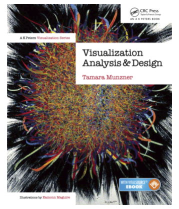
# Visualization Analysis & Design
## *Half-Day Tutorial*



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*IEEE VIS 2024 Tutorial*
*October 2024, virtual*

**https://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24**

## Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

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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.**



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Why?...



## Why have a human in the loop?

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**Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.**



## Why have a human in the loop?

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

**Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.**

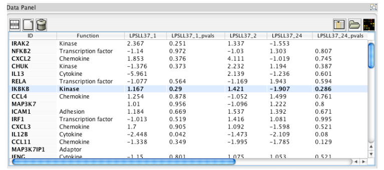
- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
  - don't know exactly what questions to ask in advance
- possibilities
  - long-term use for end users (ex: exploratory analysis of scientific data)
  - presentation of known results (ex: New York Times Upshot)
  - stepping stone to assess requirements before developing models
  - help automatic solution developers refine & determine parameters
  - help end users of automatic solutions verify, build trust



## Why use an external representation?

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

- external representation: replace cognition with perception



*[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE TVCG (Proc. InfoVis) 14(6):1253-1260, 2008.]*



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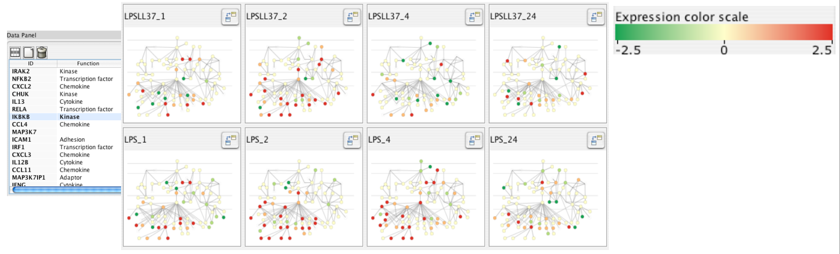


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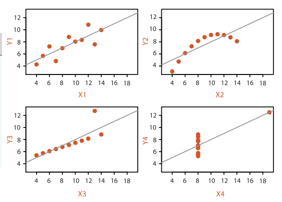
## Why represent all the data?

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

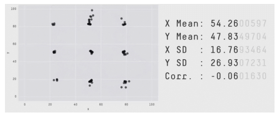
- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

**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



## Why analyze?

- imposes structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new
  - most possibilities ineffective for particular task/data combination



## Analysis framework: Four levels, three questions

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



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

- *domain situation*
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    - **what** is shown? **data** abstraction
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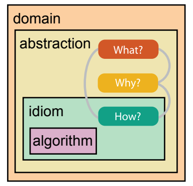


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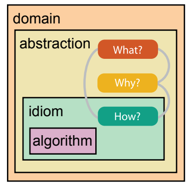
- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate

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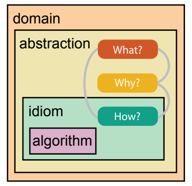
- *algorithm*
  - efficient computation

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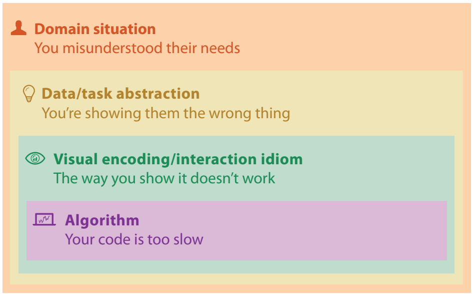
## Why is validation difficult?

- different ways to get it wrong at each level



## Why is validation difficult?

- solution: use methods from different fields at each level

Domain situation
Observe target users using existing tools
Data/task abstraction
Visual encoding/interaction idiom
Justify design with respect to alternatives
Algorithm
Measure system time/memory
Analyze computational complexity
Analyze results qualitatively
Measure human time with lab experiment (*lab study*)
Observe target users after deployment (*field study*)
Measure adoption

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computer science

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technique-driven work

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design

computer science

cognitive psychology

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anthropology/ ethnography

design

computer science

cognitive psychology

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problem-driven work (design study)

technique-driven work

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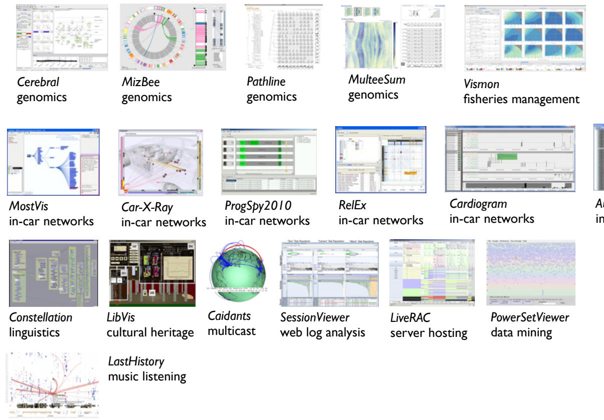
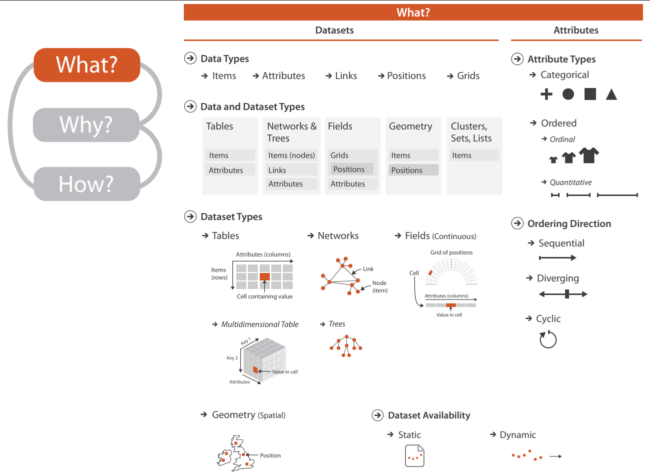
## Design Study Methodology: Reflections from the Trenches and the Stacks




[Sedlmair, Meyer, Munzner. IEEE Trans. Visualization and Computer Graphics 18(12): 2431-2440, 2012 (Proc. InfoVis 2012).]








## Three major datatypes



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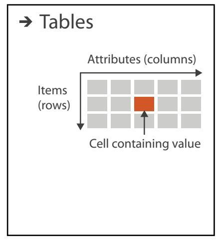
Dataset Types



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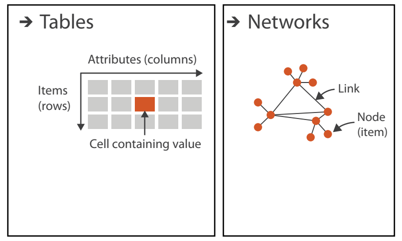




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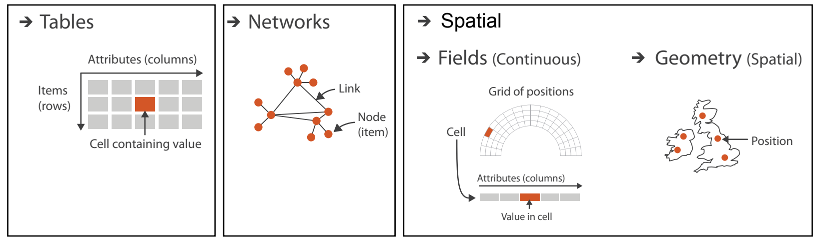




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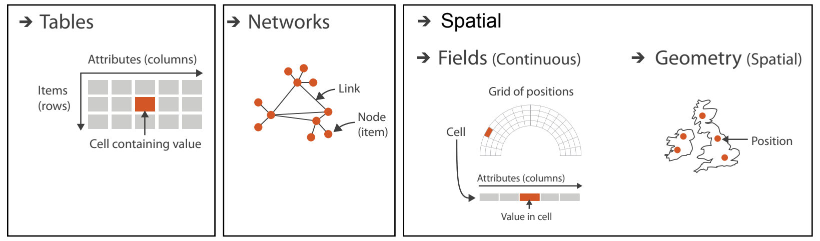
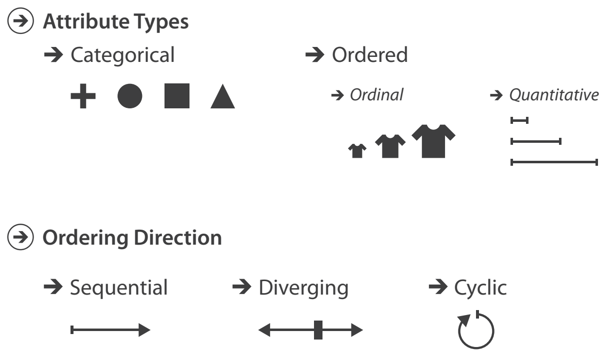


