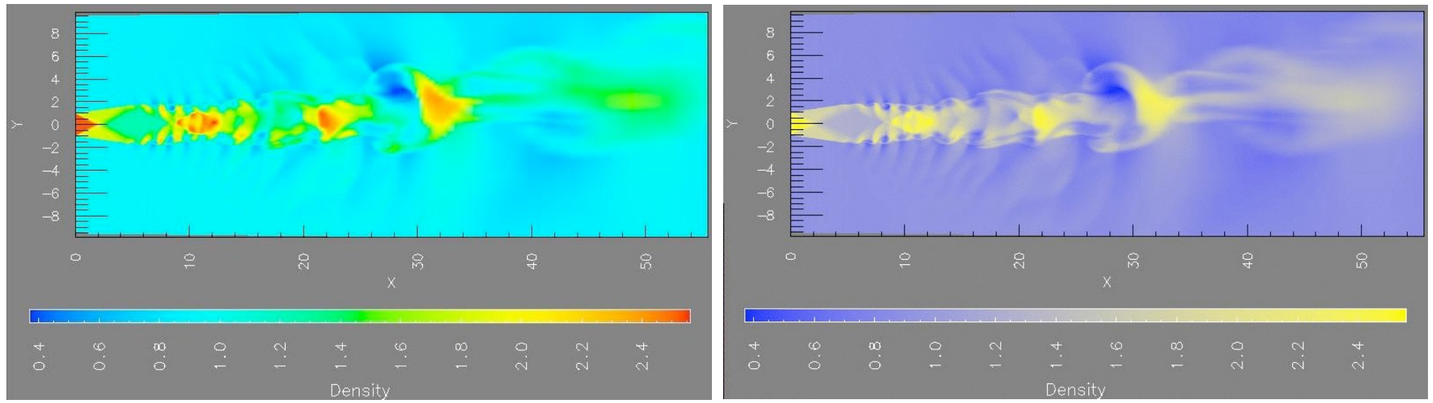
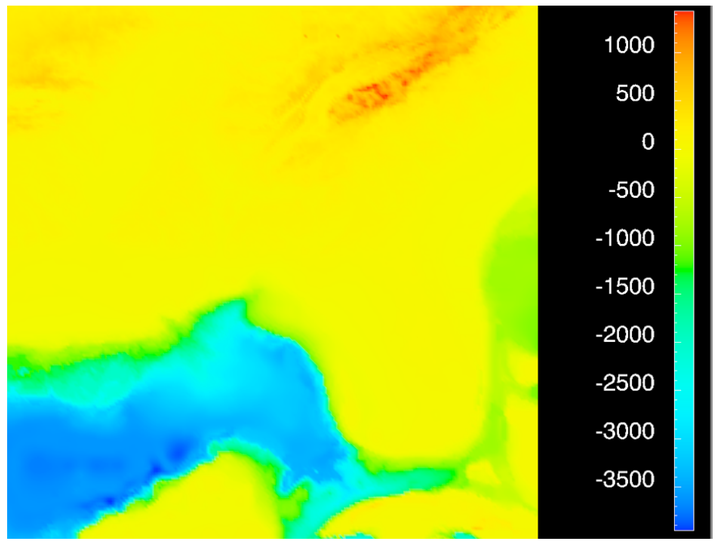
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues



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



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Ordered color: Rainbow is poor default

