

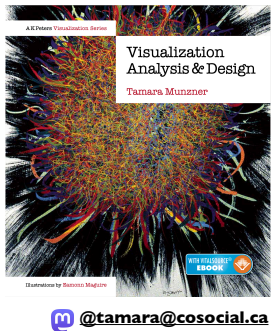
Visualization Analysis & Design

BMVC Tidbits

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UBC Biomedical Visualization and Communication
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<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.

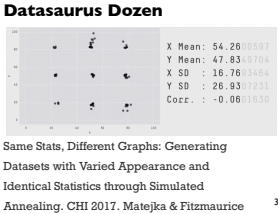
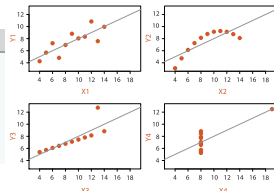
Why represent data visually?

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

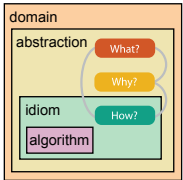
Identical statistics	
x mean	9
x variance	10
y mean	7.5
y variance	3.75
x/y correlation	0.816



Visualization analysis framework: Four levels, three questions

- domain situation
 - who are the target users?
- abstraction
 - 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).]

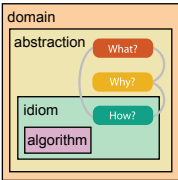


[A Multi-Level Typology of Abstract Visualization Tasks Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]

Visualization analysis framework: Four levels, three questions

- domain situation
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 - what is shown? data abstraction
 - why is the user looking at it? task abstraction
- idiom
 - how is it shown?
 - visual encoding idiom: how to draw
 - interaction idiom: how to manipulate

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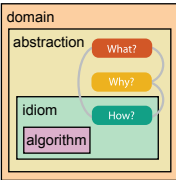


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- idiom
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 - visual encoding idiom: how to draw
 - interaction idiom: how to manipulate
- algorithm
 - efficient computation

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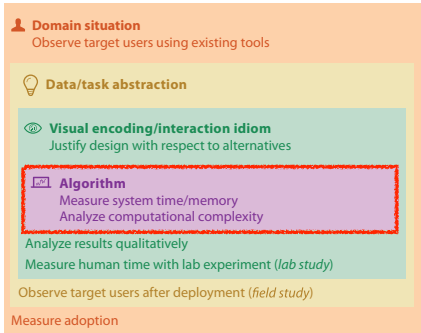
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Visualization analysis framework: Four levels, three questions

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Why is validation difficult?

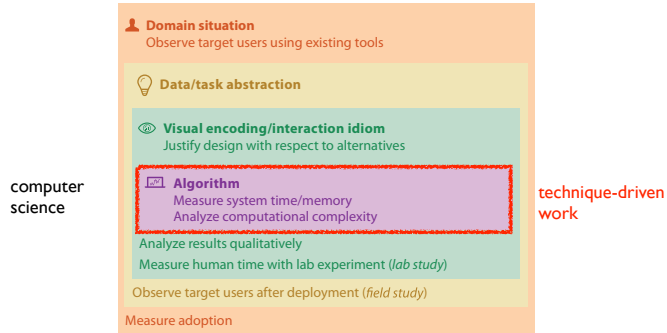
- solution: use methods from different fields at each level



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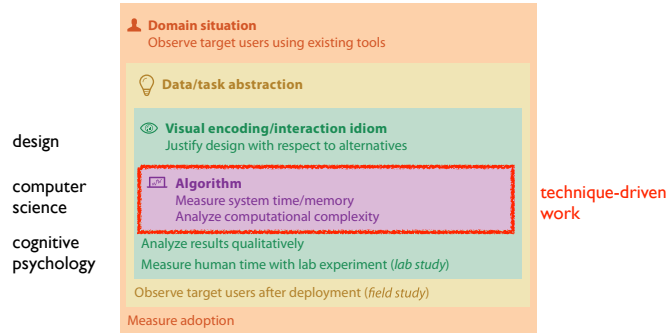
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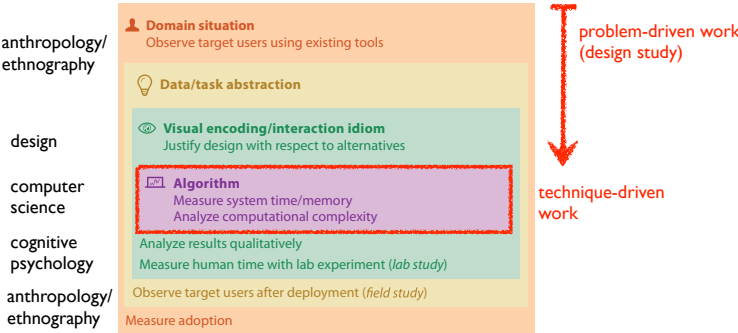
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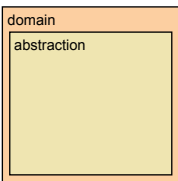
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Abstraction: Data & task