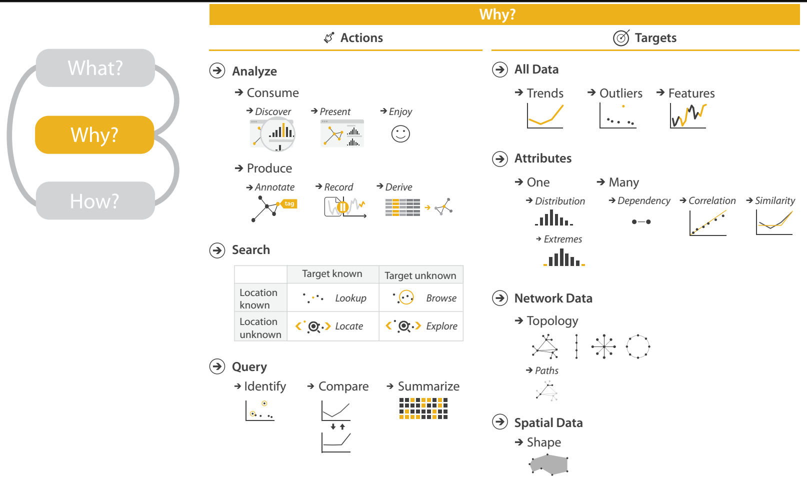

- visualization vs computer graphics
  - geometry is design decision



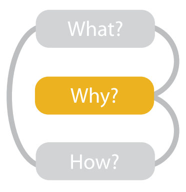
## Attribute types



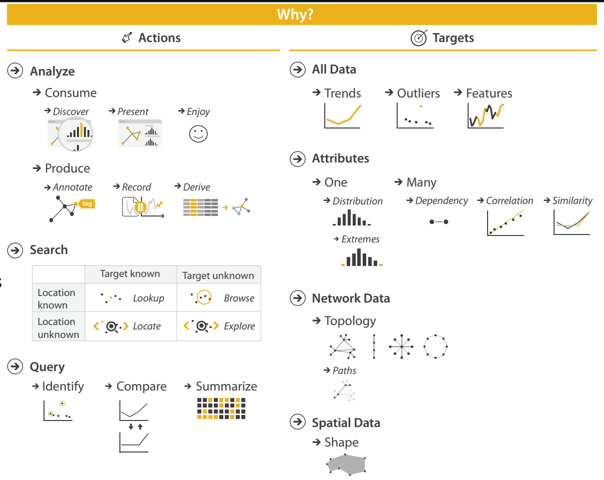




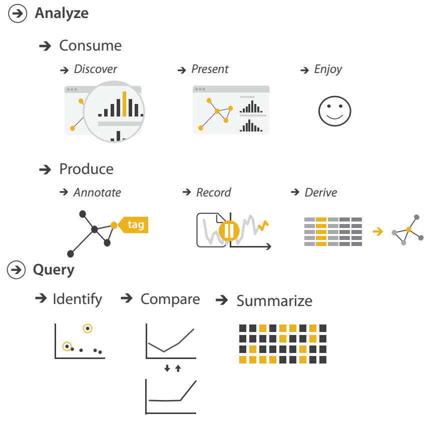

- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*






## Actions: Analyze, Query

- analyze
  - consume
    - discover vs present
      - aka explore vs explain
    - enjoy
      - aka casual, social
  - produce
    - annotate, record, derive
- query
  - how much data matters?
    - one, some, all
- independent choices
  - analyze, query, (search)



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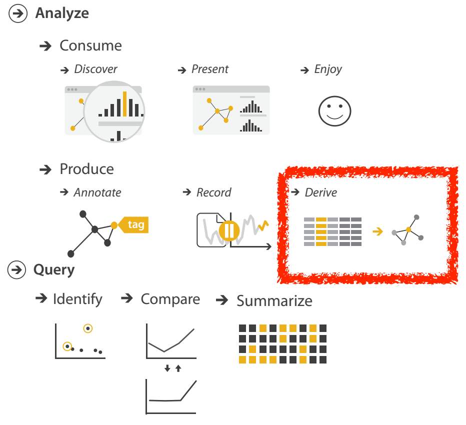


## Derive

- don't necessarily just draw what you're given!
  - decide what the right thing to show is
  - create it with a series of transformations from the original dataset
  - draw that
- one of the four major strategies for handling complexity


Original Data

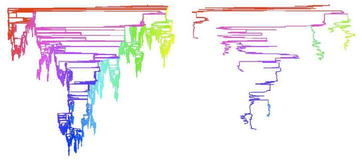
Derived Data

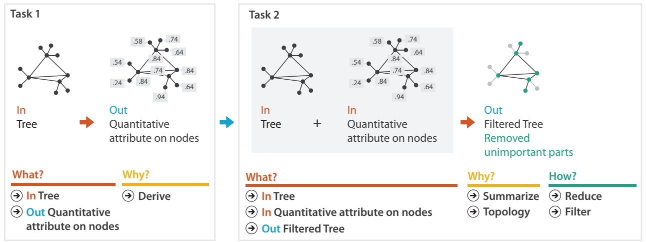


## Analysis example: Derive one attribute

- Strahler number
  - centrality metric for trees/networks
  - derived quantitative attribute
  - draw top 5K of 500K for good skeleton

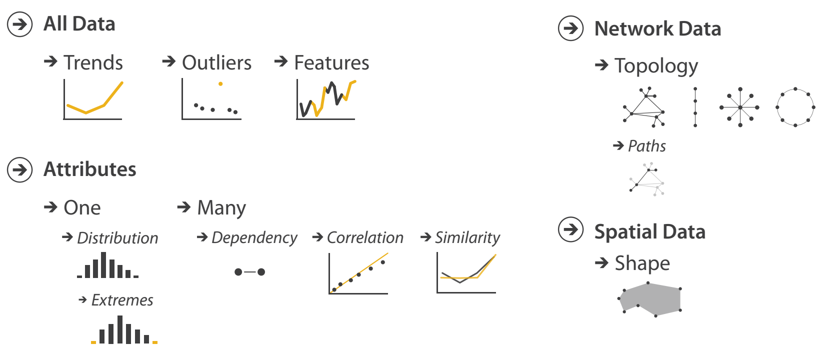
*[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56–69, 2002.]*



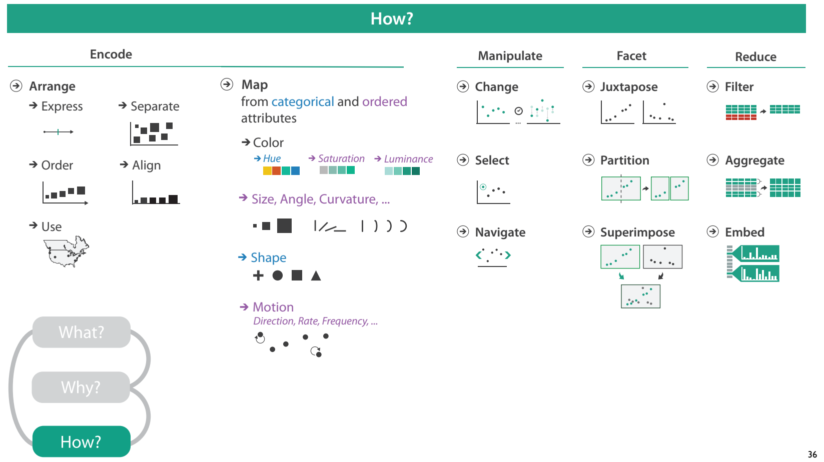





## Why: Targets








## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 1: What's Vis, and Why Do It?*
  - *Chap 2: What: Data Abstraction*
  - *Chap 3: Why: Task Abstraction*
- *A Multi-Level Typology of Abstract Visualization Tasks.* Brehmer and Munzner. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 19:12 (2013), 2376–2385.
- *Low-Level Components of Analytic Activity in Information Visualization.* Amar, Eagan, and Stasko. Proc. IEEE InfoVis 2005, p 111–117.
- *A taxonomy of tools that support the fluent and flexible use of visualizations.* Heer and Shneiderman. Communications of the ACM 55:4 (2012), 45–54.
- *Rethinking Visualization: A High-Level Taxonomy.* Tory and Möller. Proc. IEEE InfoVis 2004, p 151–158.
- Visualization of Time-Oriented Data. Aigner, Miksch, Schumann, and Tominski. Springer, 2011.



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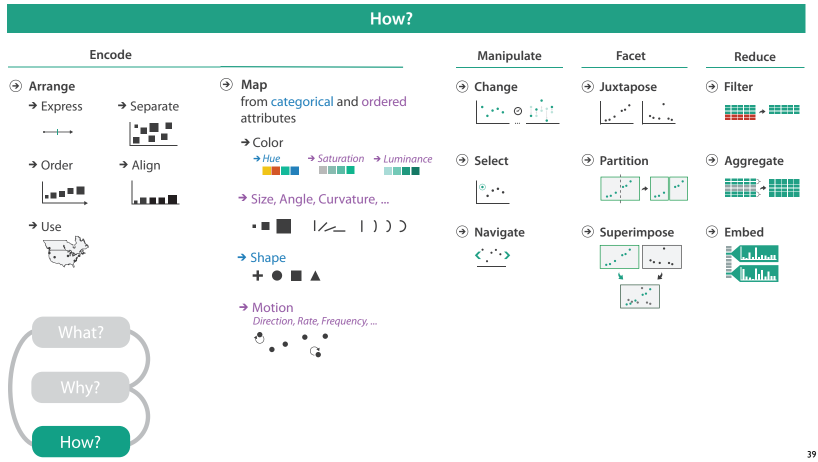
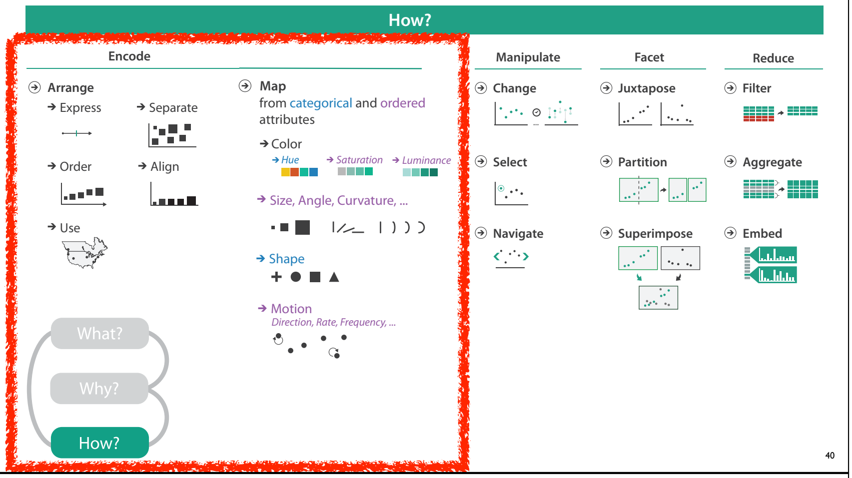


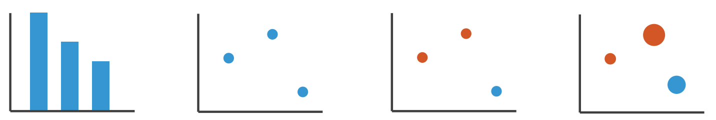





## Visual encoding

- analyze idiom structure





## Definitions: Marks and channels



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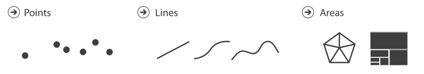
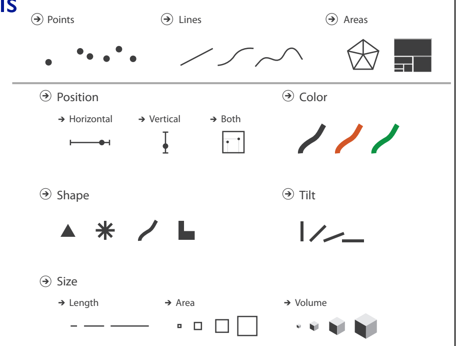
- marks
  - geometric primitives