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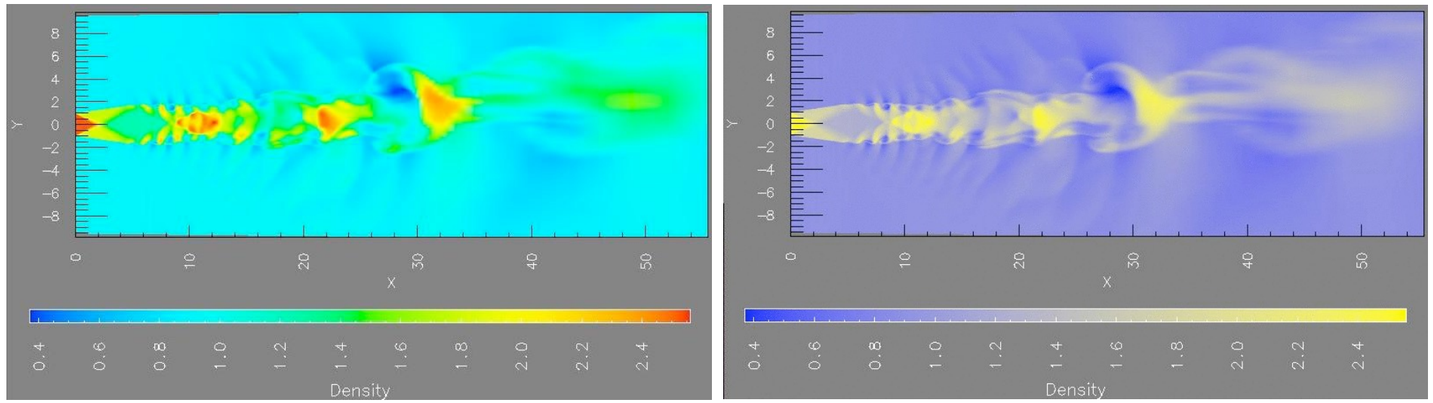
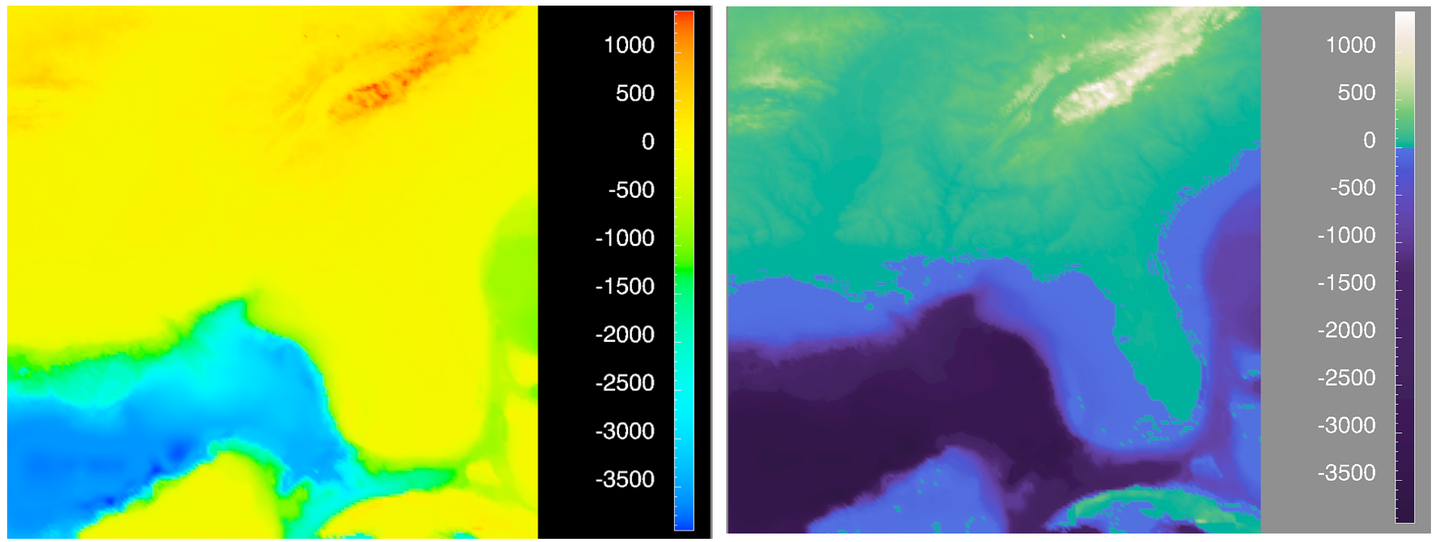
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



