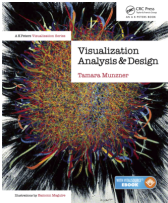


Visualization Analysis & Design

Half-Day Tutorial

Tamara Munzner
Department of Computer Science
University of British Columbia



VIS 2025 Tutorial
November 2025, Vienna Austria

<https://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25> [@tamara@cosocial.ca](mailto:tmm@cosocial.ca)

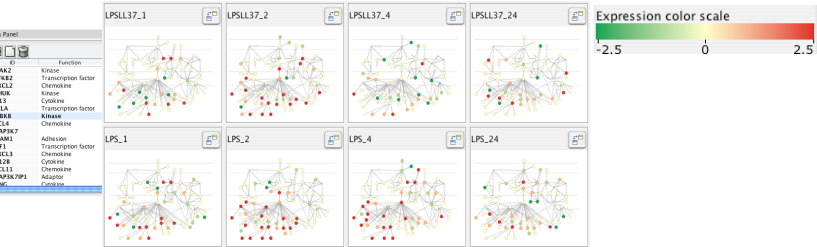
Why have a human in the loop?

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

Why use an external representation?

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

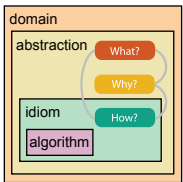
- external representation: replace cognition with perception



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

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

Visualization Analysis & Design Tutorial

- Session 1
 - Analysis: What, Why, How
 - Marks and Channels
 - Q&A
 - Visualizing Tabular Data
 - Visualizing Spatial Data
 - Q&A
- Session 2
 - Visualizing Network Data
 - Color
 - Q&A
 - Interactive & Multiple Views
 - Reduce: Filter, Aggregate
 - Q&A

[@tamara@cosocial.ca](mailto:tmm@cosocial.ca)
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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.

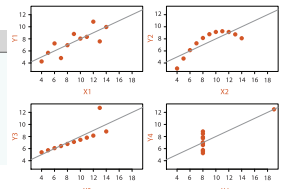
Why represent all the data?

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

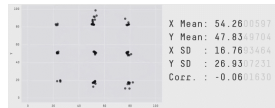
- summaries lose information, details matter
 - confirm expected and find unexpected patterns
 - assess validity of statistical model

Anscombe's Quartet

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



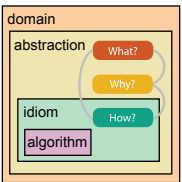
Datasaurus Dozen



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

Analysis framework: Four levels, three questions

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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



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

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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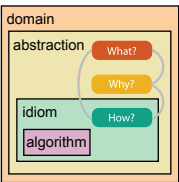
- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
 - don't know exactly what questions to ask in advance
- possibilities
 - long-term use for end users (ex: exploratory analysis of scientific data)
 - presentation of known results (ex: data journalism)
 - 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 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?
- abstraction
 - translate from specifics of domain to vocabulary of vis
 - 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
- algorithm
 - efficient computation



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

Defining visualization (vis)

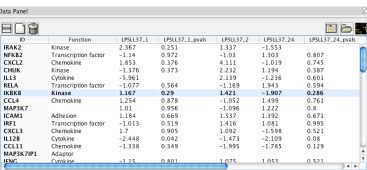
Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Why?...

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- external representation: replace cognition with perception



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

Analysis framework: Four levels, three questions

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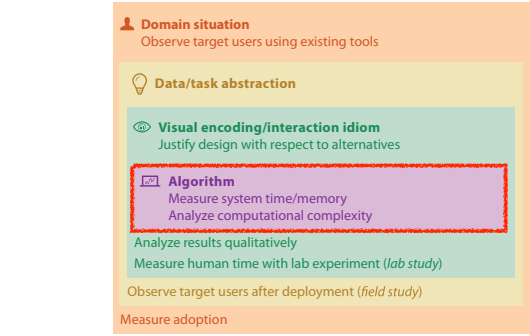
Why is validation difficult?

- different ways to get it wrong at each level



Why is validation difficult?

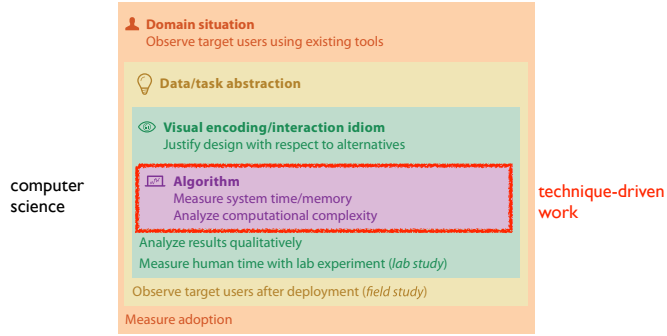
- solution: use methods from different fields at each level



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

Why is validation difficult?

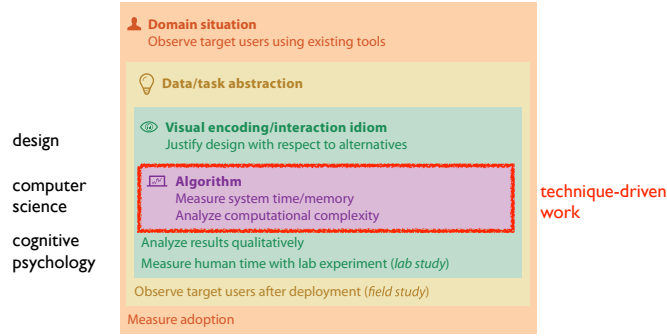
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[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

Why is validation difficult?

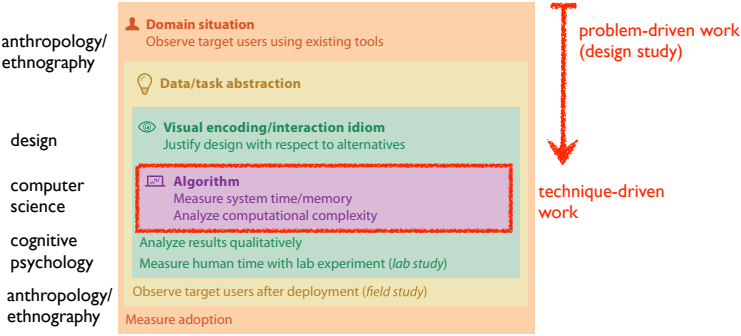
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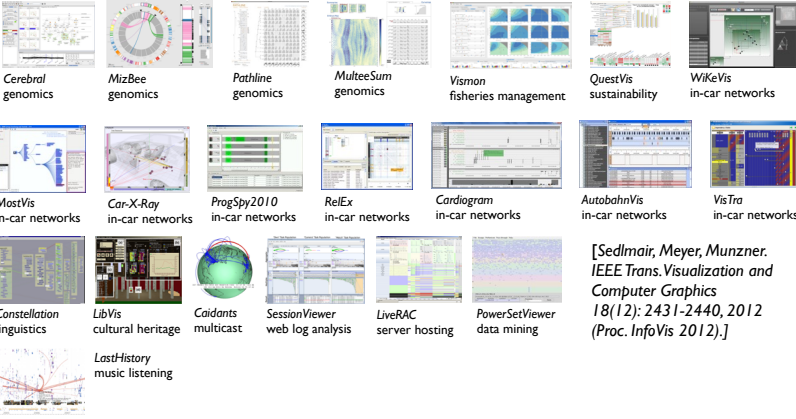
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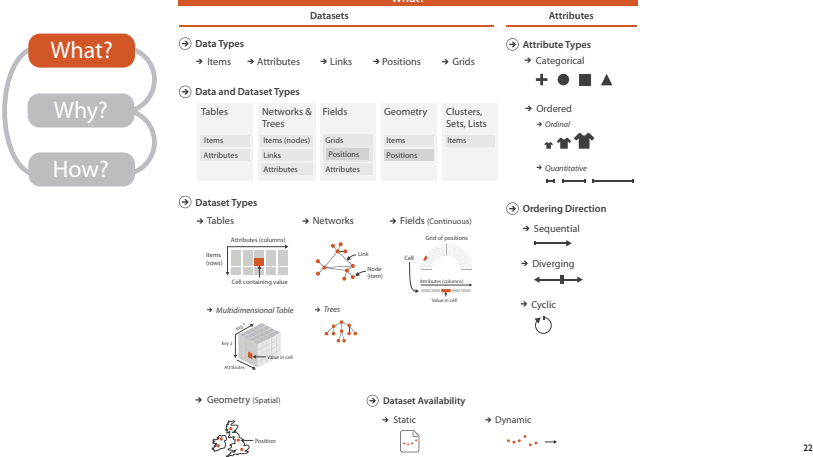


[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

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).]



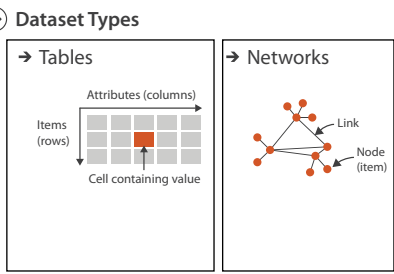
Three major datatypes



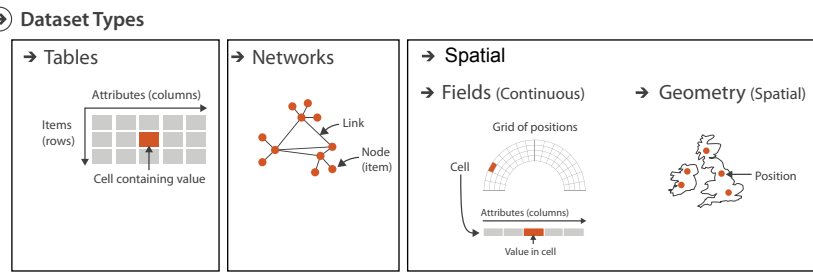
Three major datatypes



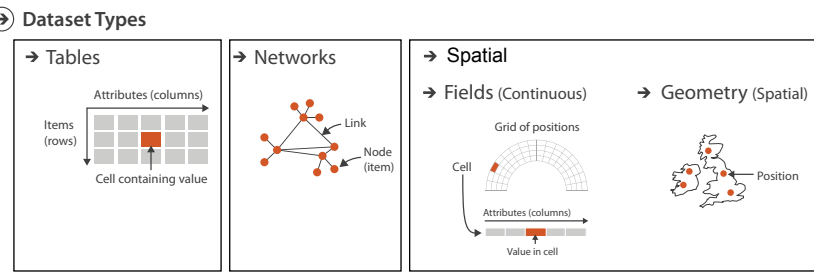
Three major datatypes



Three major datatypes

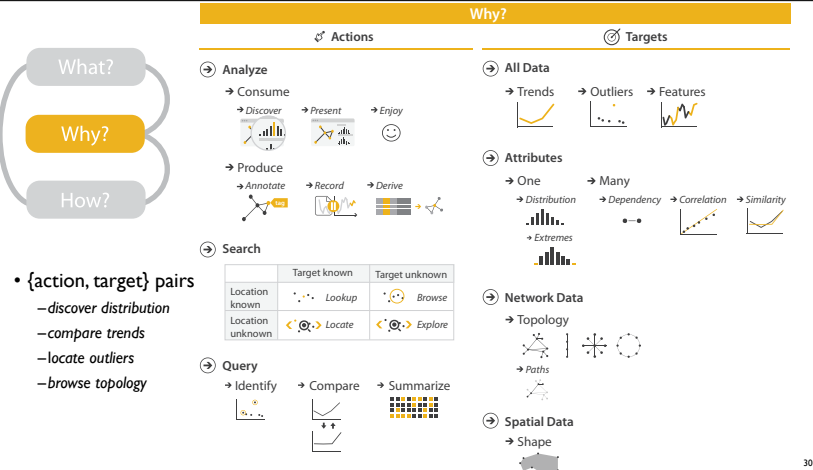
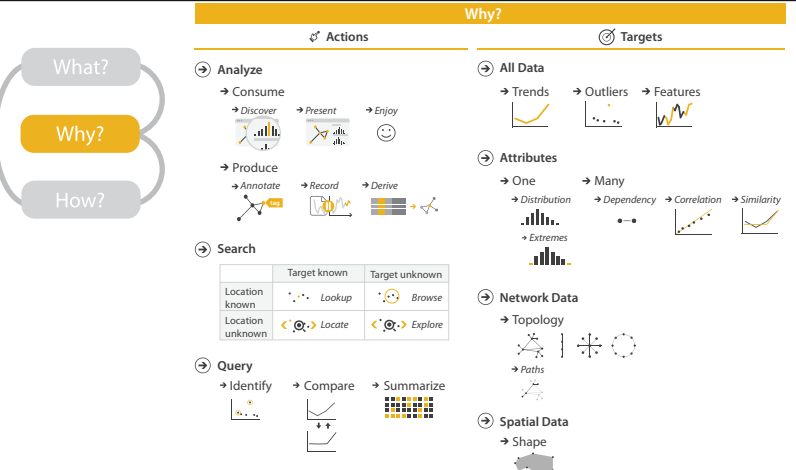
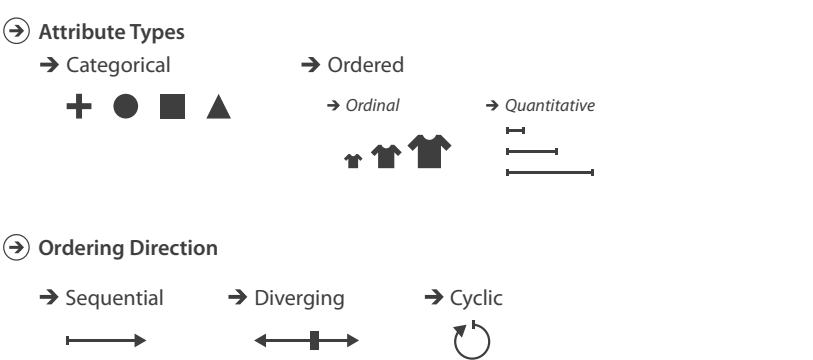