## Definitions: Marks and channels

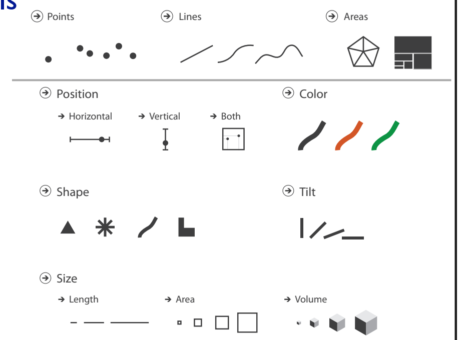
- marks
  - geometric primitives
- channels
  - control appearance of marks






## Definitions: Marks and channels

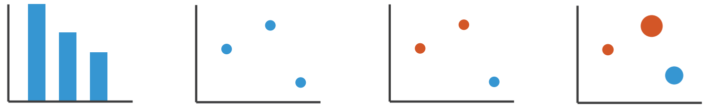
- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
  - type & amount of information that can be conveyed to human perceptual system






## Visual encoding

- analyze idiom structure as combination of marks and channels



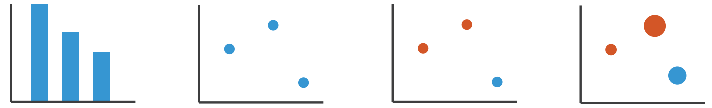
1: vertical position

mark: line



## Visual encoding

- analyze idiom structure as combination of marks and channels



1: vertical position — mark: line

2: vertical position, horizontal position — mark: point



## Visual encoding

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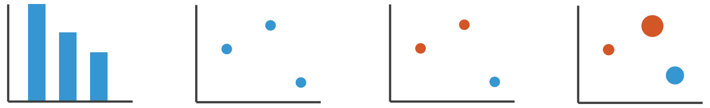


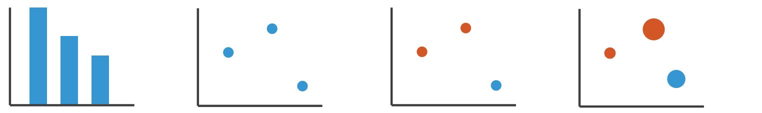
1: vertical position — mark: line

2: vertical position, horizontal position — mark: point

3: vertical position, horizontal position, color hue — mark: point

## Visual encoding

- analyze idiom structure as combination of marks and channels



1: vertical position — mark: line

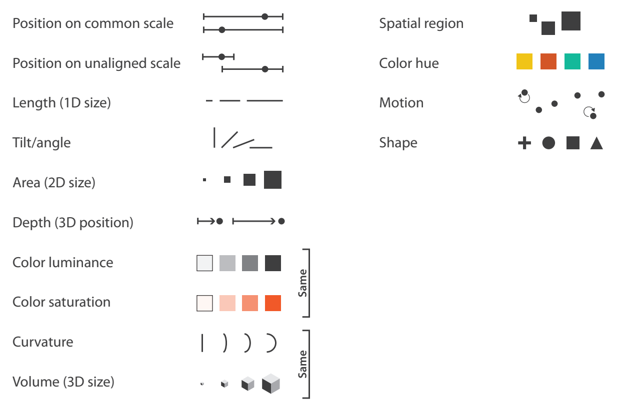
2: vertical position, horizontal position — mark: point

3: vertical position, horizontal position, color hue — mark: point

4: vertical position, horizontal position, color hue, size (area) — mark: point



## Channels: Rankings



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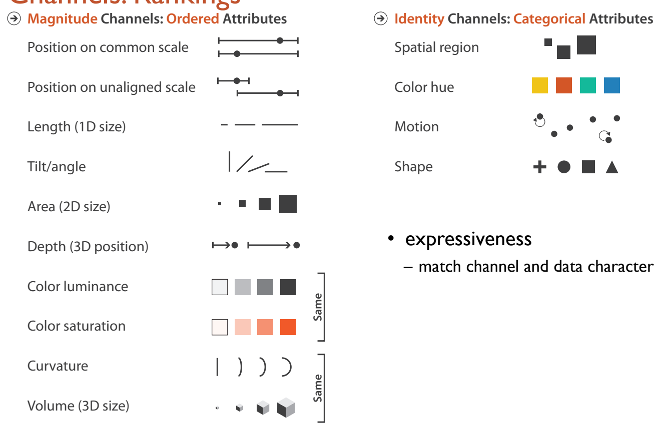
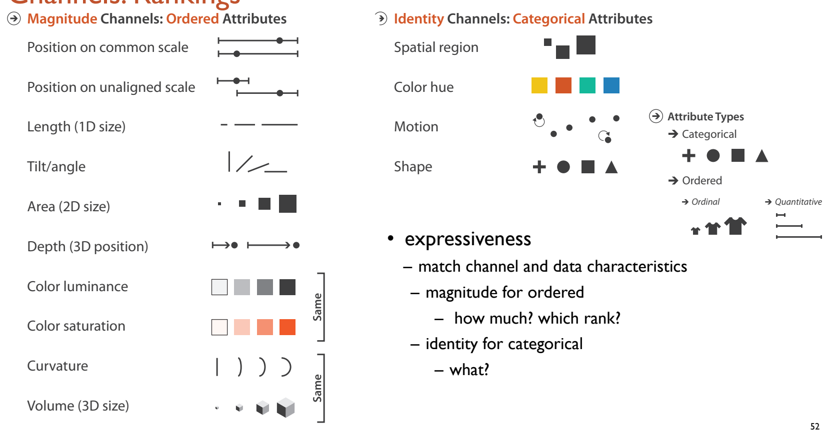



- expressiveness
  - match channel and data characteristics



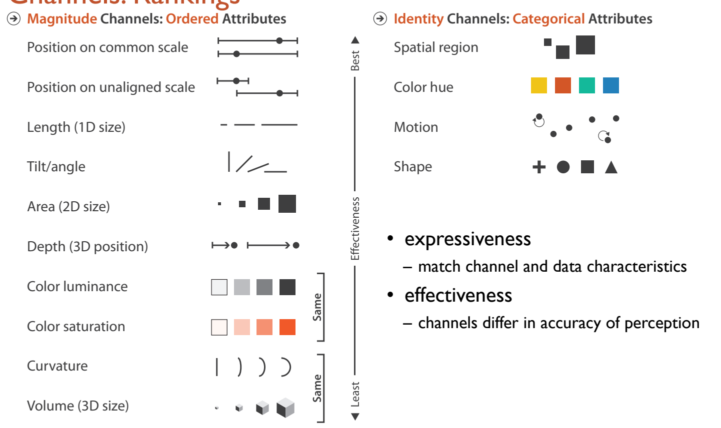
## Channels: Rankings




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



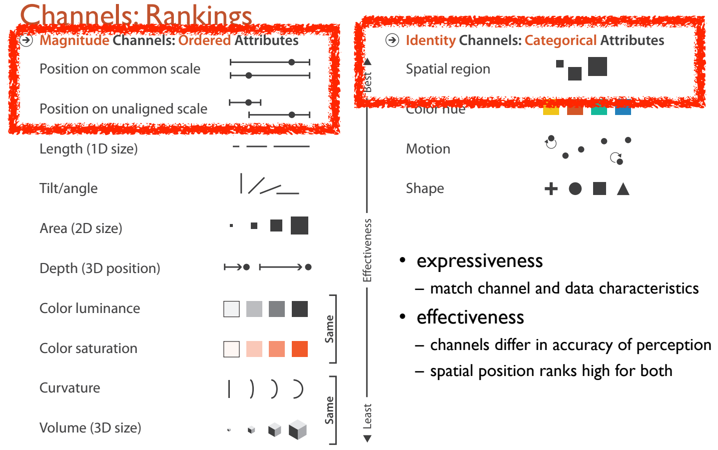
## Channels: Rankings




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



## Channels: Rankings

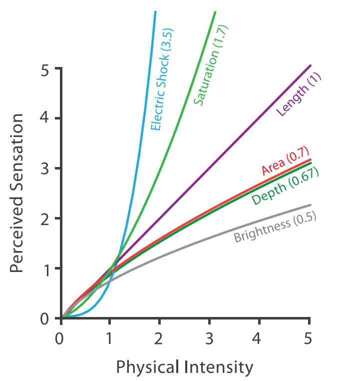



- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
  - spatial position ranks high for both



## Accuracy: Fundamental Theory

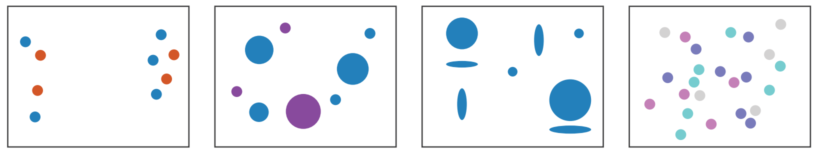
Steven's Psychophysical Power Law: $S = I^N$






## Separability vs. Integrality

Position + Hue (Color) | Size + Hue (Color) | Width + Height | Red + Green



Fully separable — 2 groups each

Some interference — 2 groups each

Some/significant interference — 3 groups total: integral area

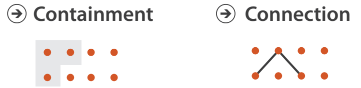
Major interference — 4 groups total: integral hue



## Grouping

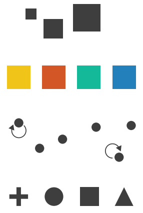
- containment
- connection

Marks as Links




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

Identity Channels: Categorical Attributes






## Further reading


- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 5: Marks and Channels*
- *On the Theory of Scales of Measurement.* Stevens. Science 103:2684 (1946), 677–680.
- Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. Stevens. Wiley, 1975.
- *Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods.* Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.
- *Perception in Vision.* Healey. http://www.csc.ncsu.edu/faculty/healey/PP
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.