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

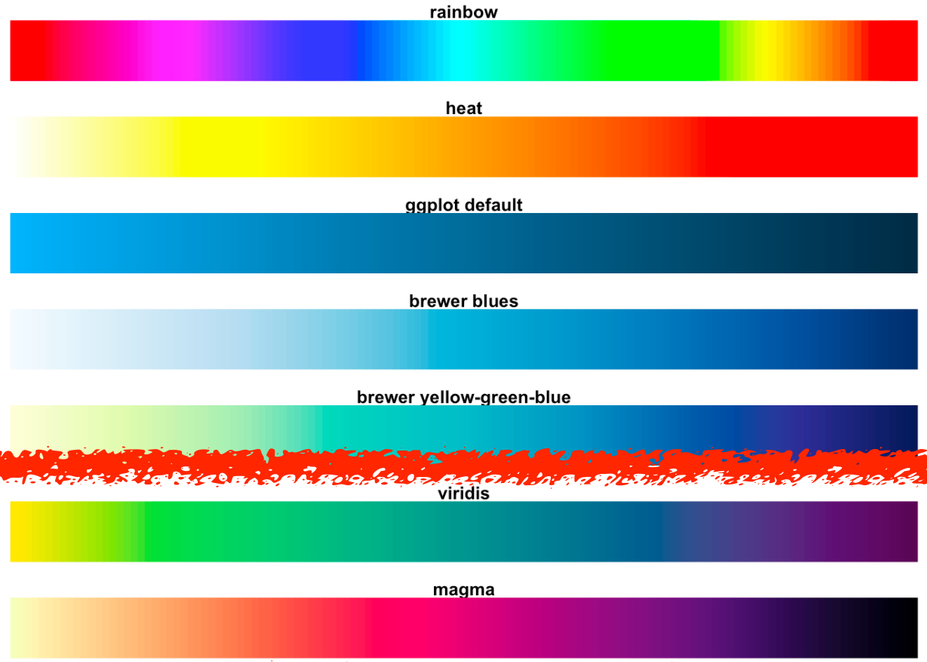


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

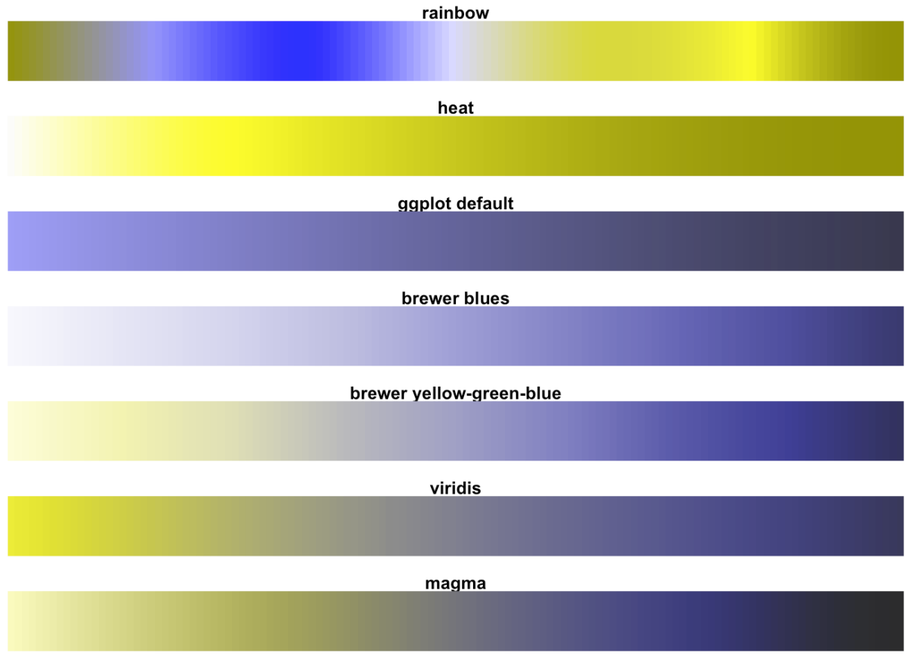
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Viridis

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



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



Ordered color: Rainbow is poor default

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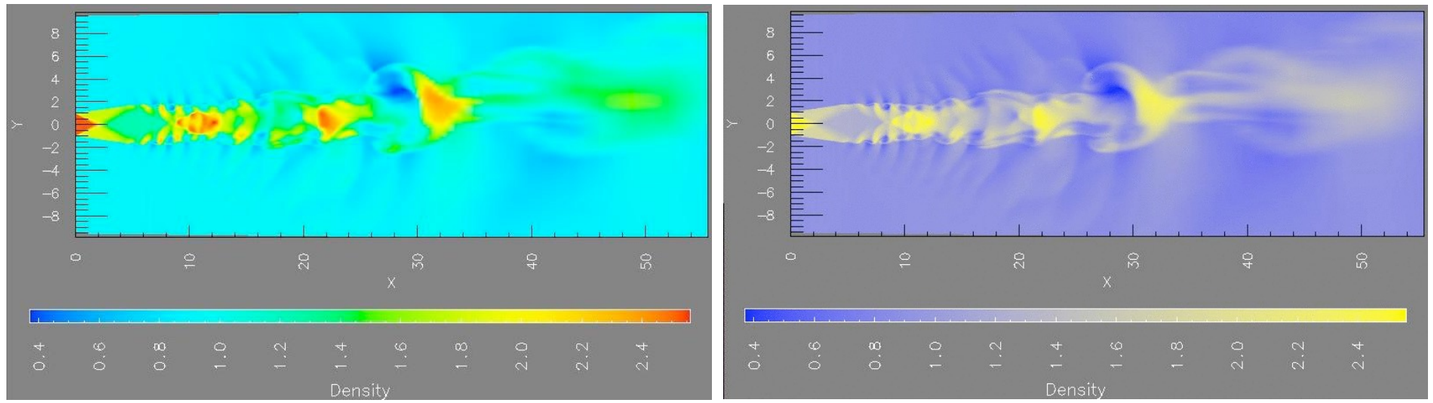
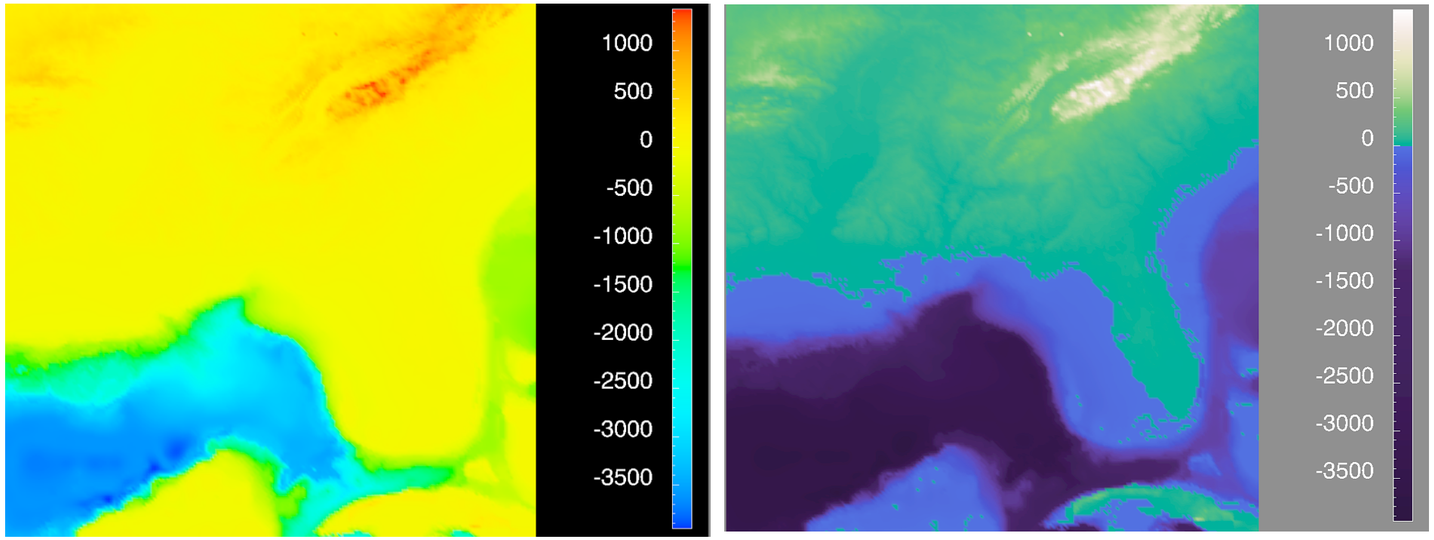
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
  - segmented rainbows for binned or categorical