Three major datatypes



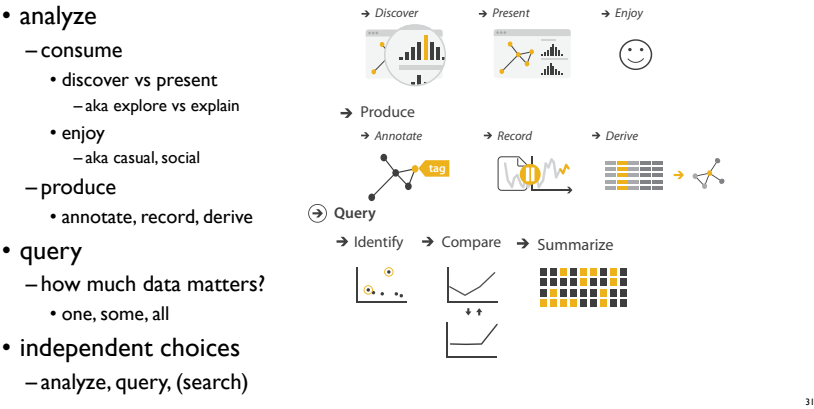
- visualization vs computer graphics
- geometry is design decision

Attribute types



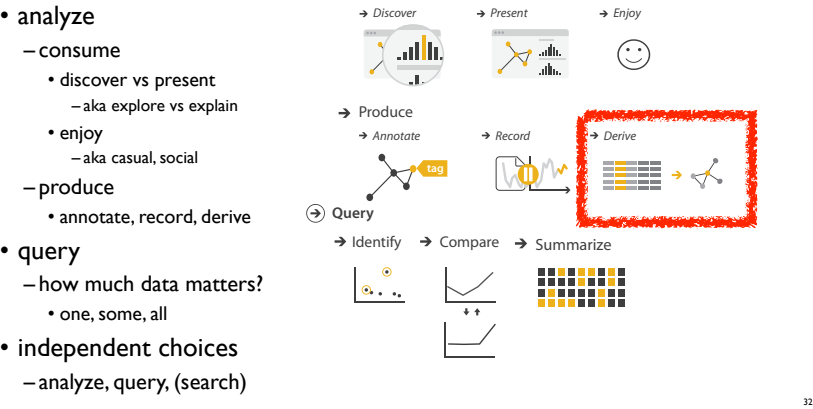
- {action, target} pairs
- discover distribution
- compare trends
- locate outliers
- browse topology

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)

Actions: Analyze, Query



- analyze
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- discover vs present
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- how much data matters?
- one, some, all
- independent choices
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Derive

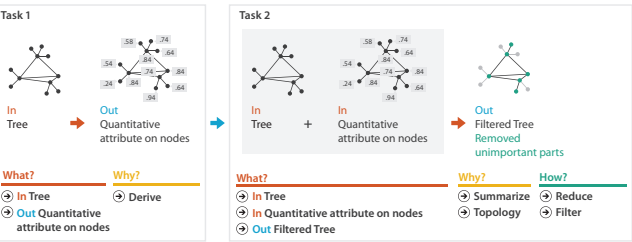
- don't necessarily just draw what you're given!
 - decide what the right thing to show is
 - create it with a series of transformations from the original dataset
 - draw that
- one of the four major strategies for handling complexity



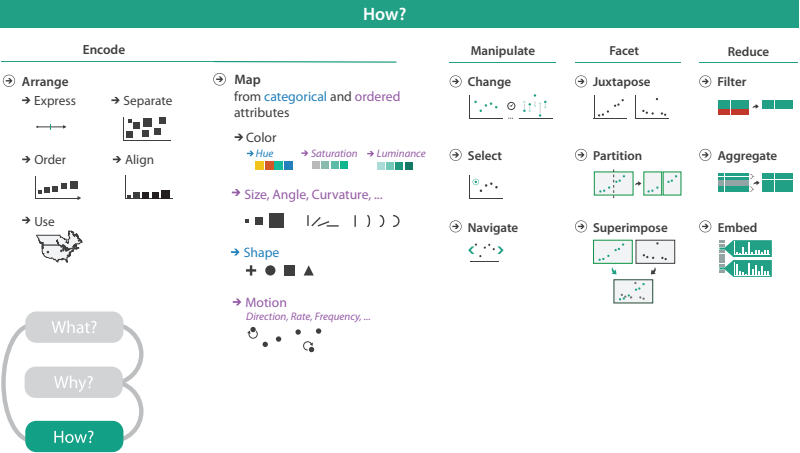
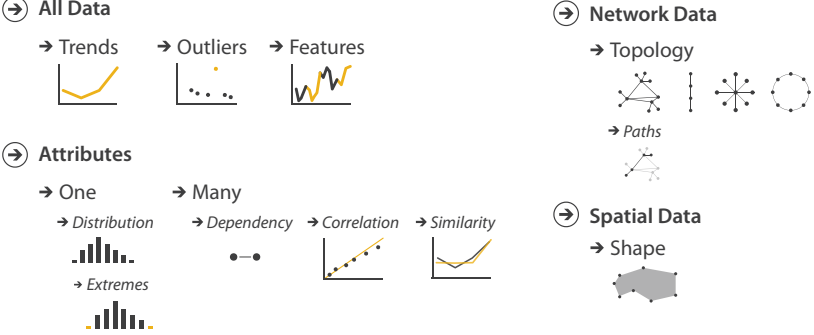
Analysis example: Derive one attribute

- 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



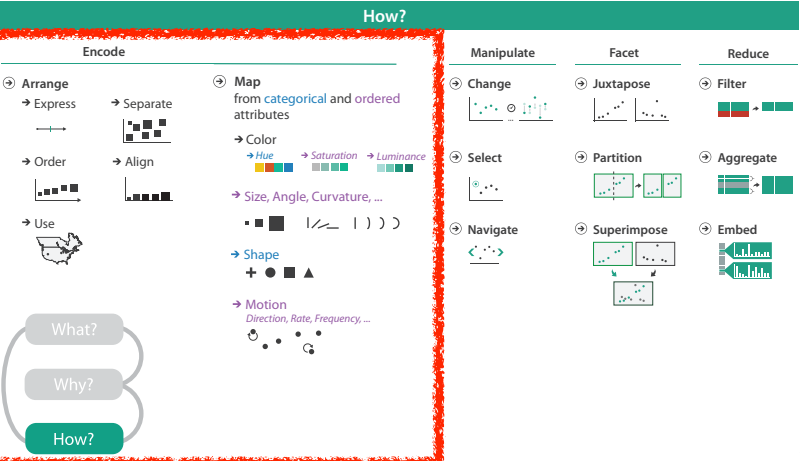
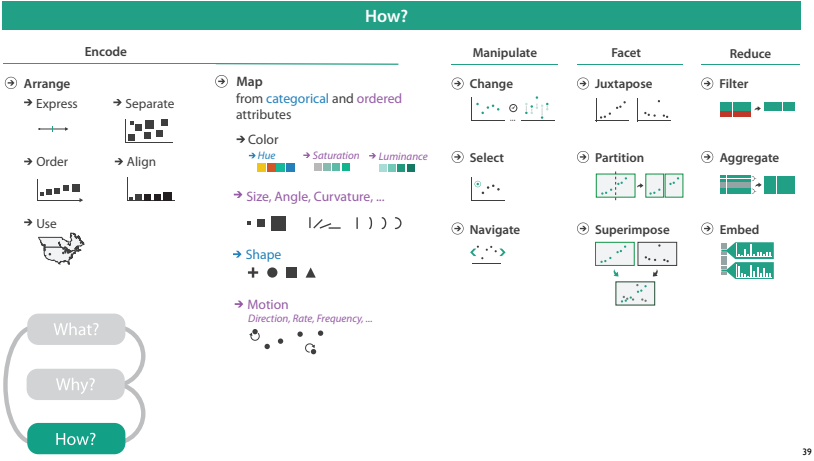
Further reading

- 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
 - Ch 4: Analysis: Four Levels for Validation
- 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

- how to systematically analyze idiom structure?



Visual encoding

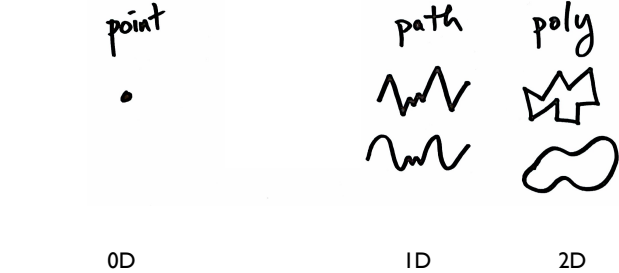
- how to systematically analyze idiom structure?



- marks & channels
 - marks: represent items or links
 - channels: change appearance of marks based on attributes

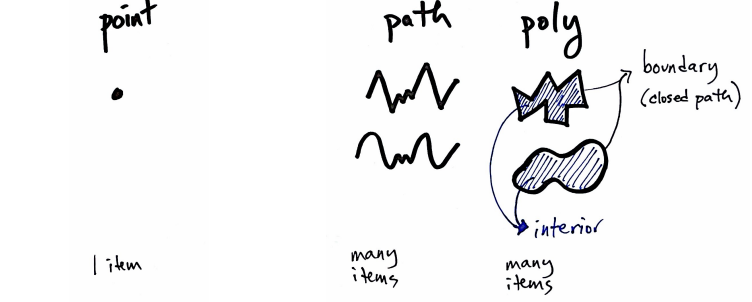
Marks for items

- basic geometric elements



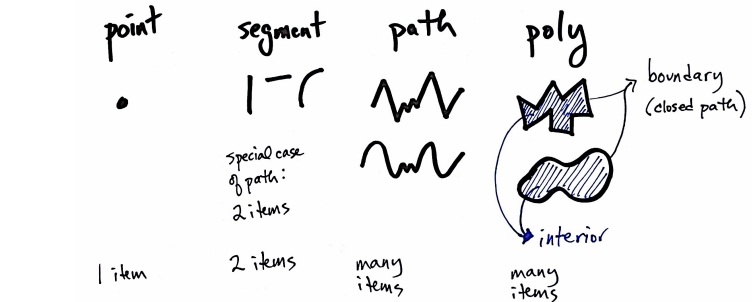
Marks for items

- basic geometric elements



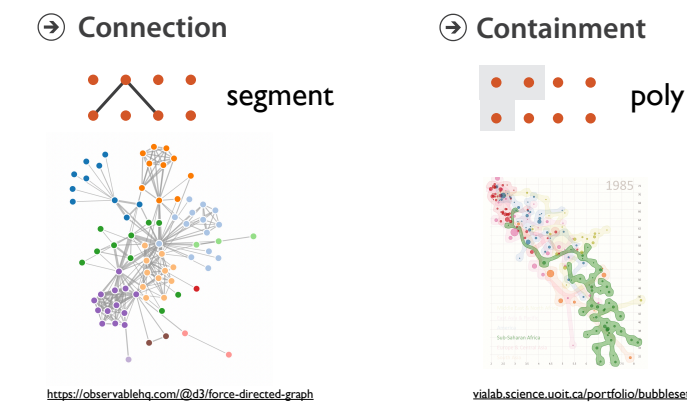
Marks for items

- basic geometric elements

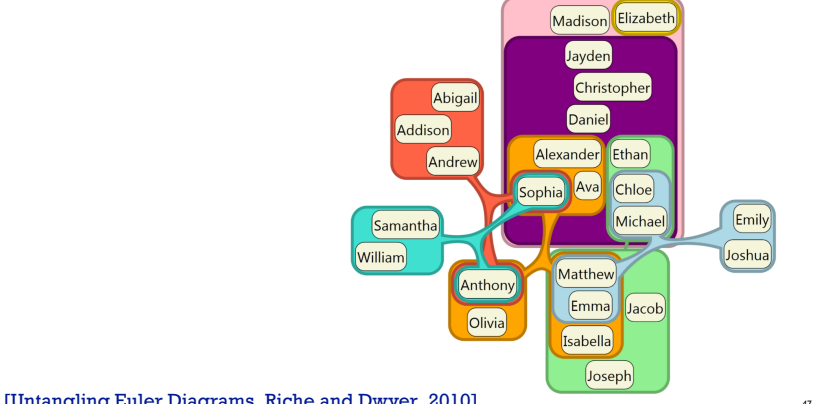


- 3D volumes: trickier case

Marks for links

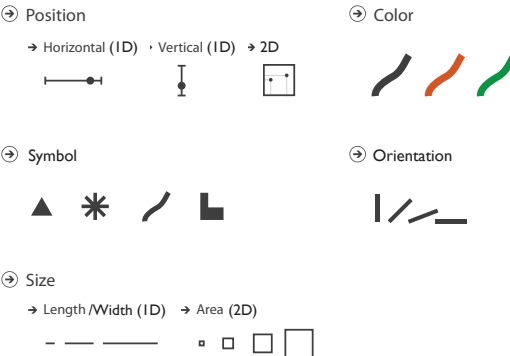


Containment can be nested



Channels

- control appearance of marks
 - proportional to or based on attributes
- many names
 - visual channels
 - visual variables
 - retinal channels
 - visual dimensions
 - ...