- 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



Abstractions

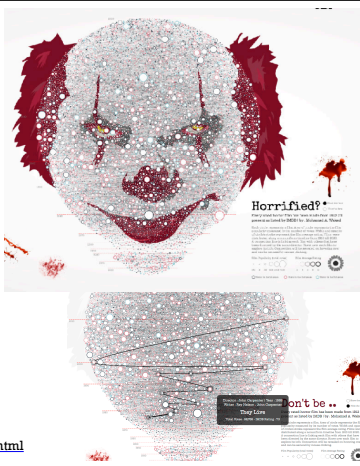
Example: Horrified

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



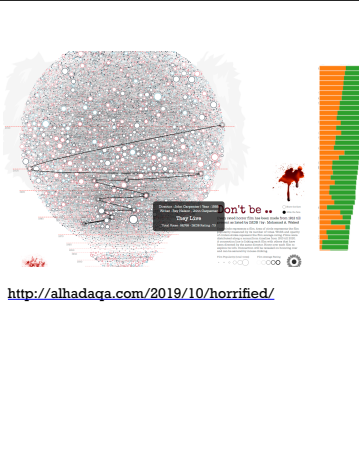
Example: Horrified

- 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



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!



Visual Encoding Idioms

Visual encoding

- analyze idiom structure



Definitions: Marks and channels

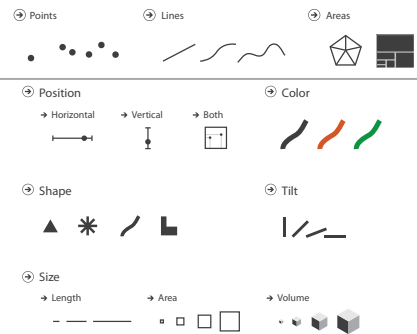
Definitions: Marks and channels

- marks
 - geometric primitives



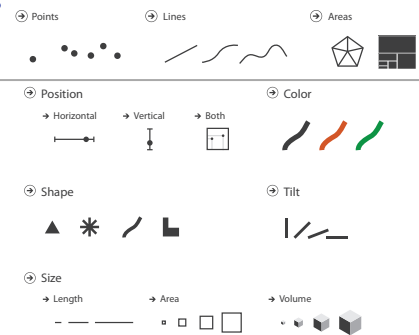
Definitions: Marks and channels

- marks
 - geometric primitives
- channels
 - control appearance of marks



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

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

mark: line

mark: point

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

3:
vertical position
horizontal position
color hue

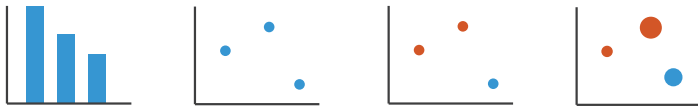
mark: line

mark: point

mark: point

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

3:
vertical position
horizontal position
color hue

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

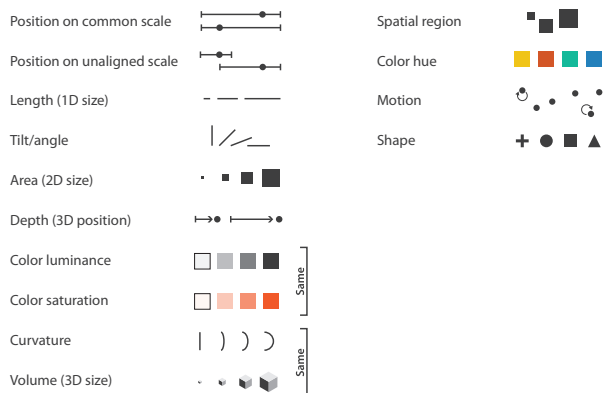
mark: line

mark: point

mark: point

mark: point

Channels: Rankings



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)
- Identity Channels: Categorical Attributes
 - Spatial region
 - Color hue
 - Motion
 - Shape
- expressiveness
 - match channel and data characteristics