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

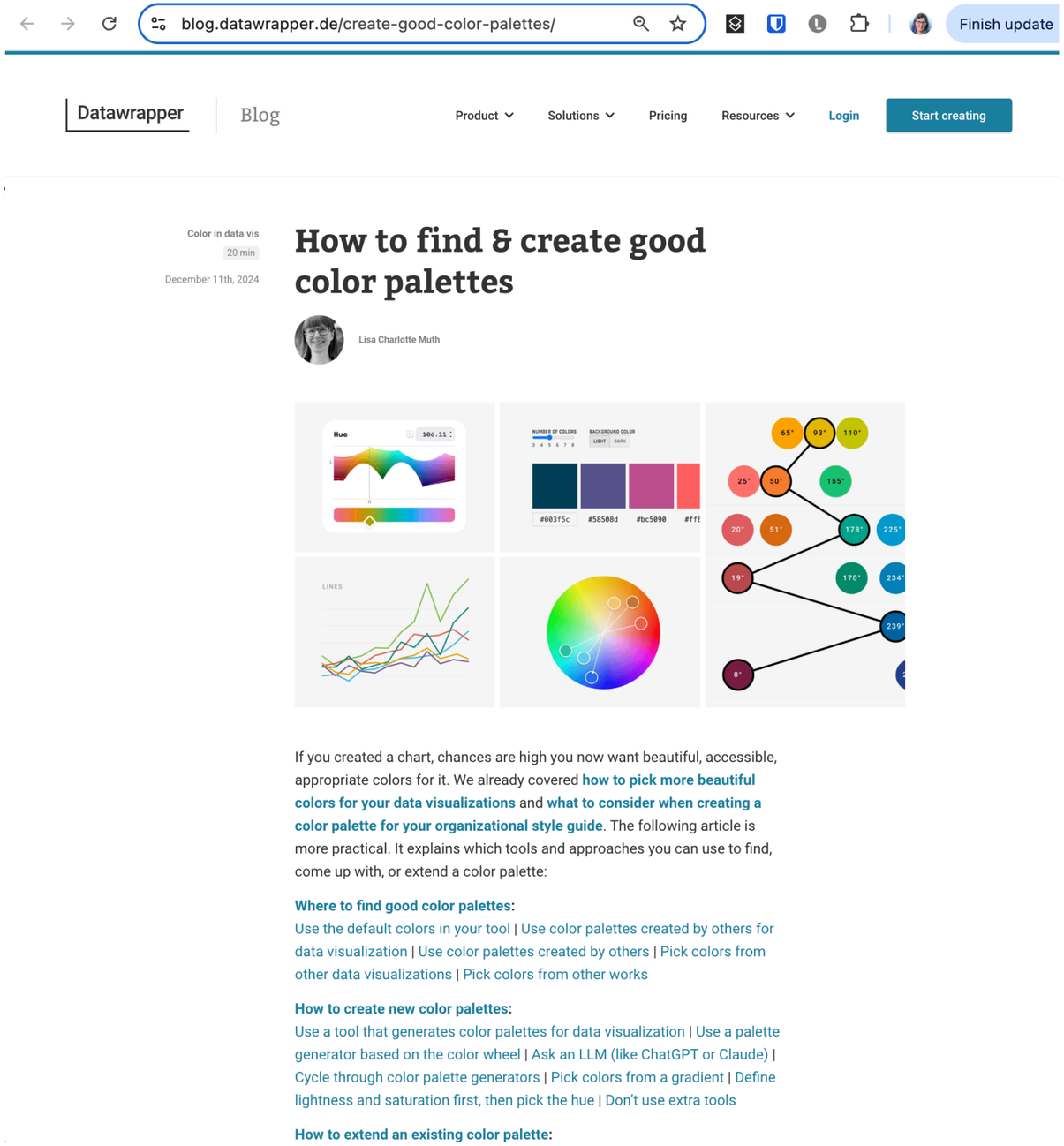


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

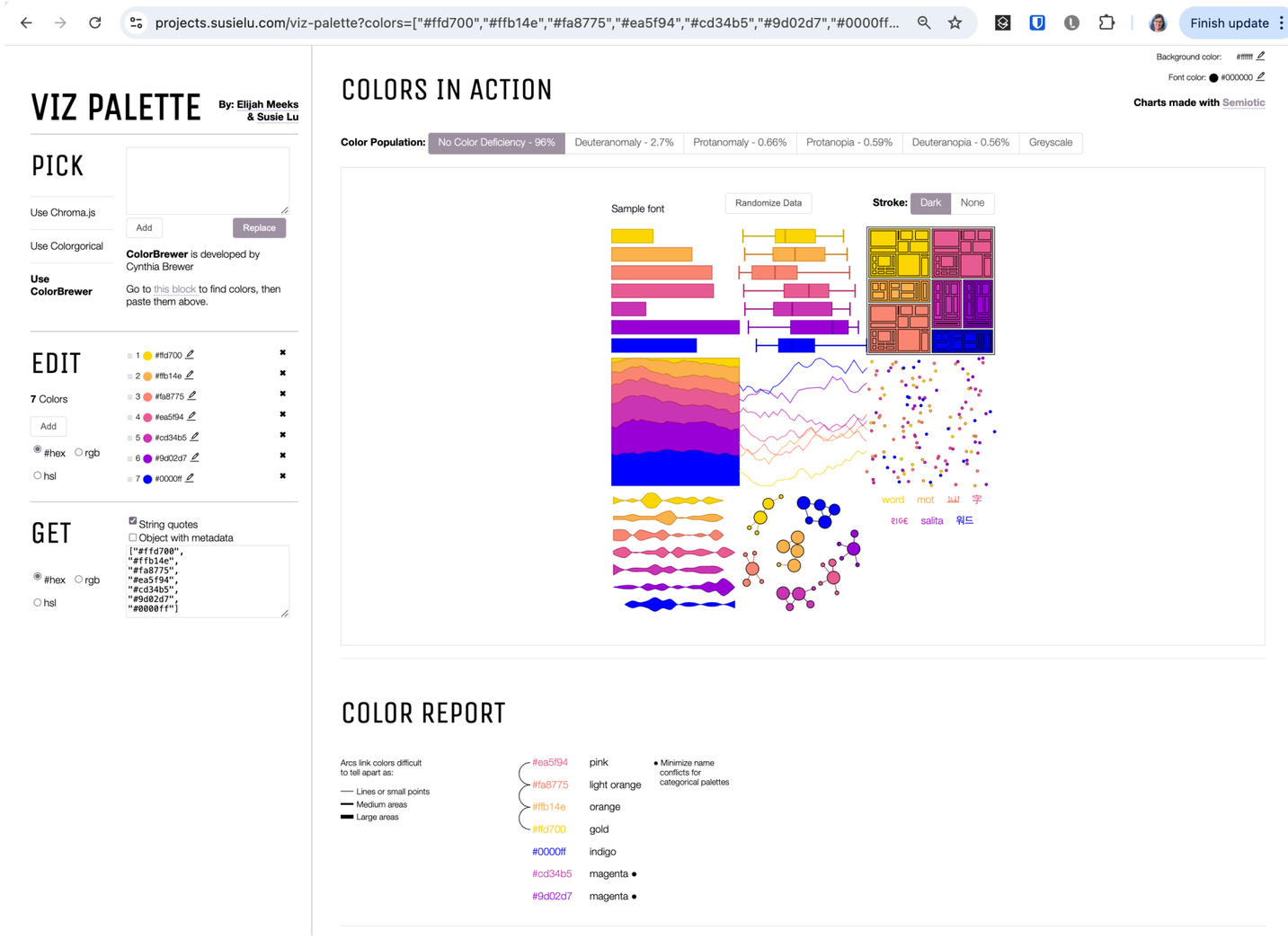