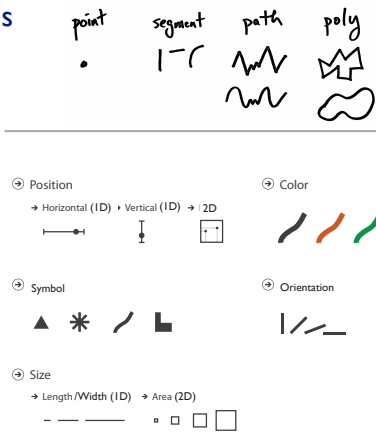
Definitions: Marks and channels

- marks
 - geometric primitives



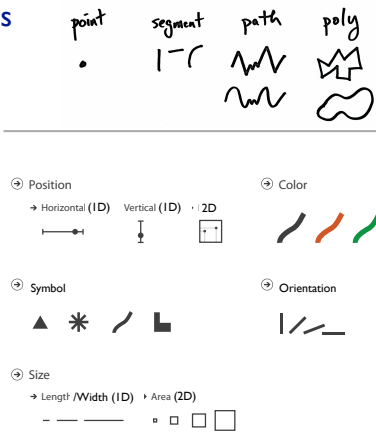
Definitions: Marks and channels

- 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



Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

mark: segment

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

mark: segment

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: segment

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)
2D size (area)

mark: segment

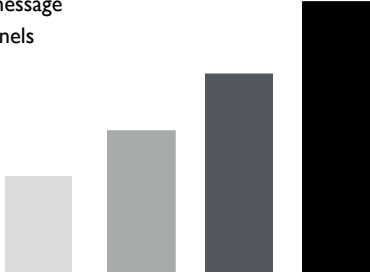
mark: point

mark: point

mark: point

Redundant encoding

- multiple channels
 - sends stronger message
 - but uses up channels



Length and Luminance

When to use which channel?

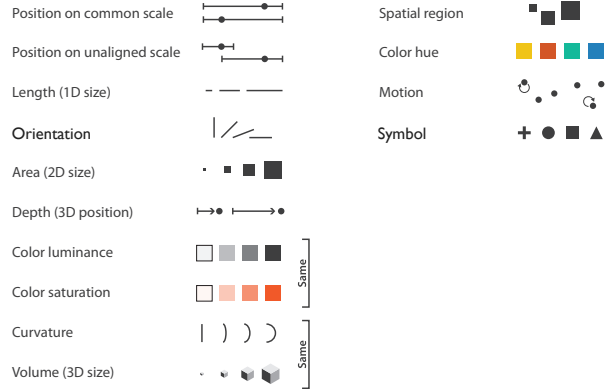
expressiveness

match channel type to data type

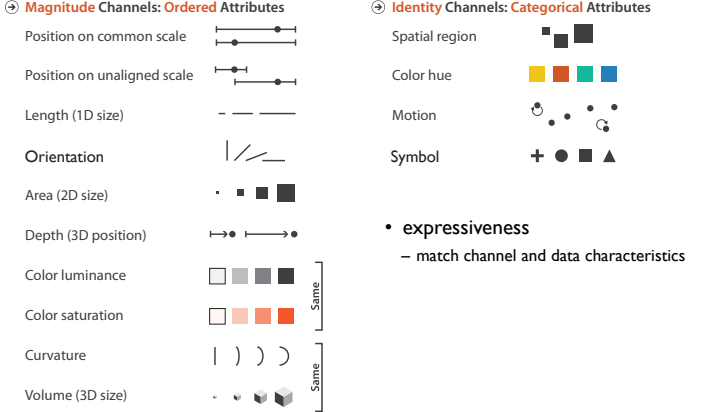
effectiveness

some channels are better than others

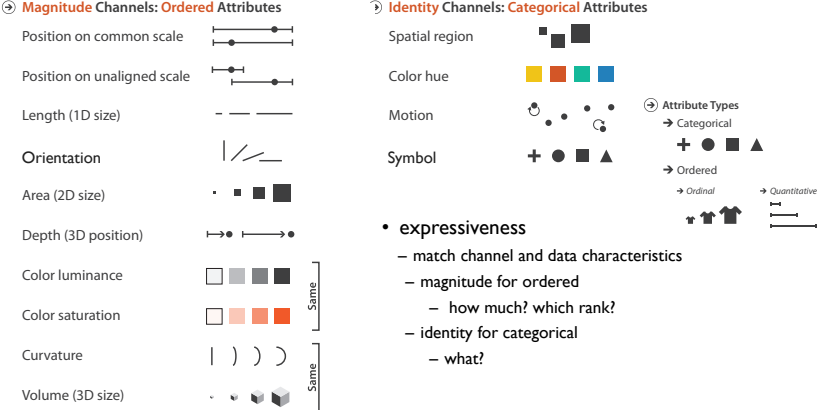
Channels: Rankings



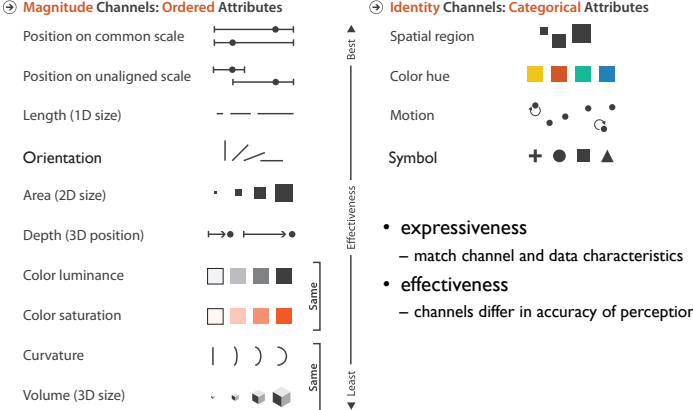
Channels: Rankings



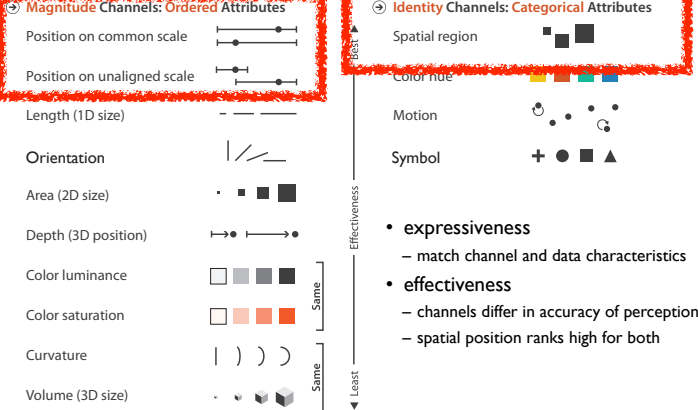
Channels: Rankings



Channels: Rankings



Channels: Rankings

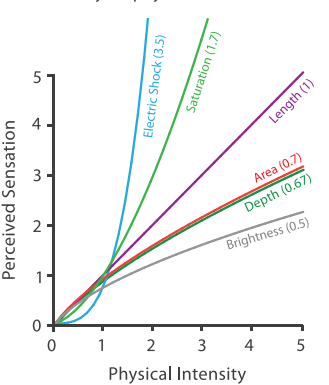


Channel effectiveness

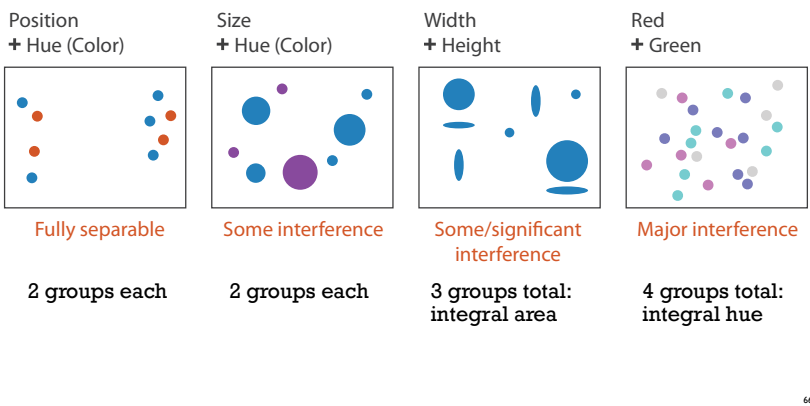
- accuracy: how precisely can we tell the difference between encoded items?
- discriminability: how many unique steps can we perceive?
- separability: is our ability to use this channel affected by another one?
- popout: can things jump out using this channel?

Accuracy: Fundamental Theory

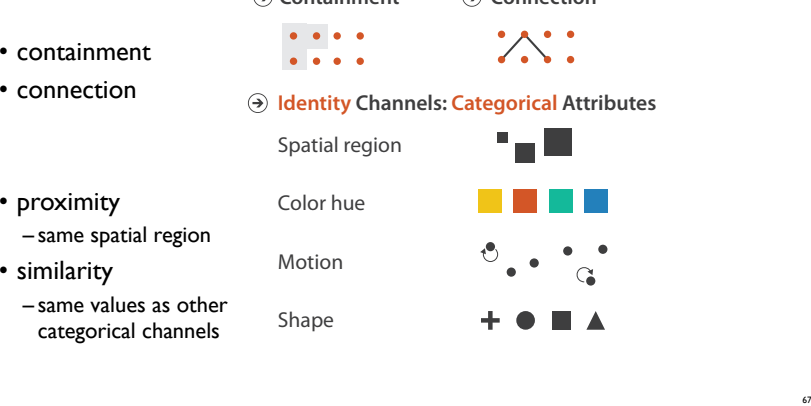
Steven's Psychophysical Power Law: $S = I^N$



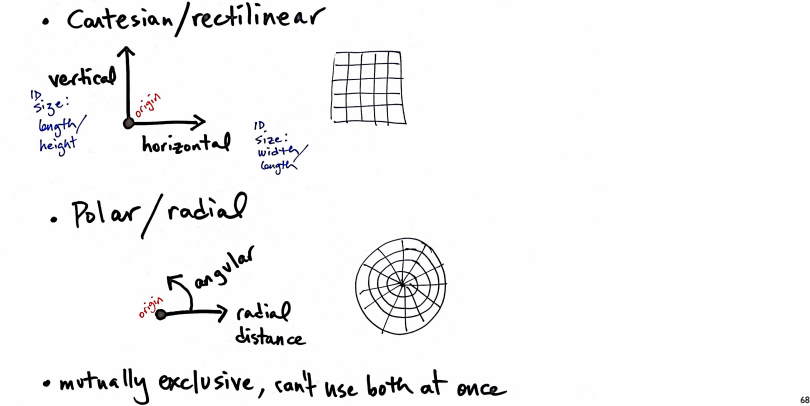
Separability vs. Integrality



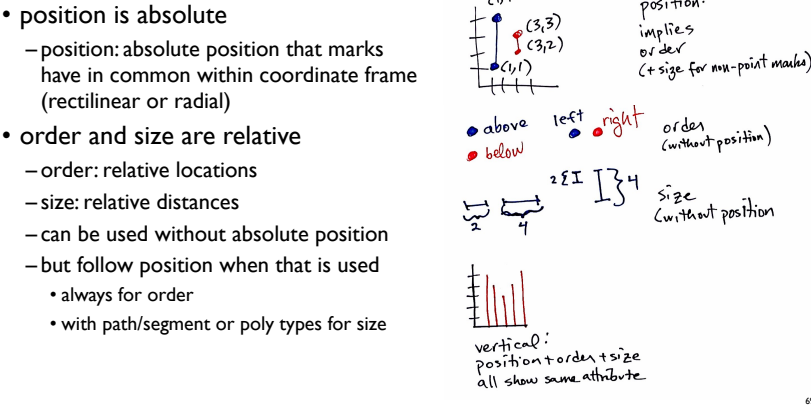
Grouping



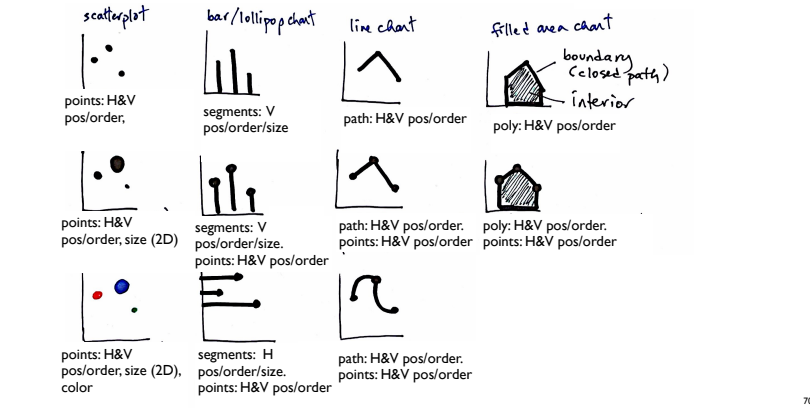
Position: Two possible coordinate systems