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 - Spatial region
 - Color hue
 - Motion
 - Shape
- Attribute Types
 - Categorical
 - + • ● ■ ▲
 - Ordered
 - + • ● ■ ▲
 - Quantitative
 - + • ● ■ ▲
- expressiveness
 - match channel and data characteristics
 - magnitude for ordered
 - how much? which rank?
 - identity for categorical
 - what?

Channels: Rankings

➡ **Magnitude** Channels: **Ordered** Attributes

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➡ **Identity** Channels: **Categorical** Attributes

- Spatial region
- Color hue
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- expressiveness
 - match channel and data characteristics
- effectiveness
 - channels differ in accuracy of perception

Channels: Rankings

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- Spatial region
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- 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.]

Discriminability: How many usable steps?

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

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute

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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

Relative luminance judgements

- perception of luminance is contextual based on contrast with surroundings

Relative luminance judgements

- perception of luminance is contextual based on contrast with surroundings

Relative color judgements

- color constancy across broad range of illumination conditions

Relative color judgements

- color constancy across broad range of illumination conditions

Grouping

Marks as Links

➡ Containment

➡ Connection

➡ **Identity** Channels: **Categorical** Attributes

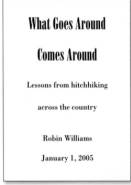
- containment
- connection
- proximity
 - same spatial region
- similarity
 - same values as other categorical channels

- Spatial region
- Color hue
- Motion
- Shape

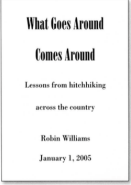
Graphic Design for Non-Designers

Form: Basic graphic design ideas

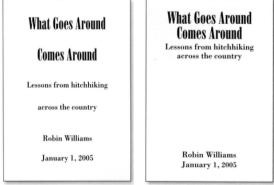
Form: Basic graphic design ideas



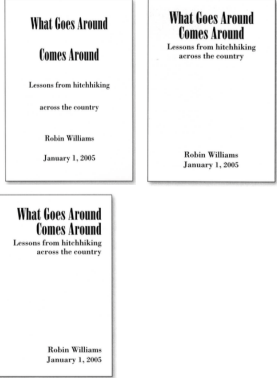
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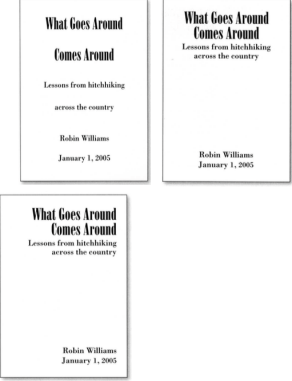


Form: Basic graphic design ideas



Form: Basic graphic design ideas

- proximity
 - do group related items together
 - avoid equal whitespace between unrelated
- alignment
 - do find/make strong line, stick to it
 - avoid automatic centering
- repetition
 - do unify by pushing existing consistencies



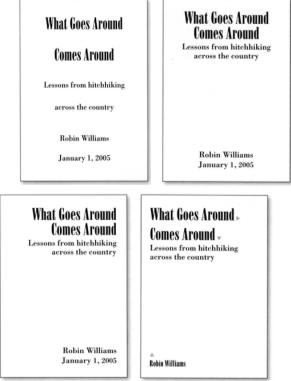
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- The Non-Designer's Design Book, 4th ed. Robin Williams, Peachpit Press, 2015.
 - fast read, very practical to work through whole thing

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)