More color resources: Muth

- 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



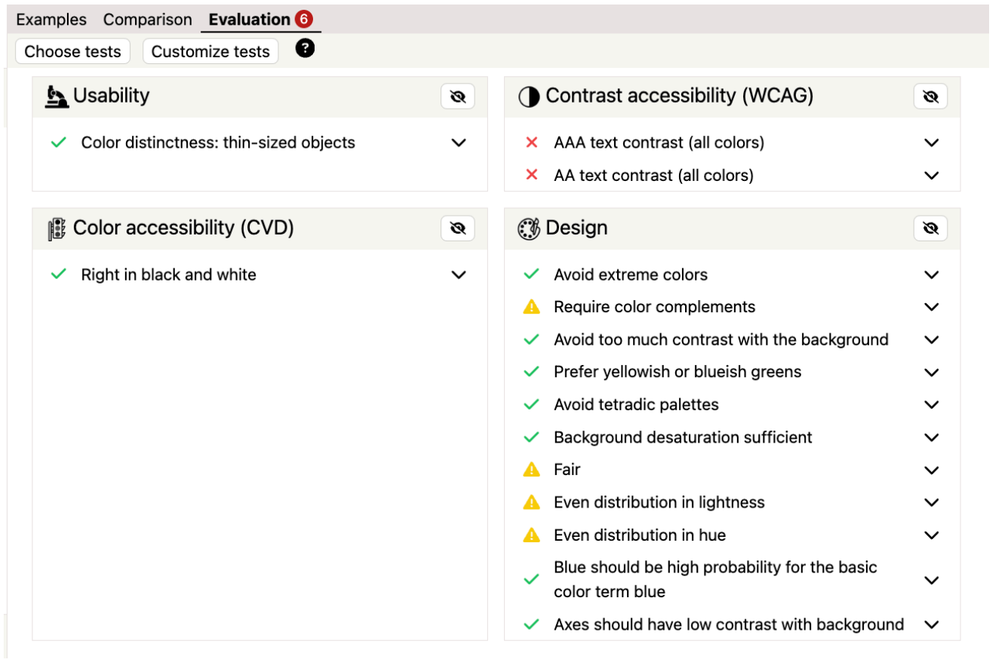
More color resources: Viz Palette

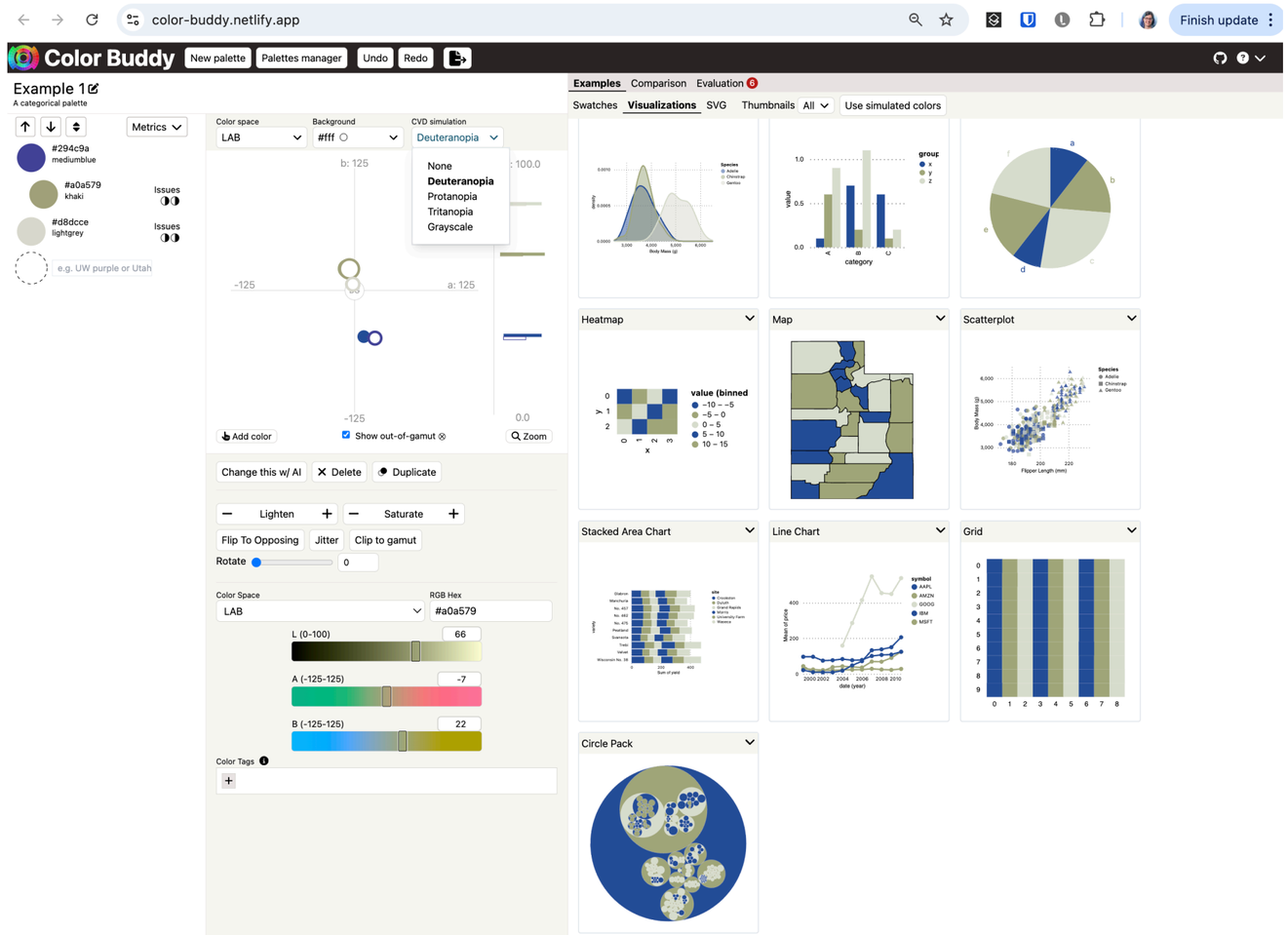
- Viz Palette, by Elijah Meeks and Susie Lu
  https://projects.susielu.com/viz-palette
  - colorblindness checks
  - examples for different mark sizes/types
  - report on distinguishability including names