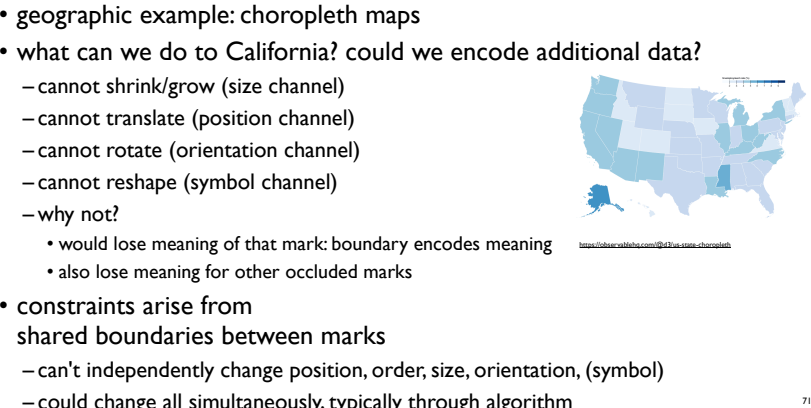
Absolute vs relative



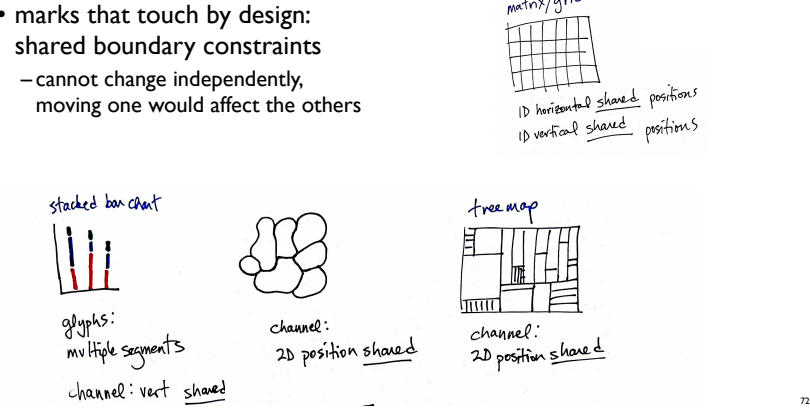
Visual encoding analysis, more examples



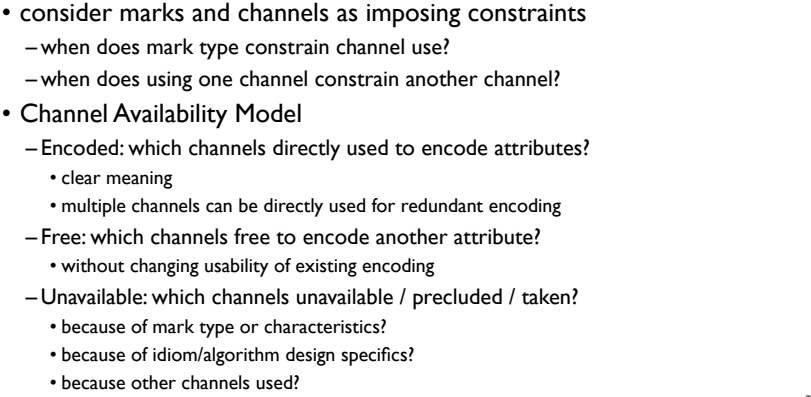
Constraints



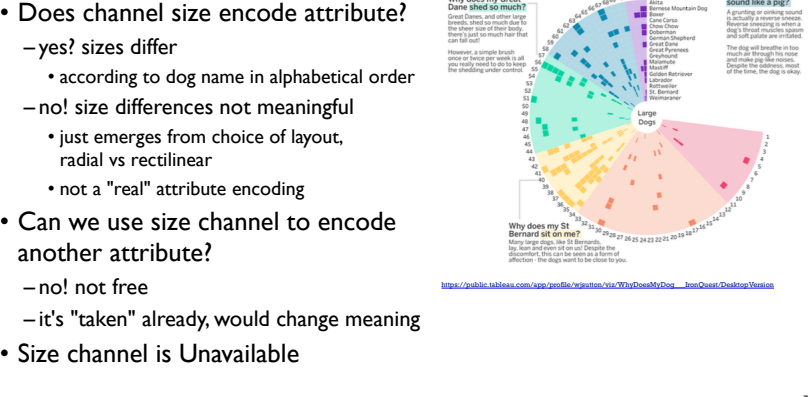
Shared boundary constraints



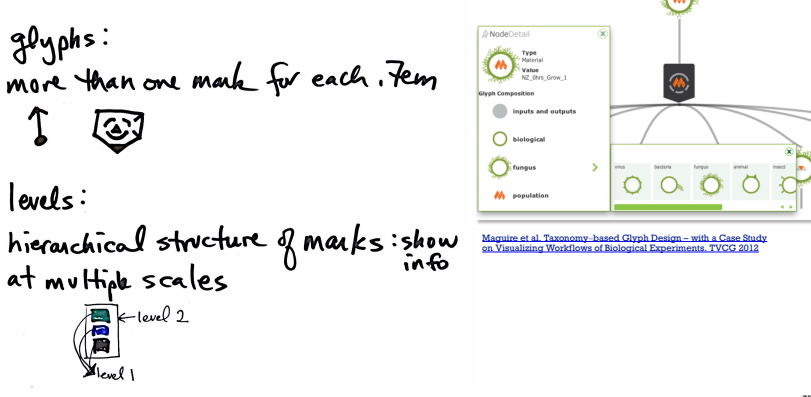
Constraints & Channel Availability



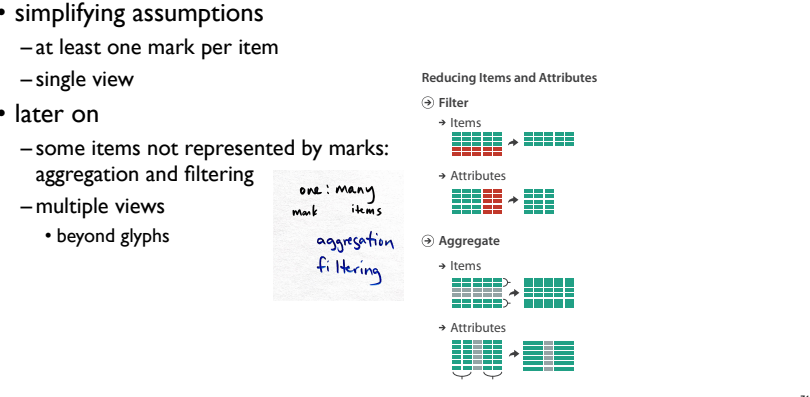
Channel use: what does it mean?



Beyond simple marks: glyphs & levels



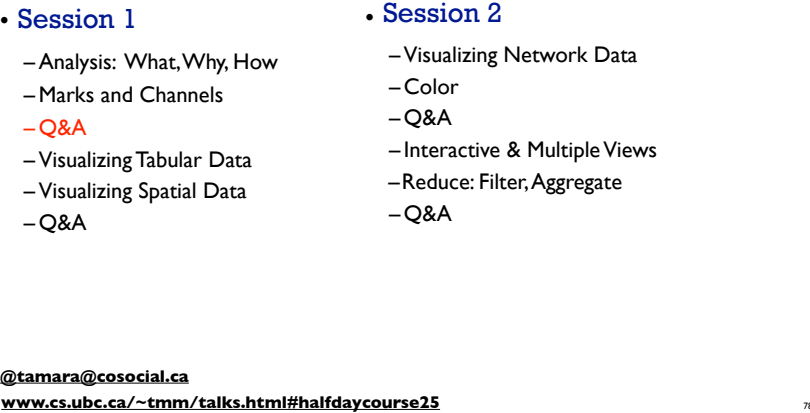
Scope of analysis



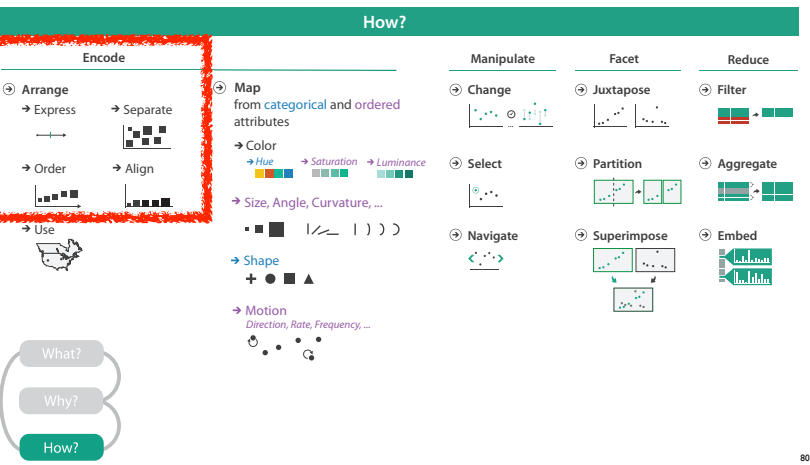
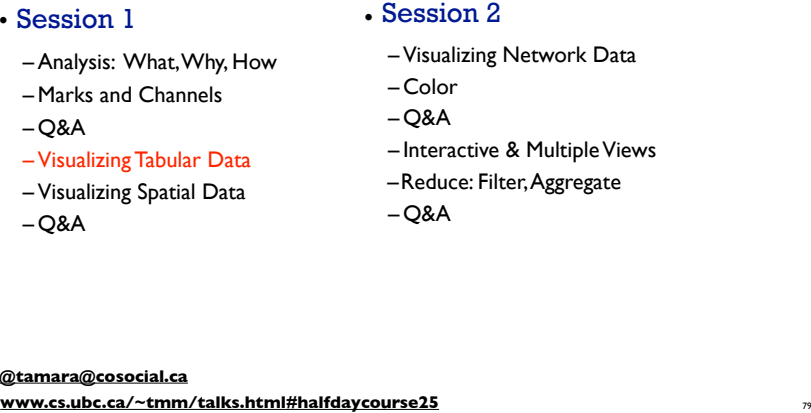
Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
- 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.
- https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch5marks

Visualization Analysis & Design Tutorial

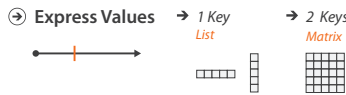
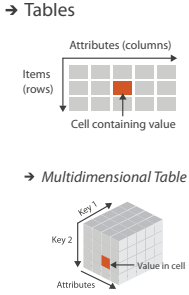


Visualization Analysis & Design, Tutorial



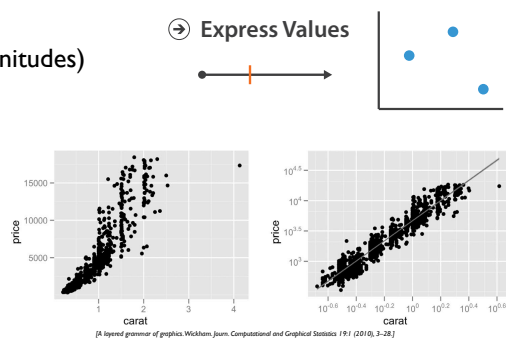
Keys and values

- 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...