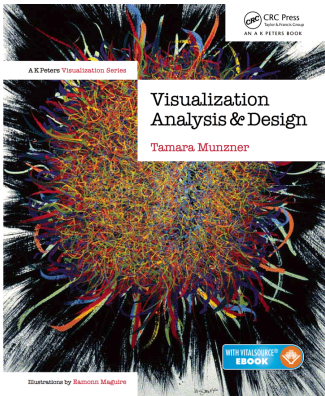
Further reading, usability

- 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

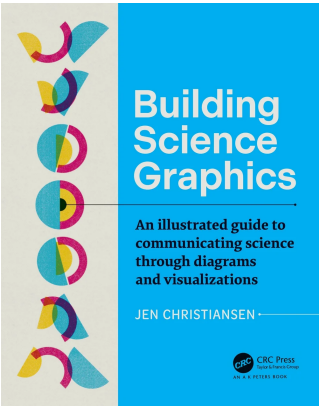
- book from which these tidbits were drawn
 - illustration acknowledgement: Eamonn Maguire
- full courses, papers, videos, software, talks
 - <http://www.cs.ubc.ca/group/infovis>
 - <http://www.cs.ubc.ca/~tmm>



<https://www.cs.ubc.ca/~tmm/vadbook>
<https://www.routledge.com/Visualization-Analysis-and-Design/Munzner/p/book/9781466508910>

Building Science Graphics

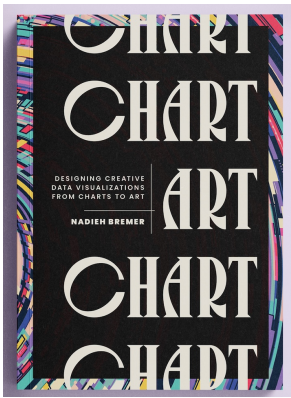
- Building Science Graphics: An illustrated guide to communicating science through diagrams and visualizations
 - Jen Christiansen



<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

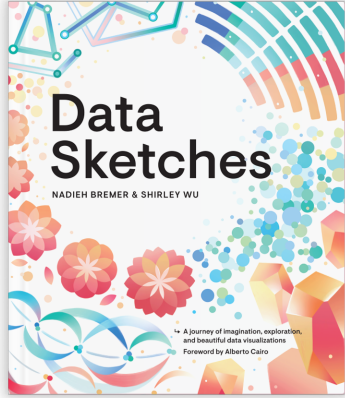


<https://www.visualcinnamon.com/chart/>

<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

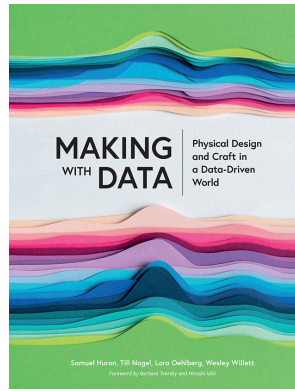


<https://www.datasketch.es/book>

<https://www.routledge.com/Data-Sketches-A-journey-of-imagination-exploration-and-beautiful-data-visualizations/Bremer-Wu/p/book/9780367000800>

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/>

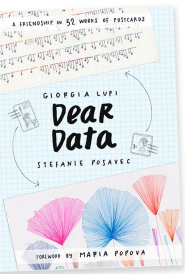
<https://www.routledge.com/Making-with-Data-Physical-Design-and-Craft-in-a-Data-Driven-World/Huron-Nagel-Oehlberg-Willett/p/book/9781032182223>