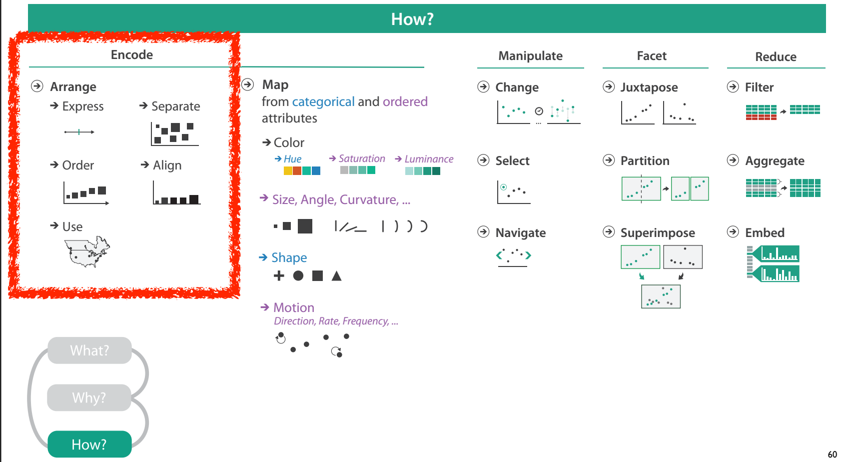

## Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24

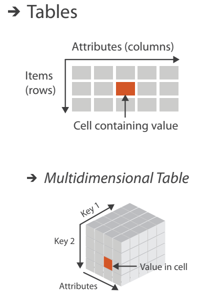


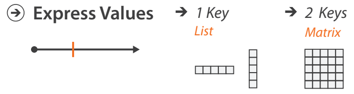





## Keys and values

- key
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys
- value
  - dependent attribute, value of cell
- classify arrangements by key count
  - 0, 1, 2, many...

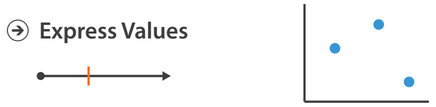


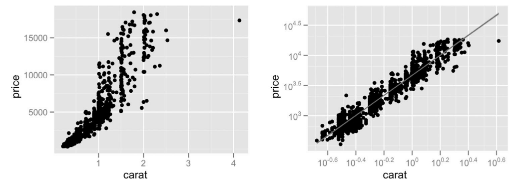






## Idiom: **scatterplot**

- ***express*** values
  - quantitative attributes
- no keys, only values
  - data
    - 2 quant attribs
  - mark: points
  - channels
    - horiz + vert position
  - tasks
    - find trends, outliers, distribution, correlation, clusters
  - scalability
    - hundreds of items




[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]



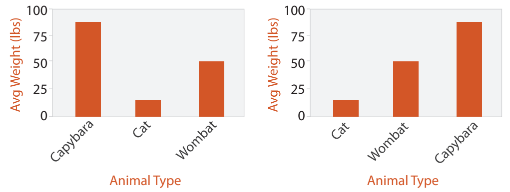
## Some keys: Categorical regions

- regions: contiguous bounded areas distinct from each other
  - using space to **separate** (proximity)
  - following expressiveness principle for categorical attributes
- use ordered attribute to **order** and **align** regions



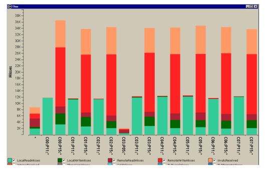

## Idiom: **bar chart**

- one key, one value
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
  - channels
    - length to express quant value
    - spatial regions: one per mark
      - separated horizontally, aligned vertically
      - ordered by quant attrib
        - » by label (alphabetical), by length attrib (data-driven)
  - task
    - compare, lookup values
  - scalability
    - dozens to hundreds of levels for key attrib



## Idiom: **stacked bar chart**

- one more key
  - data
    - 2 categ attrib, 1 quant attrib
  - mark: vertical stack of line marks
    - ***glyph***: composite object, internal structure from multiple marks
  - channels
    - length and color hue
    - spatial regions: one per glyph
      - aligned: full glyph, lowest bar component
      - unaligned: other bar components
  - task
    - part-to-whole relationship
  - scalability
    - several to one dozen levels for stacked attrib

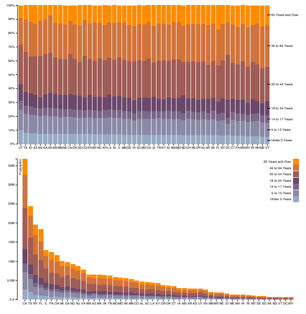


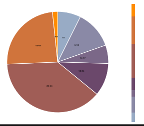
*[Using Visualization to Understand the Behavior of Computer Systems. Bosch. Ph.D. thesis, Stanford Computer Science, 2001.]*



## Idioms: **normalized stacked bar chart**

- task
  - part-to-whole judgements
- normalized stacked bar chart
  - stacked bar chart, normalized to full vert height
  - single stacked bar equivalent to full pie
    - high information density: requires narrow rectangle
- pie chart
  - information density: requires large circle



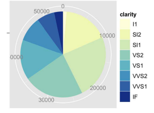


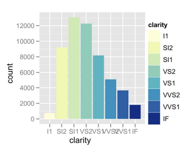
https://blocks.roadtolarissa.com/mbostock/3887235,
https://blocks.roadtolarissa.com/mbostock/3886208,
https://blocks.roadtolarissa.com/mbostock/3886394.

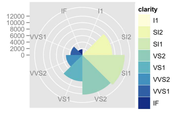


## Idioms: **pie chart, coxcomb chart**

- pie chart
  - area marks with angle channel
  - accuracy: angle/area/arclength less accurate than line length
- data
  - 1 categ key attrib, 1 quant value attrib
- task
  - part-to-whole judgements
- coxcomb chart
  - more direct analog to bar charts
  - line marks, radial layout





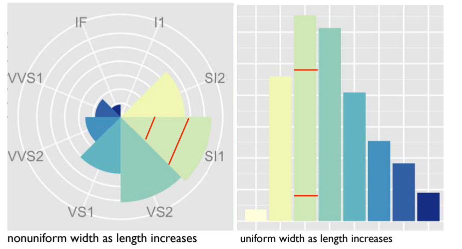


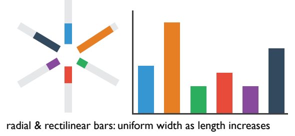
*[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]*



## Coxcomb: perception

- encode: 1D length
- decode/perceive: 2D area
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!
- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases

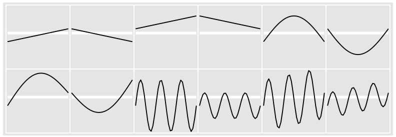


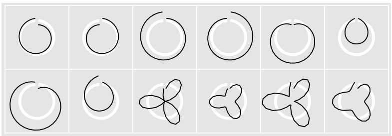



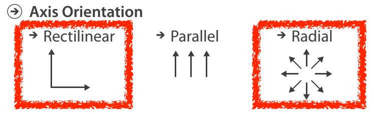



## Idiom: **glyphmaps**

- rectilinear good for linear vs nonlinear trends
- radial good for cyclic patterns





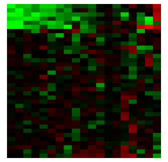


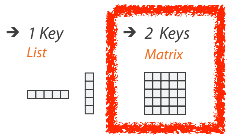

*[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmetrics 23:5 (2012), 382–393.]*



## Idiom: **heatmap**

- two keys, one value
  - data
    - 2 categ attribs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: area
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)
  - task
    - find clusters, outliers
  - scalability
    - 1K categorical levels, 1M items; ~10 quantitative attribute levels





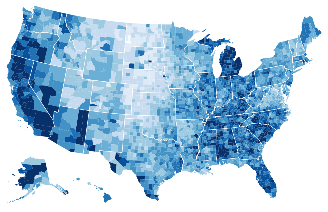



## Arrange tables




## Idiom: **choropleth map**

- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic geometry
  - table with 1 quant attribute per region
- encoding
  - use given geometry for area mark boundaries
  - sequential segmented colormap [more later]

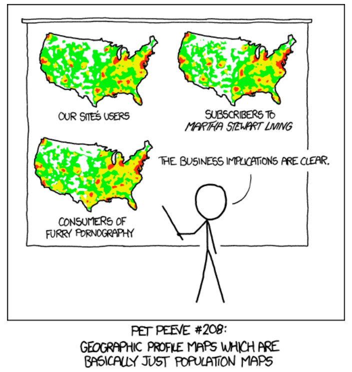


https://blocks.roadtolarissa.com/mbostock/4060606



## Beware: Population maps trickiness!

- spurious correlations: most attributes just show where people live
- consider when to normalize by population density
  - encode raw data values
    - tied to underlying population
  - but should use normalized values
    - eg unemployed people per 100 citizens
- general issue
  - absolute counts vs relative/normalized data
  - failure to normalize is common error

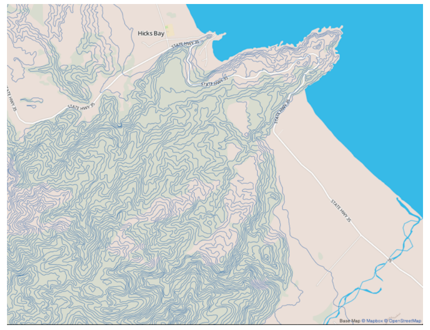



*[ https://xkcd.com/1138 ]*



## Idiom: **topographic map**

- data
  - geographic geometry
  - scalar spatial field
    - 1 quant attribute per grid cell
- derived data
  - isoline geometry
    - isocontours computed for specific levels of scalar values

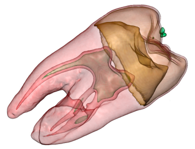


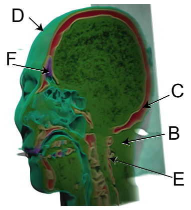
Land Information New Zealand Data Service



## Idioms: **isosurfaces, direct volume rendering**

- data
  - scalar spatial field
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships
- isosurface
  - derived data: isocontours computed for specific levels of scalar values
- direct volume rendering
  - transfer function maps scalar values to color, opacity
    - no derived geometry



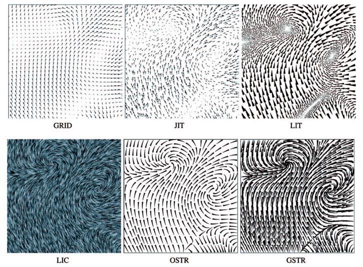



*[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]*
*[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]*