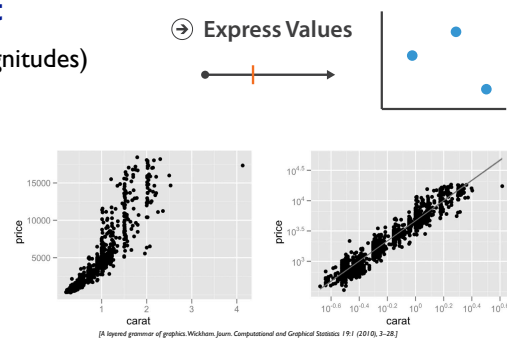
Idiom: scatterplot

- express values (magnitudes)
 - quantitative attributes
- no keys, only values



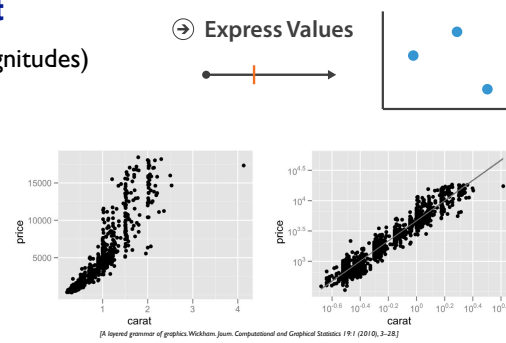
Idiom: scatterplot

- express values (magnitudes)
 - quantitative attributes
- no keys, only values
 - data
 - 2 quant attribs
 - mark: points
 - channels
 - horiz position/order
 - vert position/order



Idiom: scatterplot

- express values (magnitudes)
 - quantitative attributes
- no keys, only values
 - data
 - 2 quant attribs
 - mark: points
 - channels
 - horiz position/order
 - vert position/order
 - tasks
 - find trends, outliers, distribution, correlation, clusters
 - scalability
 - 1K items



Some keys: Categorical regions



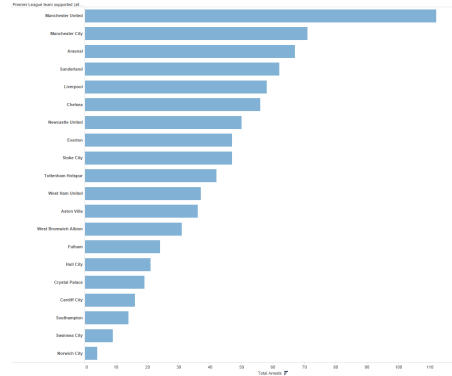
Regions: Separate, order, align



- separate into regions by any attribute: categorical or ordered
 - **regions**: contiguous bounded areas distinct from each other
 - no conflict with expressiveness principle for categorical attributes
 - one glyph/mark per region
- then can use ordered attribute to order and align regions
 - order in one direction (eg horiz), then align in other direction (eg vert)
 - align: impose shared coordinate frame so absolute position has meaning
 - difference between value and 0 point along axis

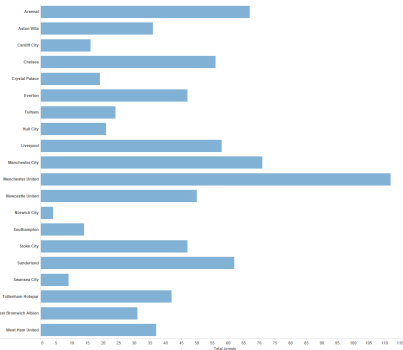
Separated and aligned and ordered

- best case



Separated and aligned but not ordered

- limitation: hard to know rank. what's 4th? what's 7th?



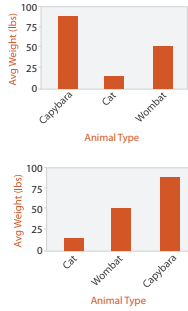
Separated but not aligned or ordered

- limitation: hard to make comparisons with 2D size (vs aligned 1D position)



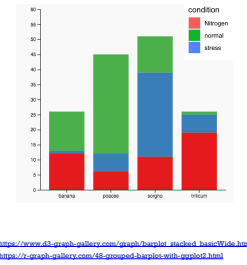
Idiom: bar chart (vertical)

- one key, one value
 - data: 1 categ attrib, 1 quant attrib
 - mark: segments (or length-coded points)
 - channels
 - separate by type into one mark per region
 - order horizontally by some quant attrib
 - » alphabetical by attrib name (easy lookup)
 - » by same attrib as vert size (easy to see distributions, find extremes)
 - horiz: position according to order, distribute at equal intervals along axis
 - align vertically: express quant value with
 - vert position/order; vert size
 - segment: emphasize distance between value & 0 point on axis below
- task: compare, lookup values
- scalability
 - dozens to hundreds of levels for key [# bars], 1K values [lengths]



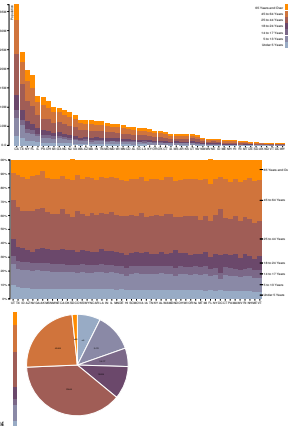
Idiom: stacked bar chart

- one more key
 - data: 2 categ attrib (both keys), 1 quant attrib
 - quant value indexed by categ pair (species, condition)
 - multi-level encoding: 2 levels
 - **glyph**: composite object, internal structure from multiple marks
 - entire-glyph level (full bar, by species)
 - within-glyph level (stacked components, by condition for each species)
 - channels
 - entire glyph (level 2): just like normal bar chart
 - separate by species, horiz order by species name, horiz position from order at equal intervals
 - vert position/order/size by value (for whole species)
 - within-glyph (level 1)
 - separate & color by condition, vert order alphabetical (by condition name)
 - vert ID size (length) is value, vertical shared boundary
 - vert position: **unavailable** except for lowest component
 - mark: segment (or length-coded point mark)
 - task: + part-to-whole relationship [components]
 - scalability: asymmetric
 - for stacked key attrib, 10-12 levels [components]
 - for main key attrib, dozens to hundreds of levels [bars]



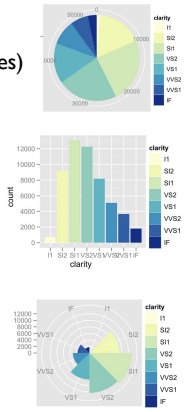
Idioms: normalized stacked bar chart

- task: part-to-whole judgements
- normalized stacked bar chart
 - stacked bar chart, normalized to full vert height
 - relative sizes show proportions
 - analysis of differences
 - level 2 (bar): vert 1D pos/size uniform & **unavailable**
 - vert pos meaningful for different 2 numbers
 - top & bottom components
 - vs bottom component & whole bar for unnormalized
- information density
 - single stacked bar equivalent to full pie
 - high info density: narrow rectangle vs large circle



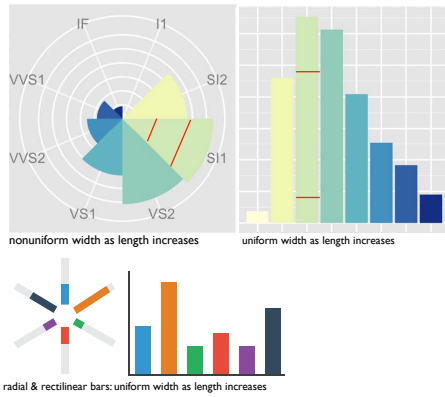
Idioms: pie chart, coxcomb chart

- pie chart
 - poly marks with angular position/order/size (shared boundaries)
 - radial position/order/size is uniform and unavailable
 - accuracy: less accurate than rectilinear aligned position
- data
 - 1 categ key attrib, 1 quant value attrib
- task
 - part-to-whole judgements
- coxcomb chart
 - more direct analog to bar charts
 - poly marks, but inverse: radial encodes & angular uniform



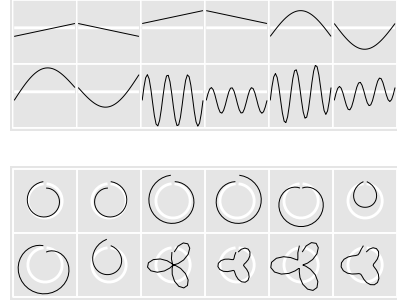
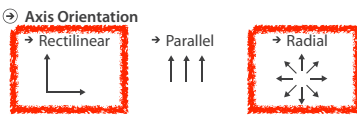
Coxcomb: perception

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



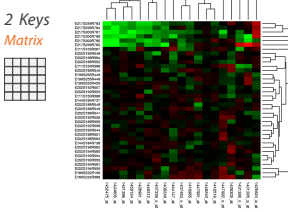
Idiom: glyphmaps

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

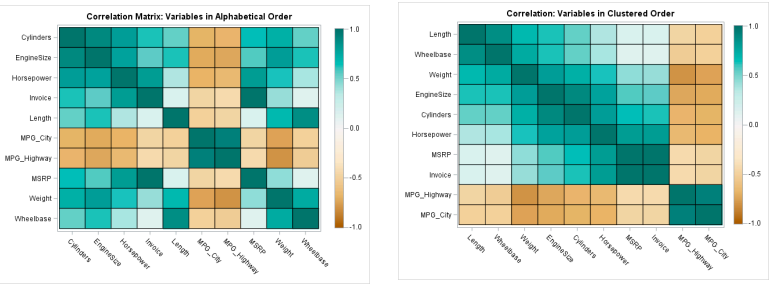


Idiom: heatmap

- two keys, one value
 - data
 - 2 categ attribs (gene, experimental condition)
 - 1 quant attrib (expression levels)
 - marks: point
 - indexed by 2 categorical key attributes
 - rectilinear: position/order, shared boundaries
 - size, orientation **unavailable**
 - channels
 - color by quant attrib (ordered diverging colormap)
 - task: find outliers, find clusters (if ordered well)
 - dendrogram from cluster hierarchy traversal: order by derived attribute, to assess cluster quality
 - scalability: asymmetric
 - 100s of categ levels, up to 1M items, but ~10 quant attrib levels



Heatmap reordering



order by attrib name (alphabetical)

order by derived attribute (data-driven clustering)

<https://blogs.sas.com/content/iml/2018/05/02/reorder-variables-correlation-heat-map.html>

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Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 7: Arrange Tables
- Visualizing Data. Cleveland. Hobart Press, 1993.
- A Brief History of Data Visualization. Friendly. 2008.
<http://www.datavis.ca/milestones>
- The History of the Cluster Heat Map. Leland Wilkinson and Michael Friendly. The American Statistician 63:2 (2009), 179-184.

- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch7tables>

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Geographic Map

poly marks with 2D shared boundaries, encode:

- position / order channels, using given spatial data

cannot use other channels to show other attributes, locked down as unavailable:

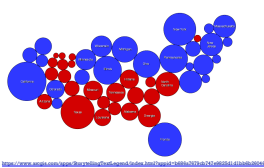
- size
- orientation
- symbol/shape



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Idiom: Dorling (circle) cartogram

- Dorling cartogram
 - throw away shape by regularizing to circles
 - point marks, with shared 2D boundaries
 - encode quant attribute with 2D size
 - encode relative locations of old polys with order
 - unavailable:
 - position: algorithm constraint to be as close as possible to original geographic locations (given spatial data)
 - orientation: meaningless since circles are symmetric
 - symbol/shape: must be circle, by definition
 - free: color
 - can treat as special case of circle packing, with quasi-geographic position constraints

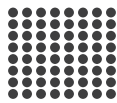


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Layout density

Layout Density

→ Dense



→ Space-Filling



Visualization Analysis & Design Tutorial

Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

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Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

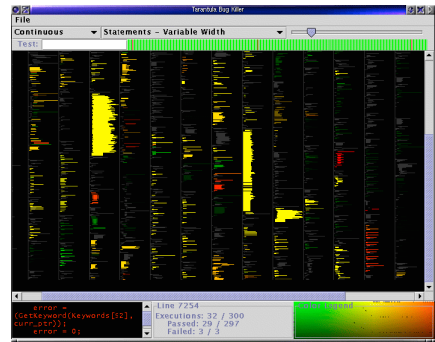
98

Idiom: Dense software overviews

- data: text
 - text + 1 quant attrib per line
- derived data: table of line lengths
- encoding
 - length coded lines, one pixel high
 - wrap long list into many columns
 - color line by attribute
- scalability
 - 10K+ lines

Layout Density

→ Dense



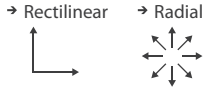
[Visualization of test information to assist fault localization. Jones, Harrold, Stasko. Proc. ICSE 2002, p. 467-477.]