More color resources: Color Buddy

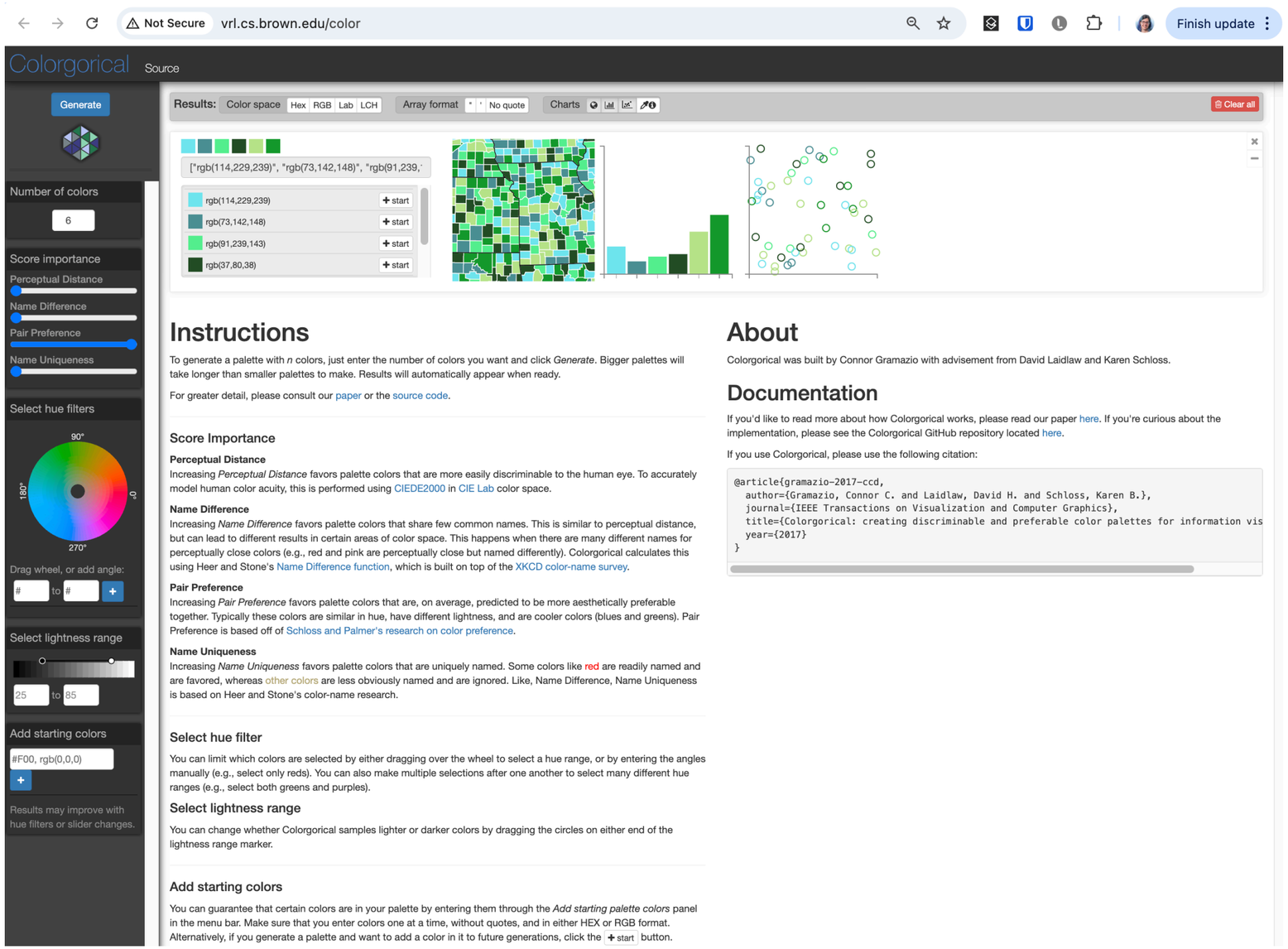
- Color Buddy, by Andrew McNutt and Maureen Stone
  https://color-buddy.netlify.app/
  - check against colorblindness
  - check different mark types/sizes
  - evaluate against design guidelines