Dear Data: A Friendship in 52 Weeks of Postcards

- inspiring celebration of data humanism



Giorgia Lupi and
Stefanie Posavec



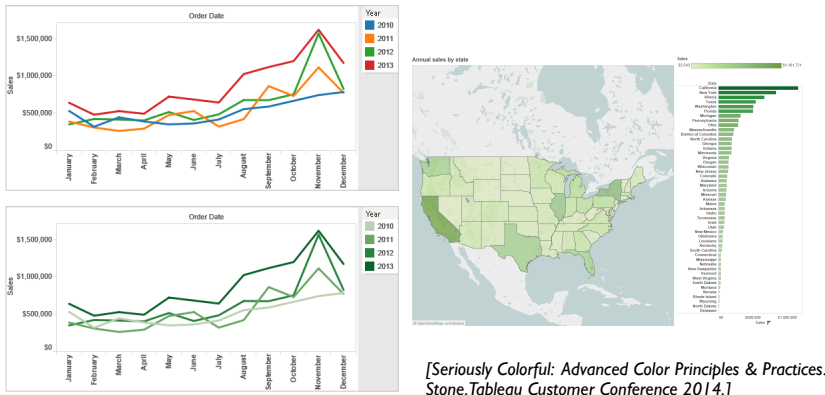
<http://www.dear-data.com/by-week/>

<https://giorgialupi.com/dear-data>

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

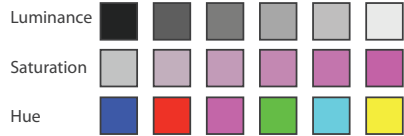
Color

Categorical vs ordered color



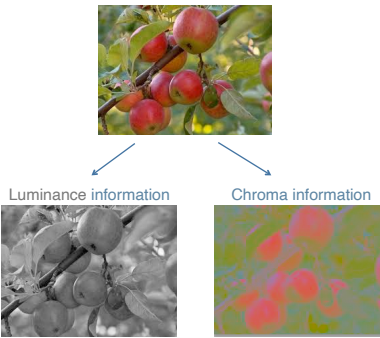
Decomposing color

- 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?



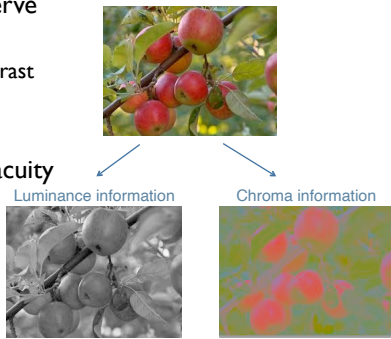
Luminance

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



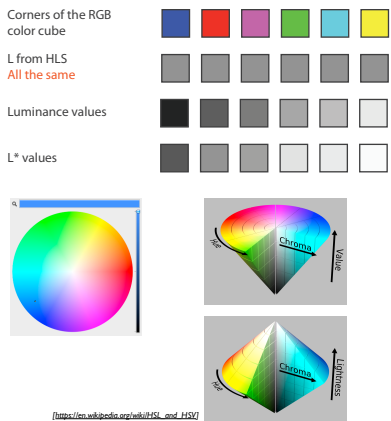
Opponent color and color deficiency

- 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

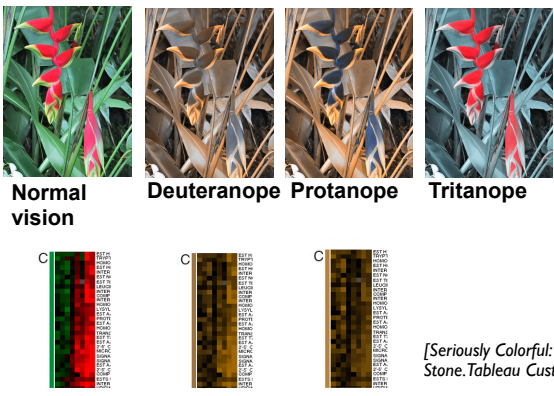


Color spaces

- 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



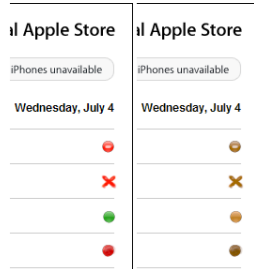
Designing for color deficiency: Check with simulator



<http://rehue.net>

Designing for color deficiency: Avoid encoding by hue alone

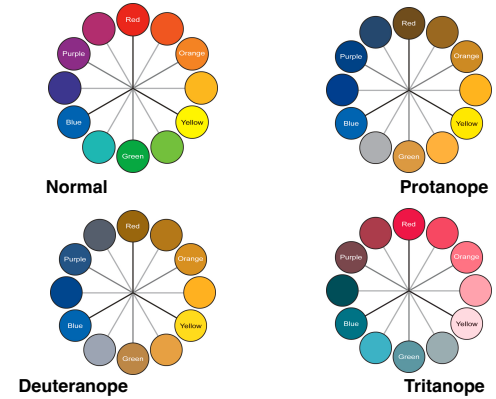
- redundantly encode
– vary luminance
– change shape