Arrange tables

Express Values



Axis Orientation



Separate, Order, Align Regions



Align



1 Key List



2 Keys Matrix



Layout Density

→ Dense

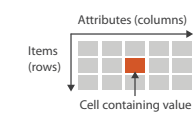


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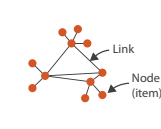
Focus on Spatial

Dataset Types

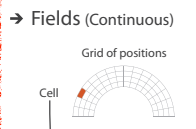
Tables



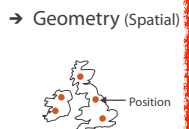
Networks



Spatial

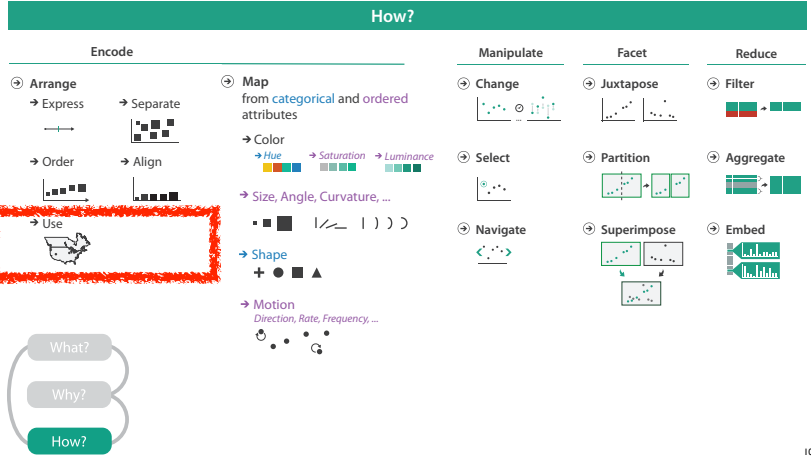


Geometry (Spatial)



- when central task is understanding spatial relationships
 - use given spatial data

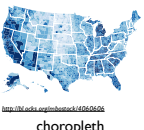
103



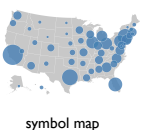
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Thematic maps

- show spatial variability of attribute ("theme")
 - combine geographic / reference map with (simple, flat) tabular data, joining
 - region: shared-boundary poly marks (eg provinces, countries) or point marks (eg cities)
 - region: categorical key attribute in table, use to look up value attributes
- major idioms
 - choropleth: color
 - but salience depends on size
 - symbol maps: add mark
 - but occlusion possible
 - dot maps: add many marks
 - but same non-uniform size issue
 - cartograms: recompute all
 - but requires familiarity



choropleth



symbol map



dot map

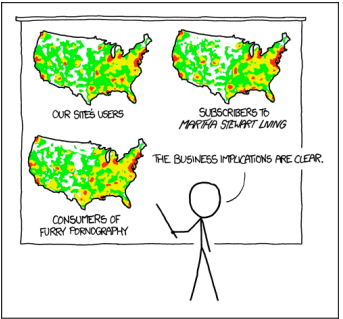


cartogram

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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, even beyond maps
 - absolute counts vs relative/normalized data
 - failure to normalize is common error



PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE
BASICALLY JUST POPULATION MAPS
[<https://xkcd.com/1138/>]

Idiom: Contiguous cartogram

- poly marks with 2D shared boundaries
 - aka area-proportional continuous cartogram
- derive new interlocking polys
 - based on combination of original interlocking marks and new quantitative attribute
 - encode: area (2D size) for new quant attribute
 - encode: order, maintaining relative position of polys
 - unavailable: position, orientation, shape/symbol
- algorithm to create new marks
 - input: target size (quant attribute)
 - goal: keep shape, position, orientation as close as possible to given spatial data for original polys
 - requirement: maintain constraints
 - order (relative position)
 - contiguous shared boundaries with neighbours

<http://webhome.crk.edu/~mcp/cartograms/>

<https://www.anychart.com/blog/2020/11/06/selection-maps-use-node-size-variables/>



Greenhouse Emissions



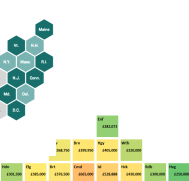
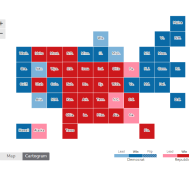
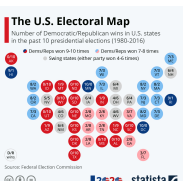
Child Mortality

D. Area-proportional continuous cartogram



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Idiom: Equal-area (Grid) Cartogram



- regularize shape & size, arranged in grid
 - derive new point marks with 2D shared boundaries
 - unavailable channels: size, shape/symbol, orientation
 - possible shapes: circles, squares, hexagons
 - unavailable: position, algorithm constraint to keep as close as possible to given spatial data
 - encode relative location/arrangement of original polys with order
 - encode quant attribute with color, just like with choropleth

- aka: grid map, mosaic cartogram, pseudo-Demers cartogram, geofacets, geogrid, tile grid map, tile map

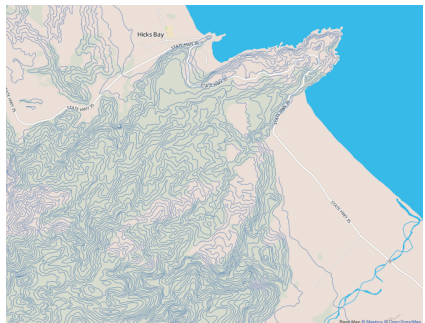
<https://www.anychart.com/blog/2020/11/06/selection-maps-use-node-size-variables/>

<https://www.anychart.com/blog/2020/11/06/selection-maps-use-node-size-variables/>

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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

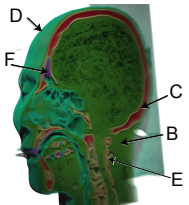
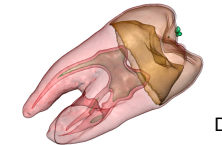


Land Information New Zealand Data Service

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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



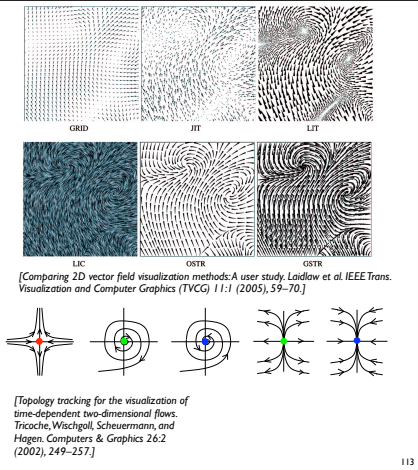
[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

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Vector and tensor fields

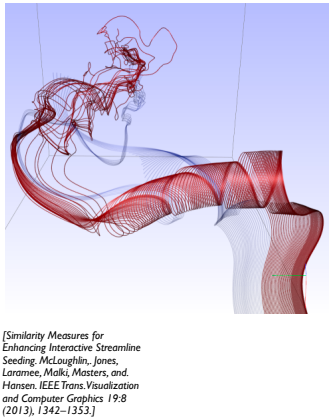
- data
 - multiple attributes per cell
- idiom families
 - flow glyphs
 - purely local
 - geometric flow
 - derived data from tracing particle trajectories
 - sparse set of seed points
 - texture flow
 - derived data, dense seeds
 - feature flow
 - global computation to detect features
 - encoded with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



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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



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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)



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 8: Arrange Spatial Data
- 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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch8spatial>

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Visualization Analysis & Design Tutorial

- Session 1
 - Analysis: What, Why, How
 - Marks and Channels
 - Q&A
 - Visualizing Tabular Data
 - Visualizing Spatial Data
 - Q&A
- Session 2
 - Visualizing Network Data
 - Color
 - Q&A
 - Interactive & Multiple Views
 - Reduce: Filter, Aggregate
 - Q&A

@tamara@cosocial.ca
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

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- BREAK 10:30-11

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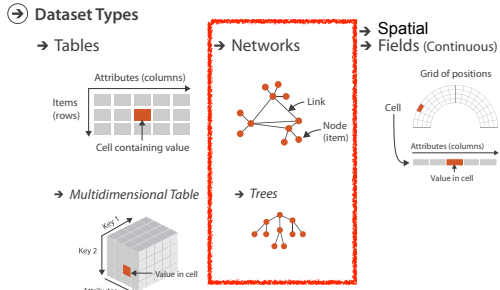
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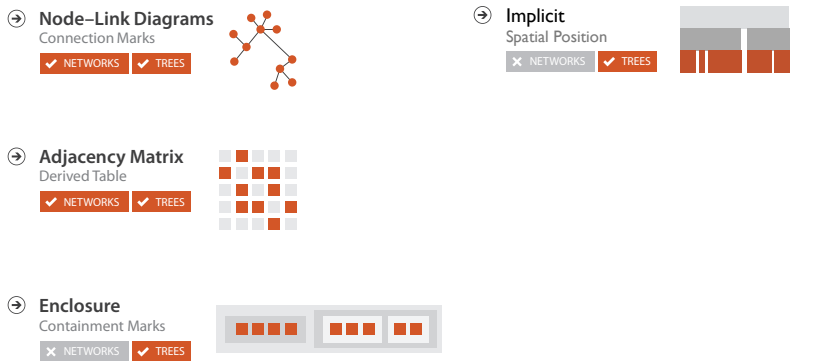
Network data

- networks
 - model relationships between things
 - aka graphs
 - two kinds of items, both can have attributes
 - nodes
 - links
- tree
 - special case
 - no cycles
 - one parent per node



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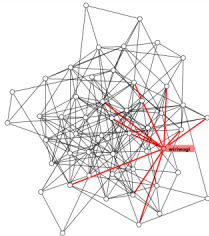
Arrange networks and trees



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Network tasks: topology-based and attribute-based

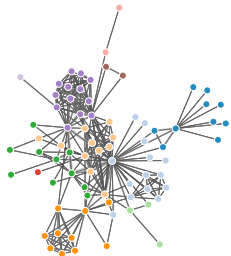
- topology based tasks
 - find paths
 - find (topological) neighbors
 - compare centrality/importance measures
 - identify clusters / communities
- attribute based tasks (similar to table data)
 - find distributions, ...
- combination tasks, incorporating both
 - example: find friends-of-friends who like cats
 - topology: find all adjacent nodes of given node
 - attributes: check if has-pet (node attribute) == cat



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Idiom: **force-directed placement**

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

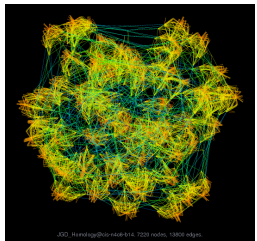


<https://observablehq.com/@d3/force-directed-graph/2>

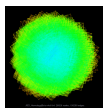
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Idiom: **sfdp** (multi-level force-directed placement)

- data
 - original: network
 - derived: cluster hierarchy atop it
- considerations
 - better algorithm for same encoding technique
 - same: fundamental use of space
 - hierarchy used for algorithm speed/quality but not shown explicitly
- scalability
 - nodes, edges: 1K-10K
 - hairball problem eventually hits



[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]

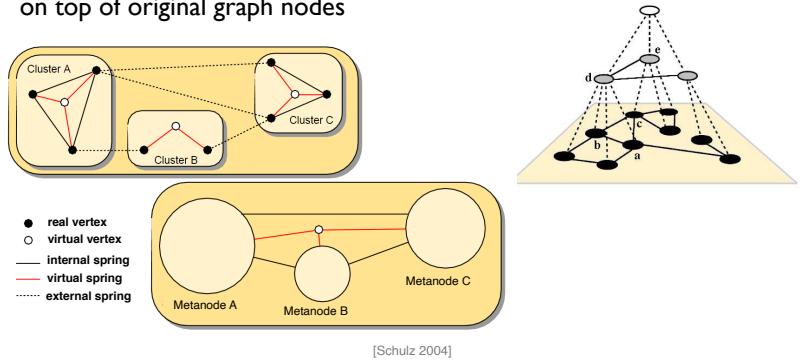


<http://www.research.att.com/yf/hu/GALLERY/GRAPHS/index.html>

124

Multilevel networks

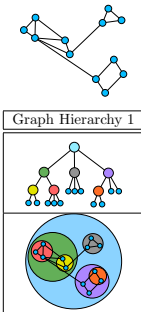
- derive cluster hierarchy of metanodes on top of original graph nodes



125

Idiom: **GrouseFlocks**

- data: compound network
 - network
 - cluster hierarchy atop it
 - derived or interactively chosen
- visual encoding
 - connection marks for network links
 - containment marks for hierarchy
 - point marks for nodes
- dynamic interaction
 - select individual metanodes in hierarchy to expand/contract

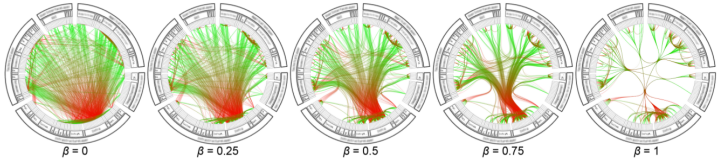


[GrouseFlocks: Steerable Exploration of Graph Hierarchy Space. Archambault, Munzner, and Auber. IEEE TVCG 14(4):900-913, 2008.]