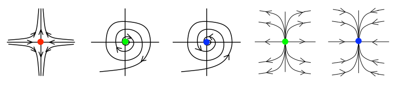


## Vector and tensor fields

- data
  - many attribs per cell
- idiom families
  - flow glyphs
    - purely local
  - geometric flow
    - derived data from tracing particle trajectories
    - sparse set of seed points
  - texture flow
    - derived data, dense seeds
  - feature flow
    - global computation to detect features
      - encoded with one of methods above




*[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]*

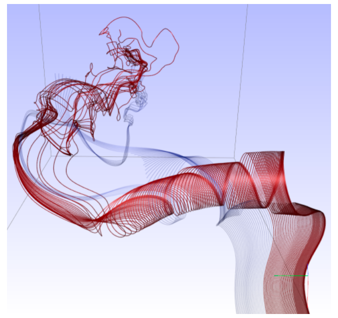


*[Topology tracking for the visualization of time-dependent two-dimensional flows. Tricoche, Wischgoll, Scheuermann, and Hagen. Computers & Graphics 26:2 (2002), 249–257.]*



## Idiom: **similarity-clustered streamlines**

- data
  - 3D vector field
- derived data (from field)
  - streamlines: trajectory particle will follow
- derived data (per streamline)
  - curvature, torsion, tortuosity
  - signature: complex weighted combination
  - compute cluster hierarchy across all signatures
  - encode: color and opacity by cluster
- tasks
  - find features, query shape
- scalability
  - millions of samples, hundreds of streamlines

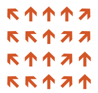


*[Similarity Measures for Enhancing Interactive Streamline Seeding. McLoughlin, Jones, Laramee, Malki, Masters, and. Hansen. IEEE Trans. Visualization and Computer Graphics 19:8 (2013), 1342–1353.]*



## Arrange spatial data

- Use Given
  - Geometry
    - *Geographic*
    - *Other Derived*
  - Spatial Fields
    - *Scalar Fields (one value per cell)*
      - *Isocontours*
      - *Direct Volume Rendering*
    - *Vector and Tensor Fields (many values per cell)*
      - *Flow Glyphs (local)*
      - *Geometric (sparse seeds)*
      - *Textures (dense seeds)*
      - *Features (globally derived)*





## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 7: Arrange Tables, Chap 8: Arrange Spatial Data*
- Visualizing Data. Cleveland. Hobart Press, 1993.
- A Brief History of Data Visualization. Friendly. 2008. http://www.datavis.ca/milestones
- How Maps Work: Representation, Visualization, and Design. MacEachren. Guilford Press, 1995.
- Overview of visualization. Schroeder and. Martin. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 3–39. Elsevier, 2005.
- Real-Time Volume Graphics. Engel, Hadwiger, Kniss, Reza-Salama, and Weiskopf. AK Peters, 2006.
- Overview of flow visualization. Weiskopf and Erlebacher. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 261–278. Elsevier, 2005.



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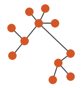
  - Reduce: Filter, Aggregate

**Break**

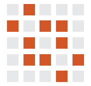
@tamaramunzner @tamara@vis.social
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24

## Arrange networks and trees

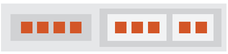
- Node–Link Diagrams
  Connection Marks
  ✔ NETWORKS ✔ TREES



- Adjacency Matrix
  Derived Table
  ✔ NETWORKS ✔ TREES



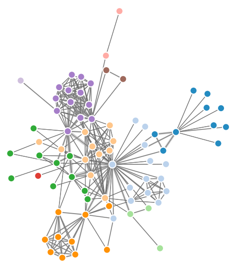
- Enclosure
  Containment Marks
  ✕ NETWORKS ✔ TREES





## Idiom: **force-directed placement**

- visual encoding: node-link diagram
  - link connection marks, node point marks
- algorithm: energy minimization
  - analogy: nodes repel, links draw together like springs
  - optimization problem: minimize crossings
- spatial position: no meaning directly encoded
  - sometimes proximity meaningful
  - sometimes proximity arbitrary, artifact of layout algorithm
- tasks
  - explore topology; locate paths, clusters
- scalability
  - node/edge density E < 4N

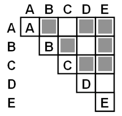


https://observablehq.com/@d3/force-directed-graph/2

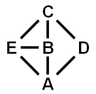


## Idiom: **adjacency matrix view**

- data: network
  - transform into same data/encoding as heatmap
- derived data: table from network
  - 1 quant attrib
    - weighted edge between nodes
  - 2 categ attribs: node list x 2
- visual encoding
  - cell shows presence/absence of edge
- scalability
  - 1K nodes, 1M edges

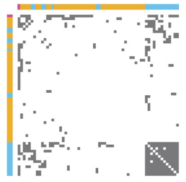


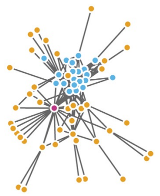






*[NodeTrix: a Hybrid Visualization of Social Networks. Henry, Fekete, and McGuffin. IEEE TVCG (Proc. InfoVis) 13(6):1302-1309, 2007.]*



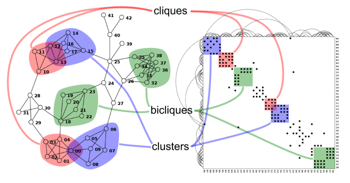


*[Points of view: Networks. Gehlenborg and Wong. Nature Methods 9:115.]*



## Connection vs. adjacency comparison

- adjacency matrix strengths
  - predictability, scalability, supports reordering
  - some topology tasks trainable
- node-link diagram strengths
  - topology understanding, path tracing
  - intuitive, no training needed
- empirical study
  - node-link best for small networks
  - matrix best for large networks
    - if tasks don't involve topological structure!





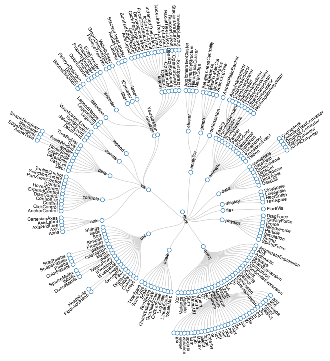
https://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

*[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]*



## Idiom: **radial node-link tree**

- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes

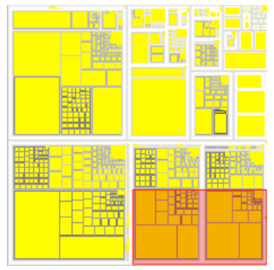


https://observablehq.com/@d3/radial-tree/2



## Idiom: **treemap**

- data
  - tree
  - 1 quant attrib at leaf nodes
- encoding
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib
- tasks
  - query attribute at leaf nodes
- scalability
  - 1M leaf nodes

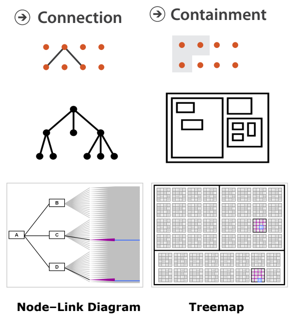


https://tulip.labri.fr/Documentation/3_7/userHandbook/html/ch06.html



## Link marks: Connection and containment

- marks as links (vs. nodes)
  - common case in network drawing
  - 1D case: connection
    - ex: all node-link diagrams
    - emphasizes topology, path tracing
    - networks and trees
  - 2D case: containment
    - ex: all treemap variants
    - emphasizes attribute values at leaves (size coding)
    - only trees





*[Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams. Dong, McGuffin, and Chignell. Proc. InfoVis 2005, p. 57-64.]*



## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 9: Arrange Networks and Trees*
- Visual Analysis of Large Graphs: State-of-the-Art and Future Research Challenges. von Landesberger et al. Computer Graphics Forum 30:6 (2011), 1719–1749.
- Simple Algorithms for Network Visualization: A Tutorial. McGuffin. Tsinghua Science and Technology (Special Issue on Visualization and Computer Graphics) 17:4 (2012), 383–398.
- Drawing on Physical Analogies. Brandes. In Drawing Graphs: Methods and Models, LNCS Tutorial, 2025, edited by M. Kaufmann and D. Wagner, LNCS Tutorial, 2025, pp. 71–86. Springer-Verlag, 2001.
- http://www.treevis.net Treevis.net: A Tree Visualization Reference. Schulz. IEEE Computer Graphics and Applications 31:6 (2011), 11–15.
- Perceptual Guidelines for Creating Rectangular Treemaps. Kong, Heer, and Agrawala. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 16:6 (2010), 990–998.



## Visualization Analysis & Design, Half-Day Tutorial

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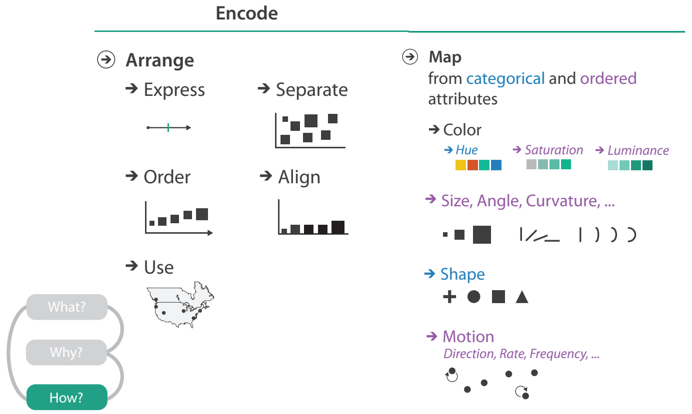
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24



## Idiom design choices: First half







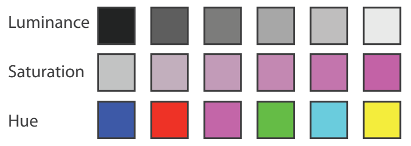
## Decomposing color

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



## Decomposing color

- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels

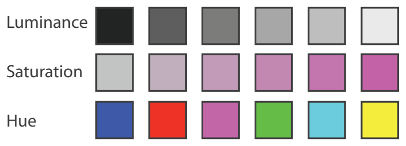






## Decomposing color

- 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
    - saturation
  - categorical can show identity
    - hue







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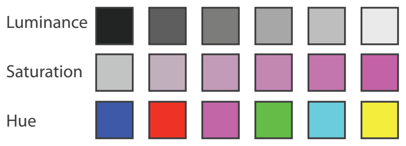
  - categorical can show identity
    - hue
- perceptual colorspace, in contrast to three channels of RGB