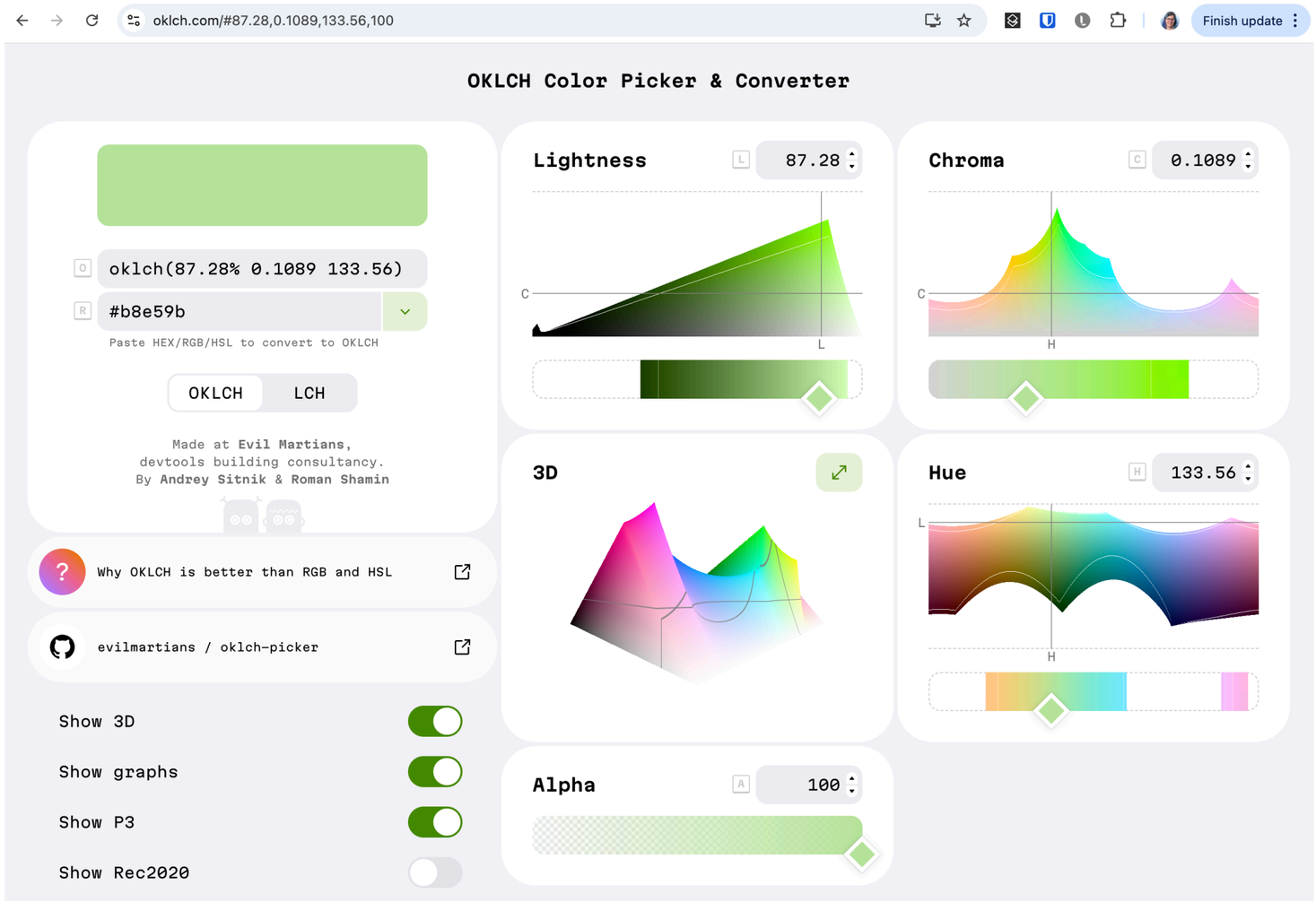
More color resources: Colorgorical

- 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