126

Idiom: **hierarchical edge bundling**

- data
 - any layout of compound network
 - network: software classes (nodes), import/export between classes (links)
 - cluster hierarchy: class package structure
 - derived: bundles of edges with same source/destination (multi-level)
- idiom: curve edge routes according to bundles
- task: edge clutter reduction

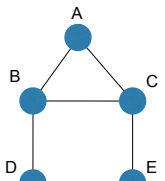


[Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data. Danny Holten. TVCG 12(5):741-748 2006]

127

Adjacency matrix representations

- derive adjacency matrix from network



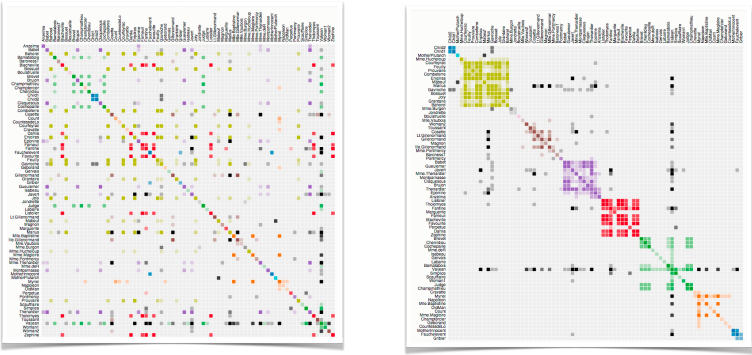
	A	B	C	D	E
A					
B					
C					
D					
E					

Adjacency Matrix
Derived Table



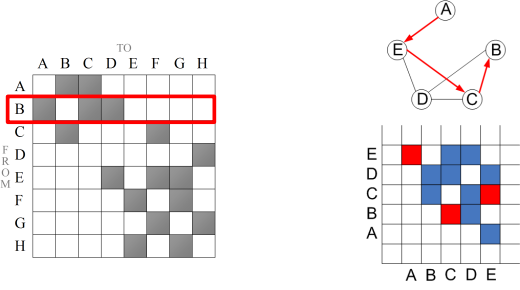
128

Node order is crucial: Reordering



<https://bost.ocks.org/mike/miserables/>

Adjacency matrix

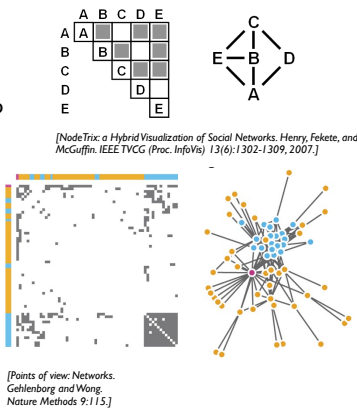


good for topology tasks
related to neighborhoods
(node 1-hop neighbors)

bad for topology tasks
related to paths

Idiom: **adjacency matrix view**

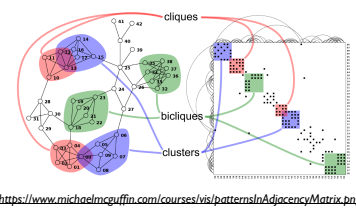
- data: network
 - transform into same data/encoding as heatmap
- derived data: table from network
 - 1 quant attrib
 - weighted edge between nodes
 - 2 categ attribs: node list x 2
- visual encoding
 - cell shows presence/absence of edge
- scalability
 - 1K nodes, 1M edges



[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!

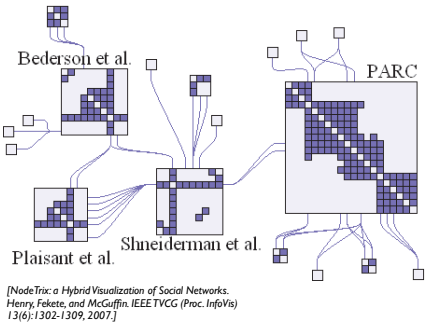


<https://www.michaelmcguffin.com/courses/vis/patterns/AdjacencyMatrix.png>

[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: **NodeTrix**

- hybrid nodelink/matrix
- capture strengths of both



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

Idiom: **radial node-link tree**

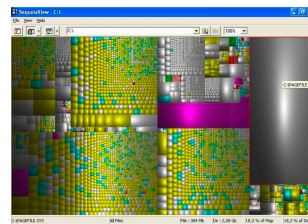
- data
 - tree
- encoding
 - link connection marks
 - node point marks
 - radial axis orientation
 - angular proximity: siblings
 - distance from center: depth in tree
- tasks
 - understanding topology, following paths
- scalability
 - 1K - 10K nodes



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

Idiom: **treemap**

- data
 - tree
 - 1 quant attrib at leaf nodes
- encoding
 - poly containment marks for hierarchical structure
 - shared boundaries
 - size encodes quant attrib
 - rectilinear orientation
- tasks
 - query attribute at leaf nodes
- scalability
 - 1M leaf nodes
- Enclosure
 - Containment Marks

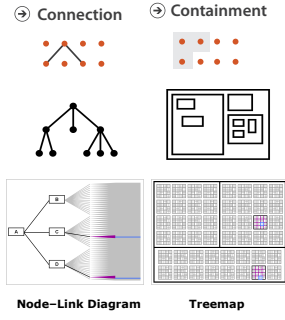


<https://www.win.tue.nl/sequoia/view/>

[Cushion Treemaps. van Wijk and van de Wetering. Proc. Symp. InfoVis 1999, 73–78.]

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

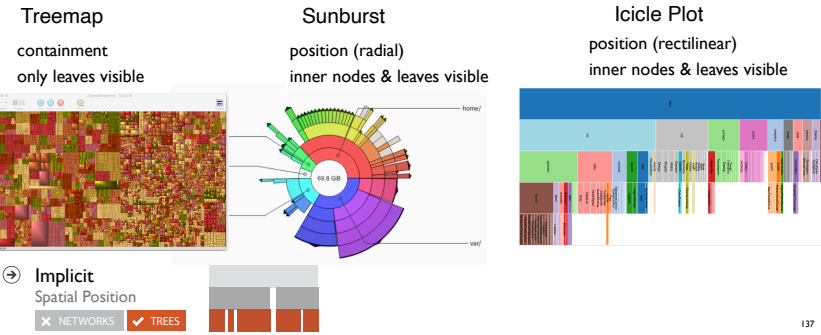


Node-Link Diagram Treemap

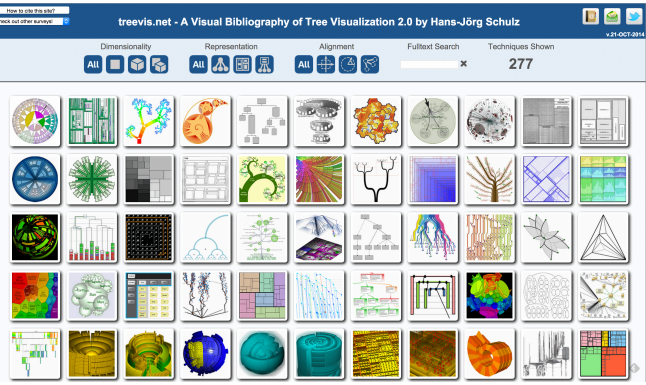
[Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams. Dong, McGuffin, and Chignell. Proc. InfoVis 2005, p. 57–64.]

Idiom: **implicit tree layouts (sunburst, icicle plot)**

- alternative to connection and containment: position
 - show parent-child relationships only through relative positions



treevis.net: Many, many options!



<https://treevis.net/>

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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch9networks>

Visualization Analysis & Design Tutorial

- Session 1
 - Analysis: What, Why, How
 - Marks and Channels
 - Q&A
 - Visualizing Tabular Data
 - Visualizing Spatial Data
 - Q&A
- Session 2
 - Visualizing Network Data
 - Color
 - Q&A
 - Interactive & Multiple Views
 - Reduce: Filter, Aggregate
 - Q&A

@tamara@cosocial.ca
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

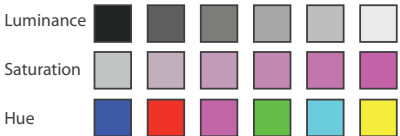
Decomposing color

- 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

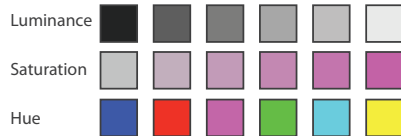


Decomposing color

- 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

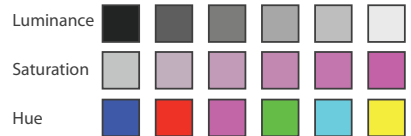


Decomposing color

- 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



- perceptual colorspace, in contrast to three channels of RGB

How?

Encode

Manipulate

Facet

Reduce

⌕ Arrange

→ Express

→ Separate

→ Order

→ Use

⌕ Map from categorical and ordered attributes

→ Color

→ Hue

→ Saturation

→ Luminance

→ Size, Angle, Curvature, ...

→ Shape

→ Motion

Direction, Rate, Frequency, ...

⌕ Change

⌕ Select

⌕ Navigate

⌕ Juxtapose

⌕ Partition

⌕ Superimpose

⌕ Filter

⌕ Aggregate

⌕ Embed

What?

Why?

How?

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How?

Encode

Manipulate

Facet

Reduce

⌕ Arrange

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⌕ Embed

What?

Why?

How?

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How to handle complexity: 2 more strategies

→ Derive

Manipulate

Facet

Reduce

⌕ Change

⌕ Select

⌕ Navigate

⌕ Juxtapose

⌕ Partition

⌕ Superimpose

⌕ Filter

⌕ Aggregate

⌕ Embed

• derive new data to show within view

• change view over time

• facet across multiple views

• reduce items/attributes within single view

163

Idiom: Change order/arrangement

• what: simple table

• how: data-driven reordering

• why: find extreme values, trends

Sort values

Sort values

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

164

Idiom: Change order

System: DataStripes

• what: table with many attributes

• how: data-driven reordering by selecting column

• why: find correlations between attributes

Column 1

Column 2

Column 3

Column 4

Column 5

Column 6

Column 7

Color

Bool

Date

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

165

Idiom: Animated transitions

• smooth interpolation from one state to another

– alternative to jump cuts, supports item tracking

– best case for animation

– staging to reduce cognitive load

• example: animated transitions in statistical data graphics

video: vimeo.com/19278444

[Animated Transitions in Statistical Data Graphics, Heer and Robertson, IEEE TVCG (Proc. InfoVis 2007), 13(6):1240-1247, 2007]

166

Idiom: Animated transitions - visual encoding

• smooth transition from one state to another

– alternative to jump cuts, supports item tracking

– best case for animation

– staging to reduce cognitive load

[Stacked to Grouped Bars](http://bl.ocks.org/mbostock/3943967)

167

Idiom: Animated transition - tree detail

• animated transition

– network drilldown/rollup

[Collapsible Tree](https://bl.ocks.org/mbostock/4339083)

168

Tooltips

• popup information for selection

– hover or click

– can provide useful additional detail on demand

– beware: does not support overview!

• always consider if there's a way to visually encode directly to provide overview

• “If you make a rollover or tooltip, assume nobody will see it. If it's important, make it explicit.”

– Gregor Aisch, NYTimes

169

Interaction technology

• what do you design for?

– mouse & keyboard on desktop?

• large screens, hover, multiple clicks

– touch interaction on mobile?

• small screens, no hover, just tap

– gestures from video / sensors?

• ergonomic reality vs movie bombast

– eye tracking?

Data visualization and the news - Gregor Aisch (37 min)

vimeo.com/182590214

I Hate Tom Cruise - Alex Kauffmann (5 min)

www.youtube.com/watch?v=QXLtT9sFcbc

slide inspired by: Alexander Lex, Utah

170

Rule of thumb: Responsiveness is required

• visual feedback: three rough categories

– 0.1 seconds: perceptual processing

• subsecond response for mouseover highlighting - ballistic motion

– 1 second: immediate response

• fast response after mouseclick, button press - Fitts' Law limits on motor control

– 10 seconds: brief tasks

• bounded response after dialog box - mental model of heavyweight operation (file load)

• scalability considerations

– highlight selection without complete redraw of view (graphics frontbuffer)

– show hourglass for multi-second operations (check for cancel/undo)

– show progress bar for long operations (process in background thread)

– rendering speed when item count is large (guaranteed frame rate)

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Navigate: Changing item visibility

⌕ Navigate

→ Item Reduction

→ Zoom

Geometric or Semantic

→ Pan/Translate

→ Constrained

• 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

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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 side of plane from camera

– project

• change mathematics of image creation

– orthographic

– perspective

– many others: Mercator, cabinet, ...

Attribute Reduction

→ Slice

→ Cut

→ Project

[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.]