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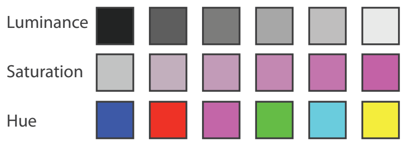






## Luminance

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

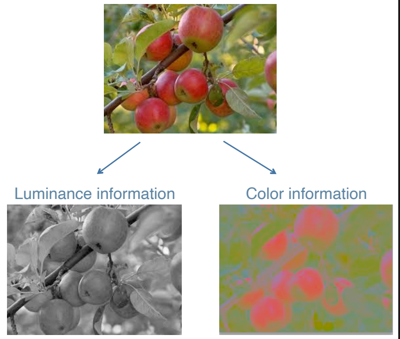
Luminance information

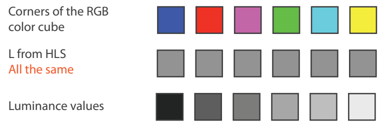
Color information

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

## Luminance

- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!
- HLS better than RGB for encoding but beware
  - L lightness ≠ L* luminance



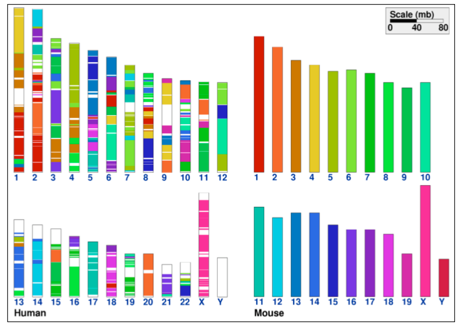




[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]



## Categorical color: Discriminability constraints

- noncontiguous small regions of color: only 6-12 bins




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



## Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear



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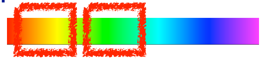
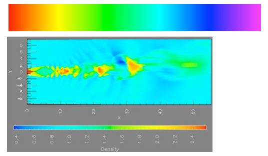


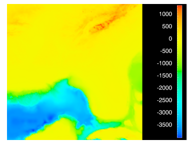


## Ordered color: Rainbow is poor default

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



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



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



## Ordered color: Rainbow is poor default

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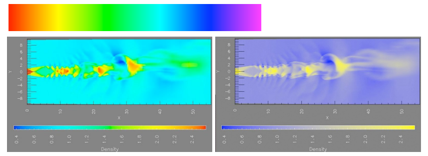
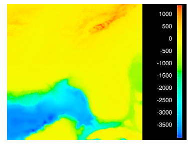
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues



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



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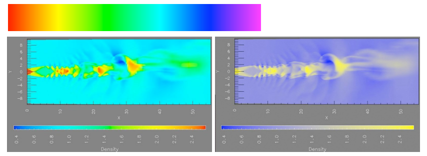
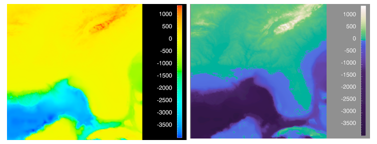
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]



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

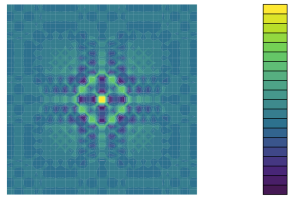


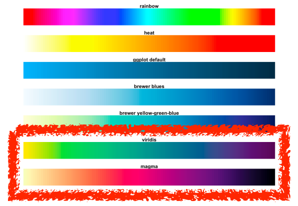
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]



## Viridis / Magma

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






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



## Ordered color: Rainbow is poor default

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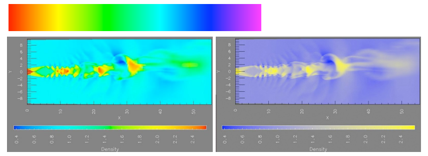
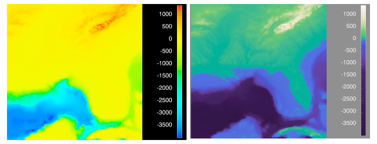
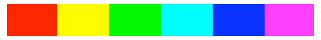
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
  - categorical: segmented saturated rainbow is good!



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



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998.]



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

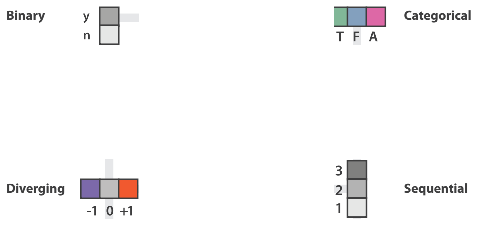
but... Rainbow Colormaps Are Not All Bad. Ware, Stone, & Szafir. IEEE CG&A 43(3):88-93, 2023



## Colormaps

→ Categorical

→ Ordered
- → Sequential
- → Diverging




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



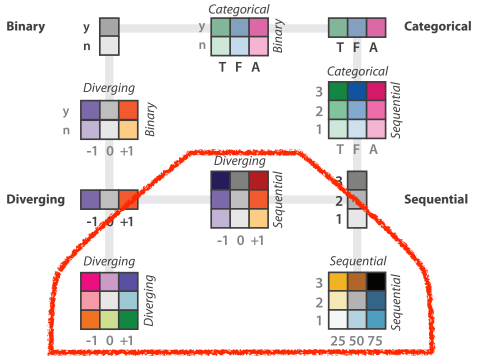
## Colormaps

→ Categorical

→ Ordered
- → Sequential
- → Diverging

→ Bivariate

use with care if more than two levels (binary)!

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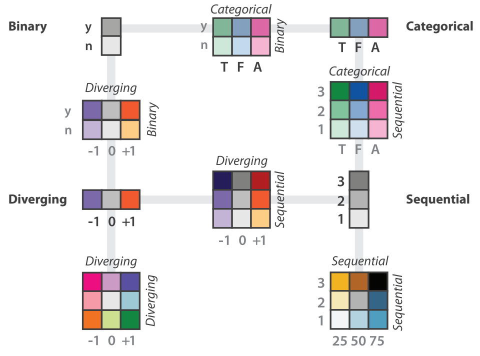
## Colormaps

→ Categorical

→ Ordered
- → Sequential
- → Diverging

→ Bivariate

- color channel interactions
  - size heavily affects salience
    - small regions need high saturation
    - large need low saturation
  - saturation & luminance: 3-4 bins max
    - also not separable from transparency




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



## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 10: Map Color and Other Channels*
- ColorBrewer, Brewer.
  - http://www.colorbrewer2.org
- *Color In Information Display.* Stone. IEEE Vis Course Notes, 2006.
  - http://www.stonesc.com/Vis06
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- *Rainbow Color Map (Still) Considered Harmful.* Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14–17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.
- http://www.r-bloggers.com/using-the-new-viridis-colormap-in-r-thanks-to-simon-garnier/



## Visualization Analysis & Design, Half-Day Tutorial

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  - Marks and Channels
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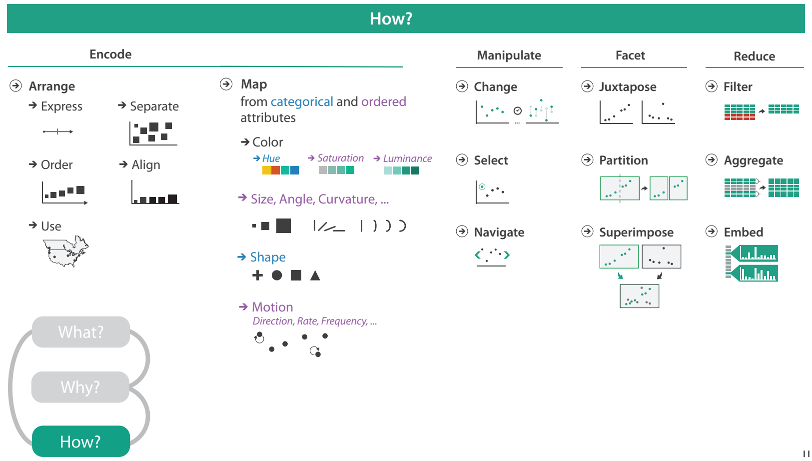
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

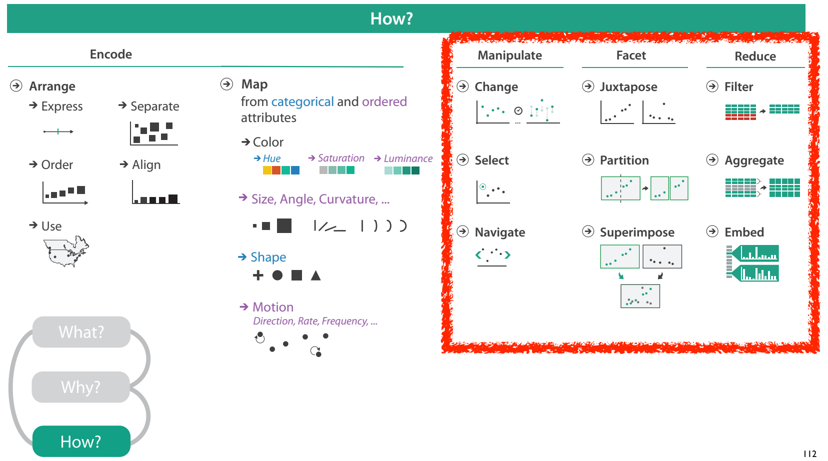
@tamaramunzner @tamara@vis.social

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24



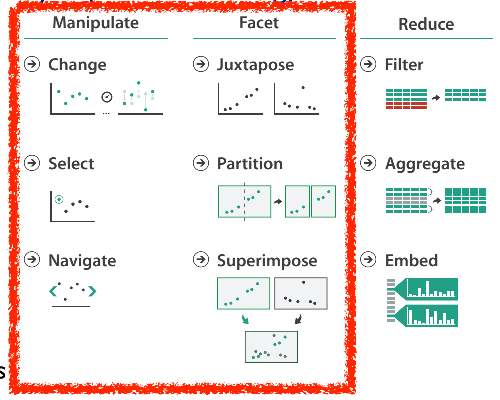




# How to handle complexity: 1 previous strategy + 3 more

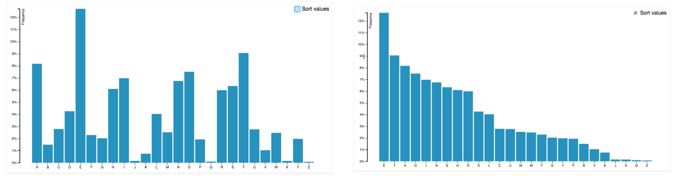

- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view






# Idiom: **Change order/arrangement**

- what: simple table
- how: data-driven reordering
- why: find extreme values, trends