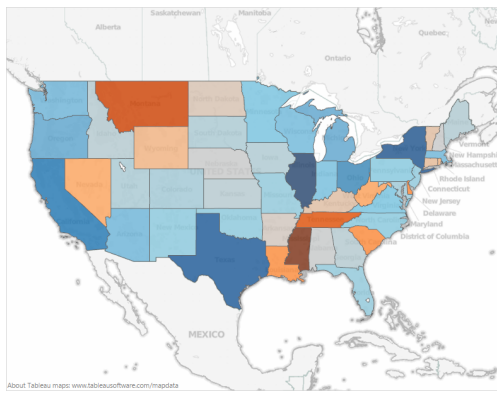
Change the shape
Vary luminance

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

Color deficiency: Reduces color to 2 dimensions

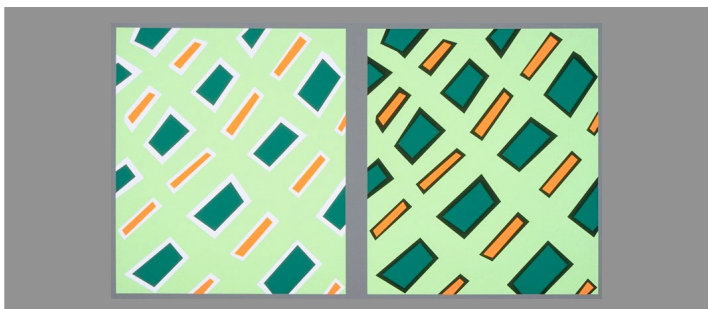


Designing for color deficiency: Blue-Orange is safe

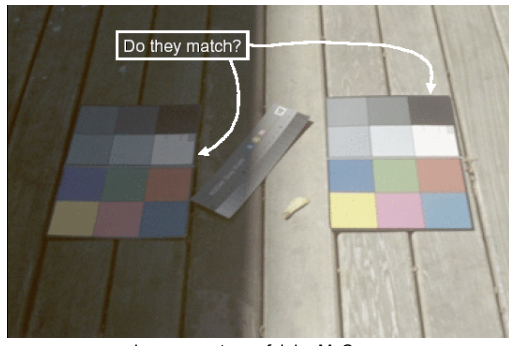


Bezold Effect: Outlines matter

- color constancy: simultaneous contrast effect



Relative judgements: Color & illumination



Relative judgements: Color & illumination

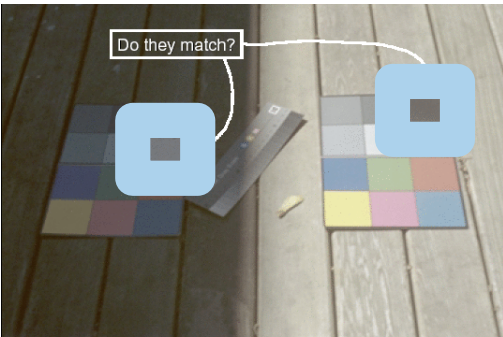
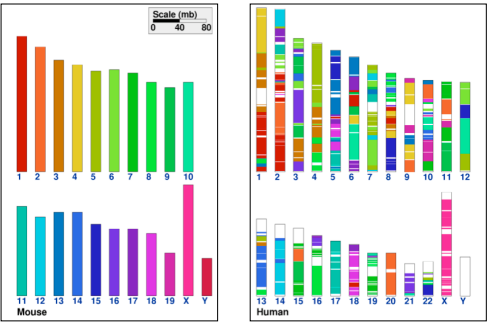


Image courtesy of John McCann via Maureen Stone

Categorical color: limited number of discriminable bins

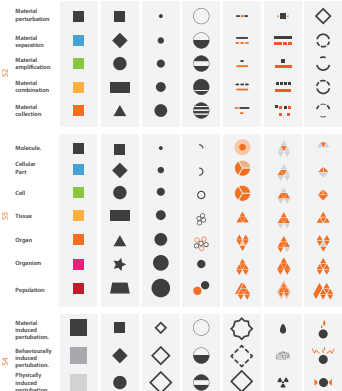
- human perception built on relative comparisons
 - great if color contiguous
 - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
 - fewer bins than you want
 - rule of thumb: 6-12 bins, including background and highlights



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

Glyphs

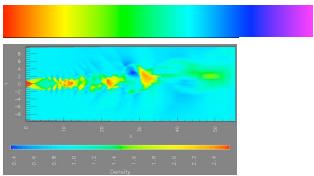
- glyphs: composite objects
 - internal structure with multiple marks
- alternative to color coding
 - or coding with any single channel



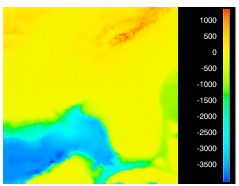
[Fig 5. Taxonomy-Based Glyph Design - with a Case Study on Visualizing Workflows of Biological Experiments. Maguire, Rocca-Serra, Sansone, Davies, and Chen. IEEE Trans. Visualization and Computer Graphics 18:12:2603-2612 (Proc. InfoVis 12).]