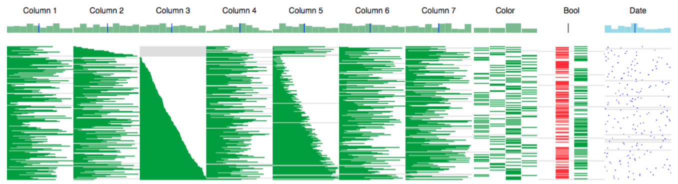


[Sortable Bar Chart](https://blocks.roadtolarissa.com/mbostock/3885705)



# Idiom: **Change order** System: **DataStripes**

- what: table with many attributes
- how: data-driven reordering by selecting column
- why: find correlations between attributes

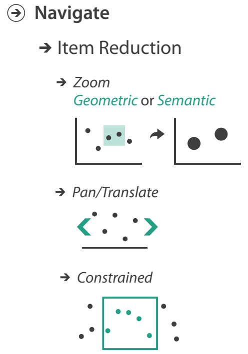



[http://carlmanaster.github.io/datastripes/]



# Navigate: Changing item visibility

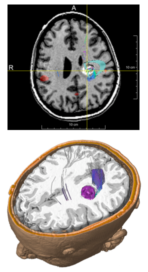
- change viewpoint
  - changes which items are visible within view
  - camera metaphor
    - zoom
      - geometric zoom: familiar semantics
      - semantic zoom: adapt object representation based on available pixels
        - » dramatic change, or more subtle one
    - pan/translate
    - rotate
      - especially in 3D
  - constrained navigation
    - often with animated transitions
    - often based on selection set

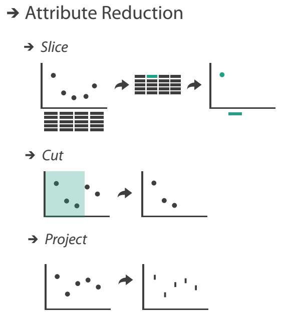





# Navigate: Reducing attributes

- continuation of camera metaphor
  - slice
    - show only items matching specific value for given attribute: slicing plane
    - axis aligned, or arbitrary alignment
  - cut
    - show only items on far slide of plane from camera
  - project
    - change mathematics of image creation
      - orthographic
      - perspective
      - many others: Mercator, cabinet, ...

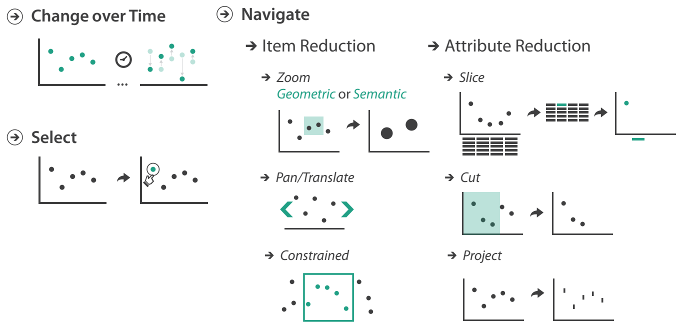





*[Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment. Rieder, Ritter, Raspe, and Peitgen. Computer Graphics Forum (Proc. EuroVis 2008) 27:3 (2008), 1055–1062.]*

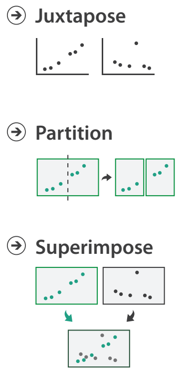


# Manipulate



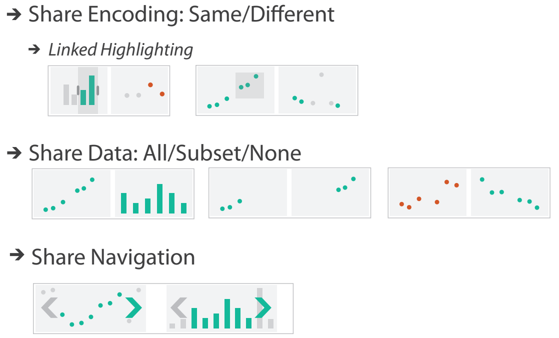



# Facet





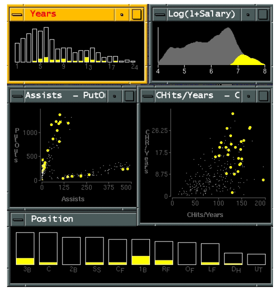

# Juxtapose and coordinate views






# Idiom: **Linked highlighting** System: **EDV**

- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - *multiform*
- data: all shared
  - all **items** shared
  - different **attributes** across the views
- aka: brushing and linking




*[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237–246. IOS Press, 1995.]*



# Idiom: **Overview-detail views** System: **Google Maps**

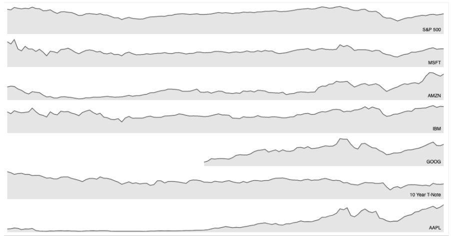
- encoding: same or different
  - ex: same (birds-eye map)
- data: subset shared
  - viewpoint differences: subset of data items
- navigation: shared
  - bidirectional linking
- other differences
  - (window size)


*[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]*



# Idiom: **Small multiples**

- encoding: same
  - ex: line charts
- data: none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies

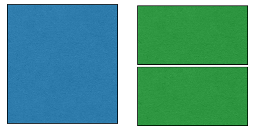


[blocks.roadtolarissa.com/mbostock/1157787]



# Juxtapose views: tradeoffs

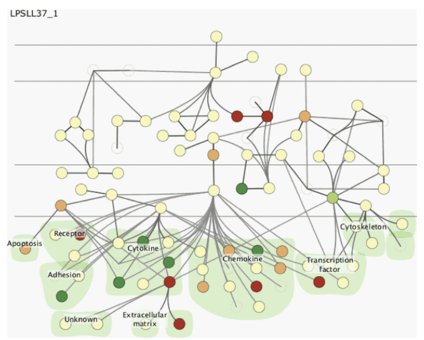
- juxtapose costs
  - display area
    - 2 views side by side: each has only half the area of one view
- juxtapose benefits
  - cognitive load: eyes vs memory
    - lower cognitive load: move eyes between 2 views
    - higher cognitive load: compare single changing view to memory of previous state





# Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions

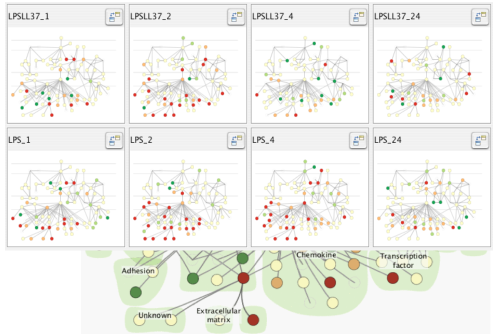



*[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]*



# Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions
- juxtapose: easier to compare across small multiples
  - different conditions (color), same gene (layout)




*[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]*



# Coordinate views: Design choice interaction

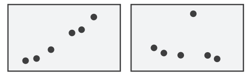
| | | Data | | |
|---|---|---|---|---|
| | | All | Subset | None |
| Encoding | Same | Redundant | Overview/ Detail | Small Multiples |
| | Different | Multiform | Multiform, Overview/ Detail | No Linkage |



# Partition into views

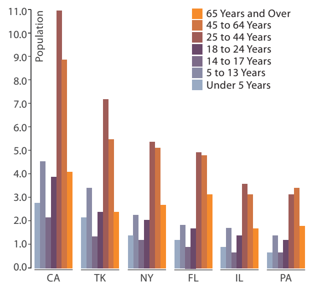
- how to divide data between views
  - split into regions by attributes
  - encodes association between items using spatial proximity
  - order of splits has major implications for what patterns are visible

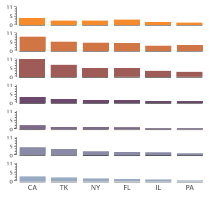
Partition into Side-by-Side Views



## Partitioning: List alignment

- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages
- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states

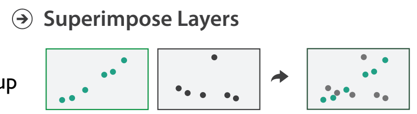




## Superimpose layers

- ***layer***: set of objects spread out over region
  - each set is visually distinguishable group
  - extent: whole view
- design choices
  - how many layers, how to distinguish?
    - encode with different, nonoverlapping channels
    - two layers achieveable, three with careful design
  - small static set, or dynamic from many possible?






## Static visual layering

- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention

*[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]*



## Static visual layering

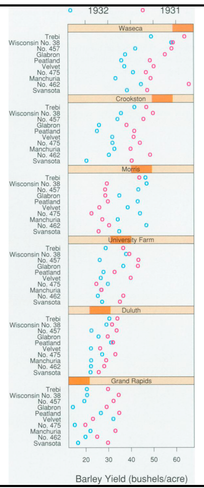
- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention
- "get it right in black and white"
  - check luminance contrast with greyscale view

*[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]*



## Idiom: **Trellis plots**

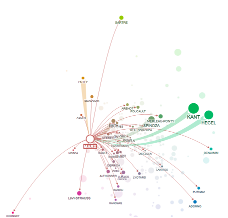
- superimpose within same frame
  - color code by year
- partitioning
  - split by site, rows are wheat varieties
- main-effects ordering
  - derive value of median for group, use to order
  - order rows within view by variety median
  - order views themselves by site median

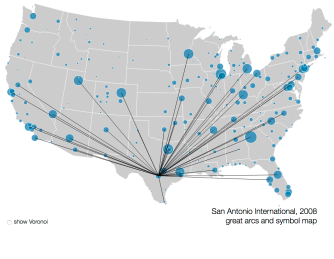





## Dynamic visual layering

- interactive based on selection
- one-hop neighbour highlighting demos: click vs hover (lightweight)






https://mariandoerk.de/edgemaps/demo/ https://mbostock.github.io/d3/talk/20111116/airports.html



## Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 11: Manipulate View & Chap 12: Facet Into Multiple Views*
- *Animated Transitions in Statistical Data Graphics.* Heer and Robertson. IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis 07) 13:6 (2007), 1240– 1247.
- *Smooth and efficient zooming and panning.* van Wijk and Nuij. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 15–22, 2003.
- *Starting Simple - adding value to static visualisation through simple interaction.* Dix and Ellis. Proc. Advanced Visual Interfaces (AVI), pp. 124–134, 1998.
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces.* Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- *Zooming versus multiple window interfaces: Cognitive costs of visual comparisons.* Plumlee and Ware. ACM Trans. on Computer-Human Interaction (ToCHI) 13:2 (2006), 179–209.
- *Exploring the Design Space of Composite Visualization.* Javed and Elmqvist. Proc. Pacific Visualization Symp. (PacificVis), pp. 1–9, 2012.
- *Visual Comparison for Information Visualization.* Gleicher, Albers, Walker, Jusufi, Hansen, and Roberts. Information Visualization 10:4 (2011), 289–309.
- *Cross-Filtered Views for Multidimensional Visual Analysis.* Weaver. IEEE Trans. Visualization and Computer Graphics 16:2 (Proc. InfoVis 2010), 192–204, 2010.
- *Linked Data Views.* Wills. In Handbook of Data Visualization, Computational Statistics, edited by Unwin, Chen, and Härdle, pp. 216–241. Springer-Verlag, 2008.
- *Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications.* Borgo, Kehrer, Chung, Maguire, Laramee, Hauser, Ward, and Chen. In Eurographics State of the Art Reports, pp. 39–63, 2013.



## Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

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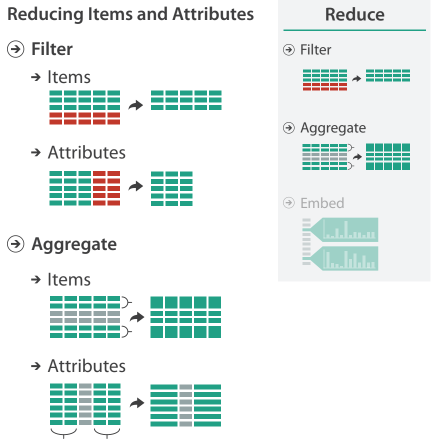
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24



## Reduce items and attributes

- reduce/increase: inverses
- filter
  - pro: straightforward and intuitive
    - to understand and compute
  - con: out of sight, out of mind
- aggregation
  - pro: inform about whole set
  - con: difficult to avoid losing signal
- not mutually exclusive
  - combine filter, aggregate
  - combine reduce, change, facet

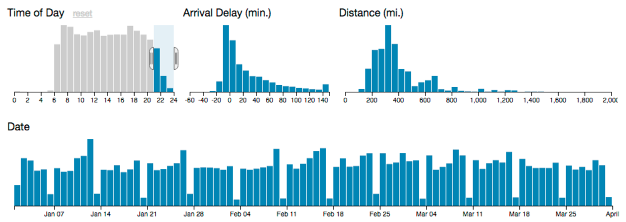





## Idiom: **cross filtering**

System: **Crossfilter**

- item filtering
- coordinated views/controls combined
  - all scented histogram bisliders update when any ranges change

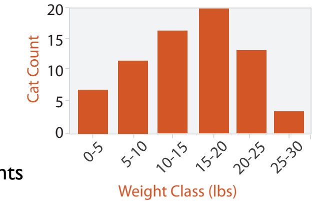



[https://square.github.io/crossfilter/]



## Idiom: **histogram**

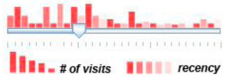
- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly



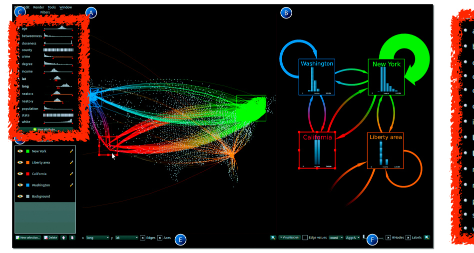


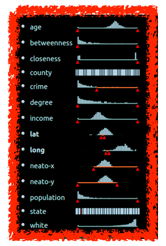

## Idiom: **scented widgets**

- augmented widgets show ***information scent***
  - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider




*[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE TVCG (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]*



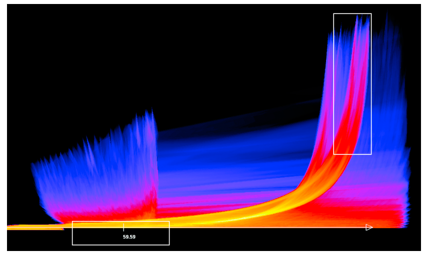


*[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]*



## Idiom: **Continuous scatterplot**

- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
  - no limits on overplotting: millions of items

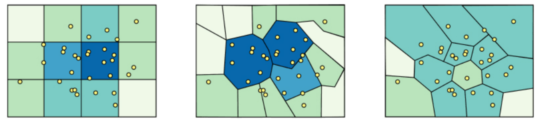


*[Continuous Scatterplots. Bachthaler and Weiskopf. IEEE TVCG (Proc. Vis 08) 14:6 (2008), 1428–1435. 2008. ]*



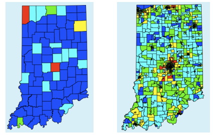
## Spatial aggregation

- MAUP: Modifiable Areal Unit Problem
  - changing boundaries of cartographic regions can yield dramatically different results
  - zone effects



[http://www.e-education.psu/edu/geog486/l4_p7.html, Fig 4.cg.6]

  - scale effects

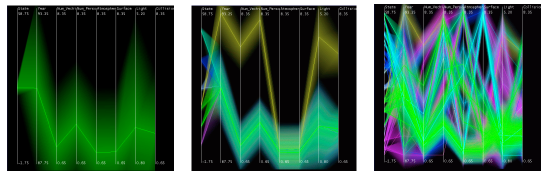


https://blog.cartographica.com/blog/2011/5/19/the-modifiable-areal-unit-problem-in-gis.html



## Idiom: **Hierarchical parallel coordinates**

- dynamic item aggregation
- derived data: ***hierarchical clustering***
- encoding:
  - cluster band with variable transparency, line at mean, width by min/max values
  - color by proximity in hierarchy



*[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43– 50, 1999.]*



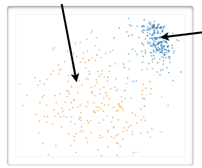
## Dimensionality reduction

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space
  - use when you can't directly measure what you care about
    - true dimensionality of dataset conjectured to be smaller than dimensionality of measurements
    - latent factors, hidden variables

Tumor Measurement Data

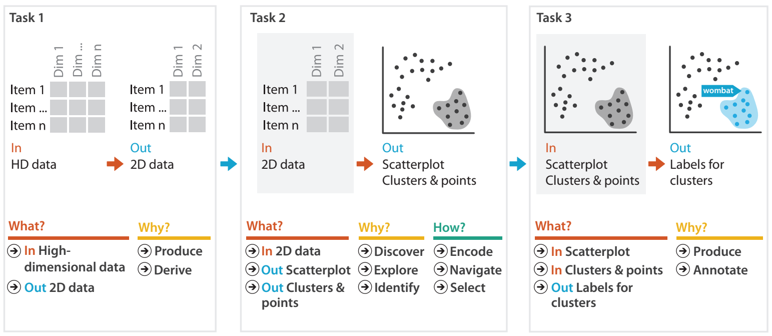
data: 9D measured space

DR




derived data: 2D target space

# Idiom: **Dimensionality reduction for documents**

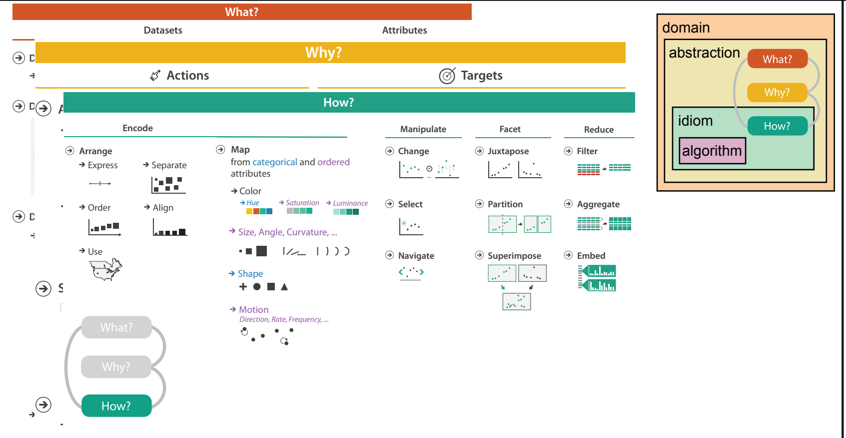





# Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 13: Reduce Items and Attributes*
- *Hierarchical Aggregation for Information Visualization: Overview, Techniques and Design Guidelines.* Elmqvist and Fekete. IEEE Transactions on Visualization and Computer Graphics 16:3 (2010), 439–454.
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces.* Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- *A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence.* Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.

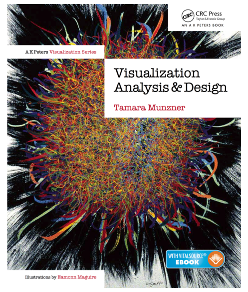







# More information

- this tutorial
  https://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse24
- book
  http://www.cs.ubc.ca/~tmm/vadbook
  - http://www.crcpress.com/product/isbn/9781466508910
  - illustration acknowledgement: Eamonn Maguire
- full courses, papers, videos, software, talks
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm
- VIS24 book table from CRC/Routledge
  - ~~physical table~~
  - virtual bookshop: https://bit.ly/IEEEVIS23




Visualization Analysis and Design. Munzner. *CRC Press, AK Peters Visualization Series, 2014.*

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