Ordered color: Rainbow is poor default

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



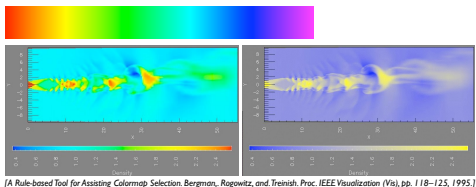
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Ragwitz, and Treish. Proc. IEEE Visualization (Vis), pp. 118-125, 1995.]



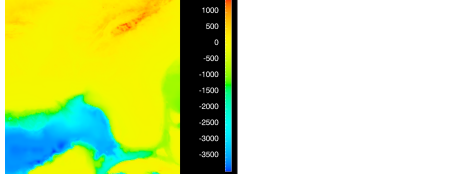
[Why Should Engineers Be Worried About Color? Treish and Ragwitz. 1998. http://www.research.ibm.com/people/llloyd/color/HTML/ [Transfer Functions in Direct Volume Rendering Design, Interface, Interaction, Kindmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

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



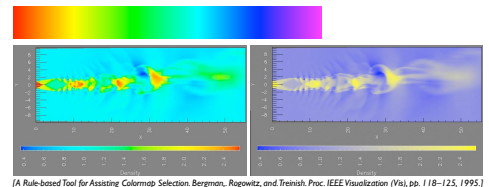
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Ragwitz, and Treish. Proc. IEEE Visualization (Vis), pp. 118-125, 1995.]



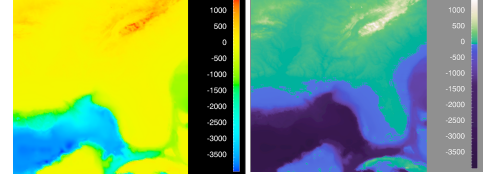
[Why Should Engineers Be Worried About Color? Treish and Ragwitz. 1998. http://www.research.ibm.com/people/llloyd/color/HTML/ [Transfer Functions in Direct Volume Rendering Design, Interface, Interaction, Kindmann. SIGGRAPH 2002 Course Notes]

Ordered color: Rainbow is poor default

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



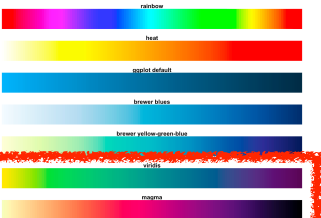
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Ragwitz, and Treish. Proc. IEEE Visualization (Vis), pp. 118-125, 1995.]



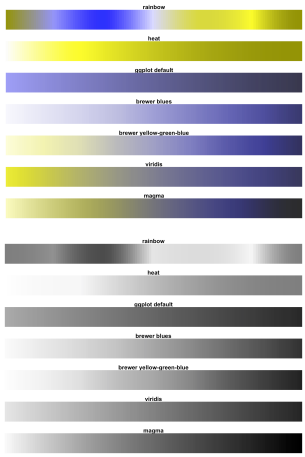
[Why Should Engineers Be Worried About Color? Treish and Ragwitz. 1998. http://www.research.ibm.com/people/llloyd/color/HTML/ [Transfer Functions in Direct Volume Rendering Design, Interface, Interaction, Kindmann. SIGGRAPH 2002 Course Notes]

Viridis

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

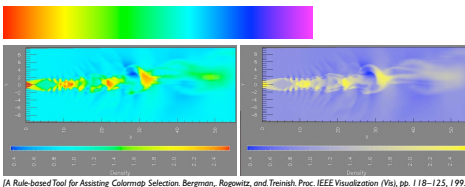


<https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html>

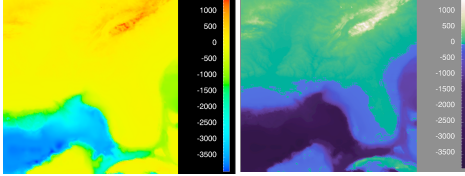


Ordered color: Rainbow is poor default

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



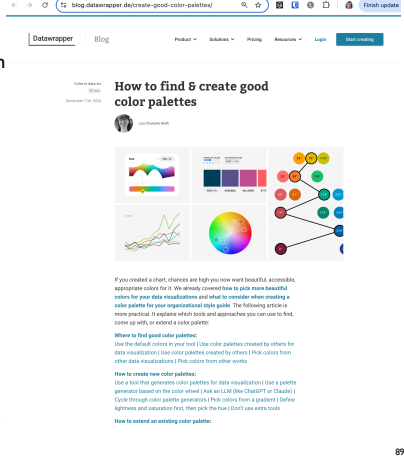
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Ragwitz, and Treish. Proc. IEEE Visualization (Vis), pp. 118-125, 1995.]



[Why Should Engineers Be Worried About Color? Treish and Ragwitz. 1998. http://www.research.ibm.com/people/llloyd/color/HTML/ [Transfer Functions in Direct Volume Rendering Design, Interface, Interaction, Kindmann. SIGGRAPH 2002 Course Notes]

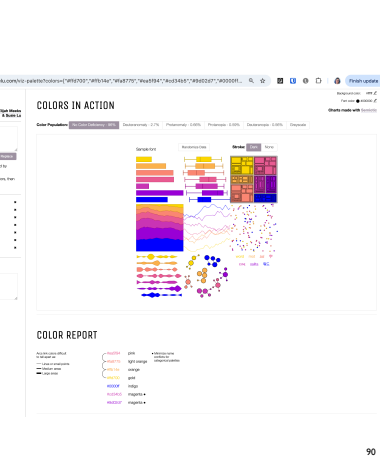
More color resources: Muth

- 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



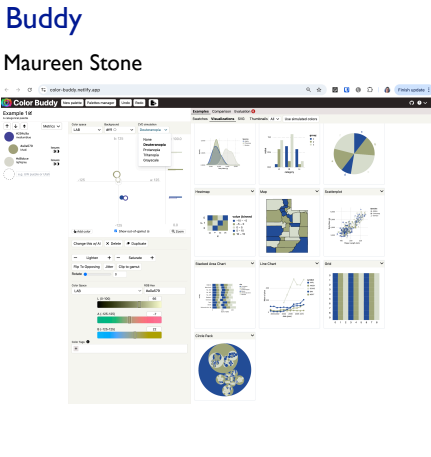
More color resources: Viz Palette

- 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



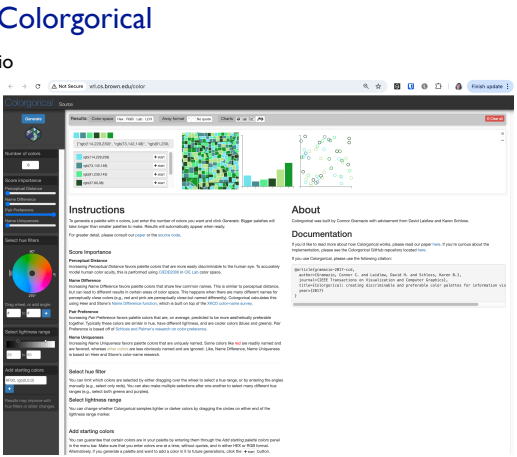
More color resources: Color Buddy

- 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



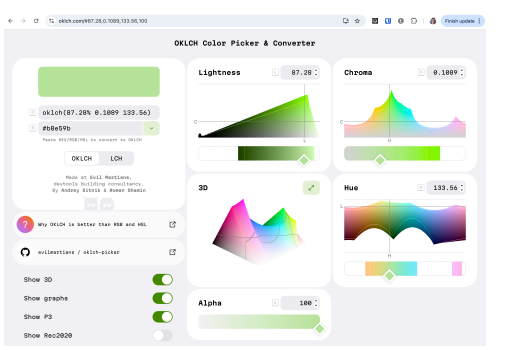
More color resources: Colorgical

- Colorgical, 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