173

Navigate: Cartographic projections

• project from 2D sphere surface to 2D plane

– can only fully preserve 2 out of 3

• angles: conformal

• area: equal area

• contiguity: no interruptions

Tissot's Indicatrix

Myriahedral projections

Goode's homolosine

Lambert cyl. eq. area

Plate carree

Mercator

https://www.jasondavies.com/maps/tissot/

https://www.win.tue.nl/~vanwijk/myriahedral/

[Every Map Projection](https://bl.ocks.org/mbostock/29cddcd006fb98beff12e60dd08f59a7)

174

Manipulate

⌕ Change over Time

⌕ Select

⌕ Navigate

→ Item Reduction

→ Zoom

Geometric or Semantic

→ Pan/Translate

→ Constrained

→ Attribute Reduction

→ Slice

→ Cut

→ Project

175

Facet

⌕ Juxtapose

⌕ Partition

⌕ Superimpose

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Juxtapose and coordinate views

→ Share Encoding: Same/Different

→ Linked Highlighting



→ Share Data: All/Subset/None



→ Share Navigation

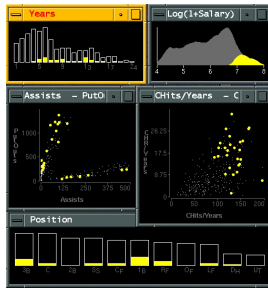


Idiom: **Linked highlighting**

System: **EDV**

- see how regions contiguous in one view are distributed within another
 - powerful and pervasive interaction idiom

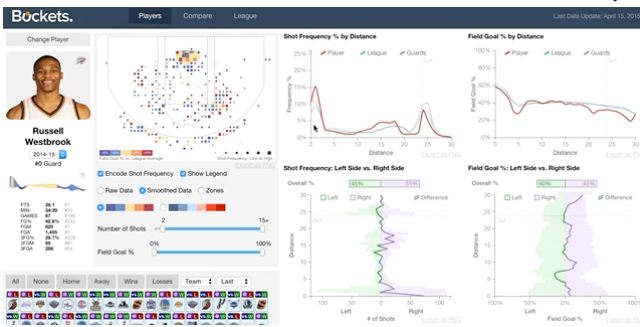
- encoding: different
 - **multiform**
- data: all shared
 - all **items** shared
 - different **attributes** across the views
- aka: brushing and linking



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

Linked views: Multidirectional linking

System: **Buckets**

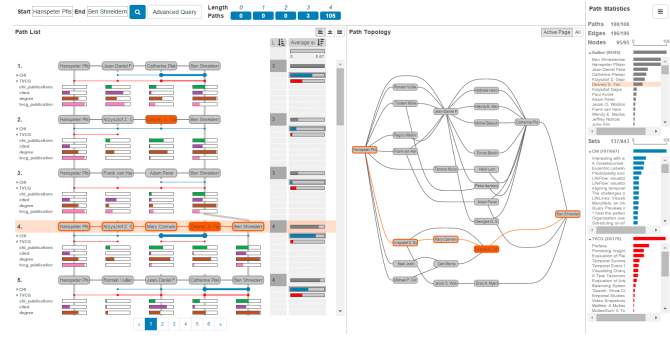


<http://buckets.peterbeshai.com/>

<https://medium.com/@pbesh/linked-highlighting-with-react-d3-js-and-reflux-16e9c9b2210e>

Complex linked multiform views

System: **Pathfinder**



<https://www.youtube.com/watch?v=aZF7AC8aNXo>

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

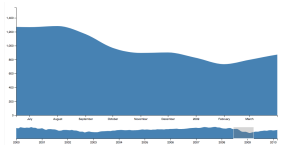
- encoding: same or different
 - ex: same (birds-eye map)
- data: subset shared
 - viewpoint differences: subset of data items
- navigation: shared
 - bidirectional linking
- other differences
 - (window size)



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

Idiom: **Overview-detail navigation**

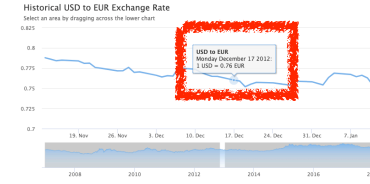
- encoding: same or different
- data: subset shared
- navigation: shared
 - unidirectional linking
 - select in small overview, change extent in large detail view



<https://observablehq.com/@uwdata/interaction>

Idiom: **Tooltips**

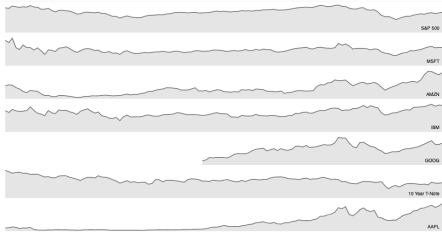
- popup information for selection
 - hover or click
 - specific case of detail view: provide useful additional detail on demand
 - beware: does not support overview!
- always consider if there's a way to visually encode directly to provide overview
- “If you make a rollover or tooltip, assume nobody will see it. If it's important, make it explicit.”
 - Gregor Aisch, NYTimes



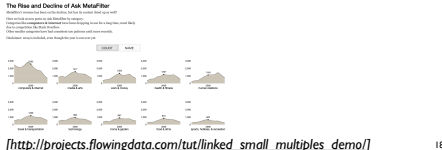
<https://www.highcharts.com/demo/dynamic-master-detail>

Idiom: **Small multiples**

- encoding: same
 - ex: line charts
- data: none shared
 - different slices of dataset
 - items or attributes
 - ex: stock prices for different companies
- linked highlighting: analogous item/attribute across views
 - same year highlighted across all charts if hover within any chart



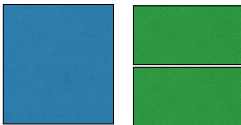
<https://blocks.roadtolarissa.com/mbostock/1157787/>



http://projects.flowingdata.com/tut/linked_small_multiples_demo/

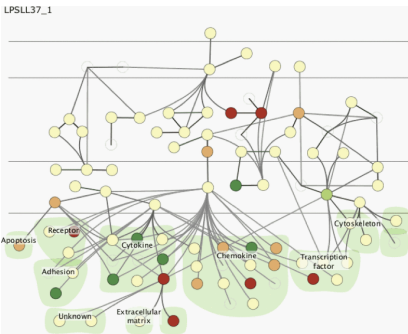
Juxtapose views: tradeoffs

- 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

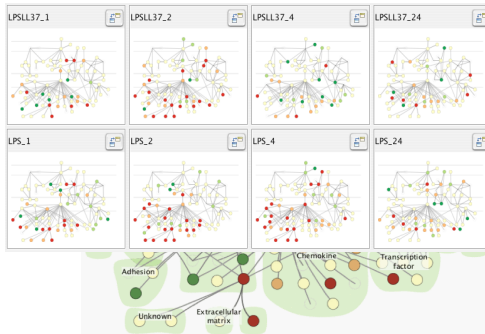
- animate: hard to follow if many scattered changes or many frames
 - vs easy special case: animated transitions



[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

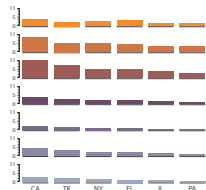
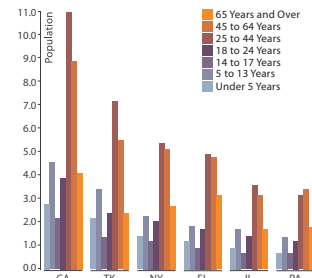
→ Partition into Side-by-Side Views

- 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



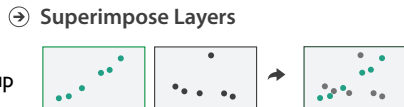
Partitioning: List alignment

- 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 states
- 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 achievable, 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/>]

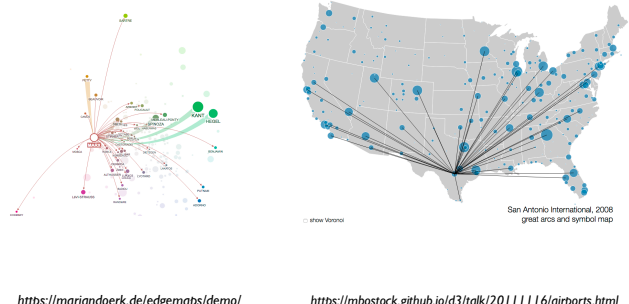
Idiom: Trellis plots

- 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/2011/11/6/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
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- 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.
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- 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.

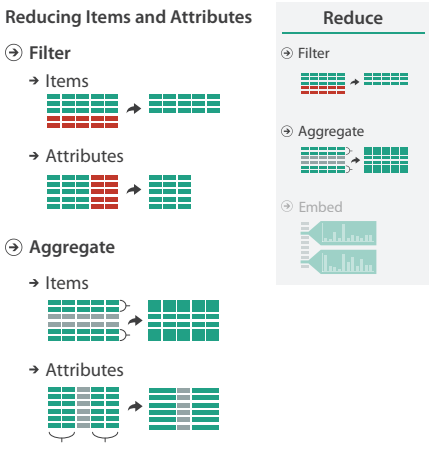
Visualization Analysis & Design Tutorial

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 - Marks and Channels
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Reduce items and attributes

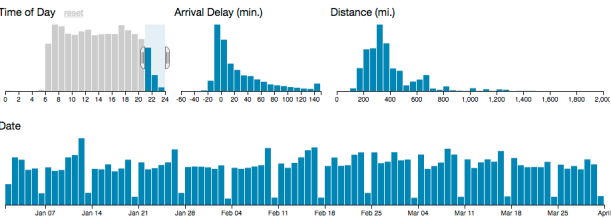
- reduce/increase: inverses
- filter
 - pro: straightforward and intuitive
 - to understand and compute
 - con: out of sight, out of mind
- aggregation
 - pro: inform about whole set
 - con: difficult to avoid losing signal
- not mutually exclusive
 - combine filter, aggregate
 - combine reduce, change,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



Idiom: cross filtering

System: Crossfilter

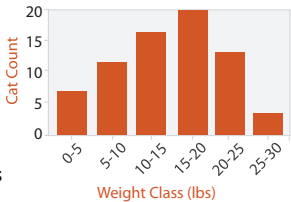
- item filtering
- coordinated views/controls combined
 - all scented histogram bislders update when any ranges change



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

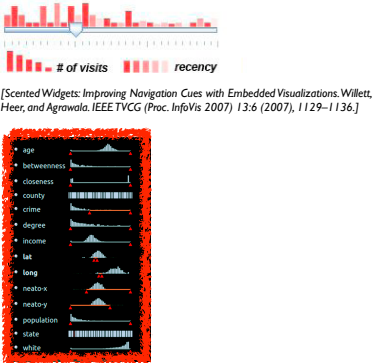
Idiom: histogram

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



Idiom: scented widgets

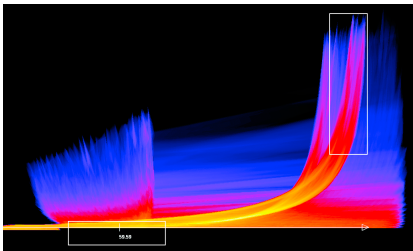
- augmented widgets show **information scent**
 - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider



[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

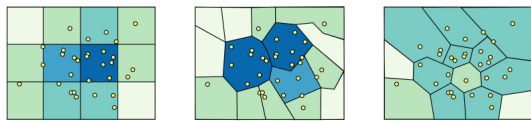
- static item aggregation
- data: table
- derived data: table
 - key attribs x,y for pixels
 - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
 - no limits on overplotting: millions of items



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

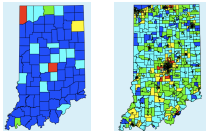
Spatial aggregation

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



[http://www.e-education.psu.edu/geog486/t4_p7.html, Fig 4.cg.6]

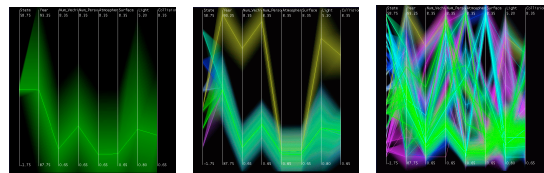
– scale effects



[<https://blog.cartographic.com/blog/2011/05/19/the-modifiable-areal-unit-problem-in-gis.html>]

Idiom: Hierarchical parallel coordinates

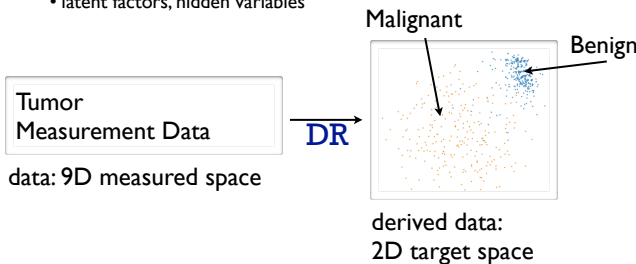
- dynamic item aggregation
- derived data: **hierarchical clustering**
- encoding:
 - cluster band with variable transparency, line at mean, width by min/max values
 - color by proximity in hierarchy



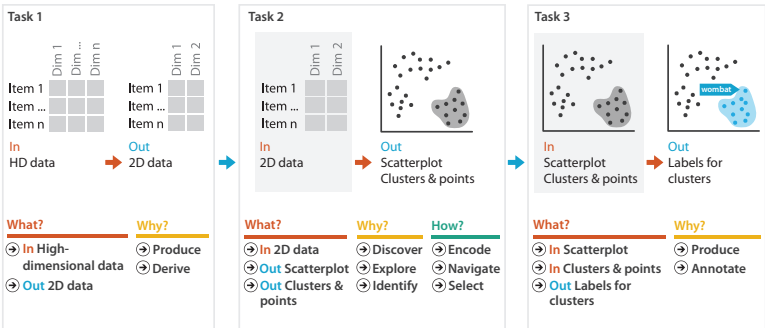
[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43–50, 1999.]

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

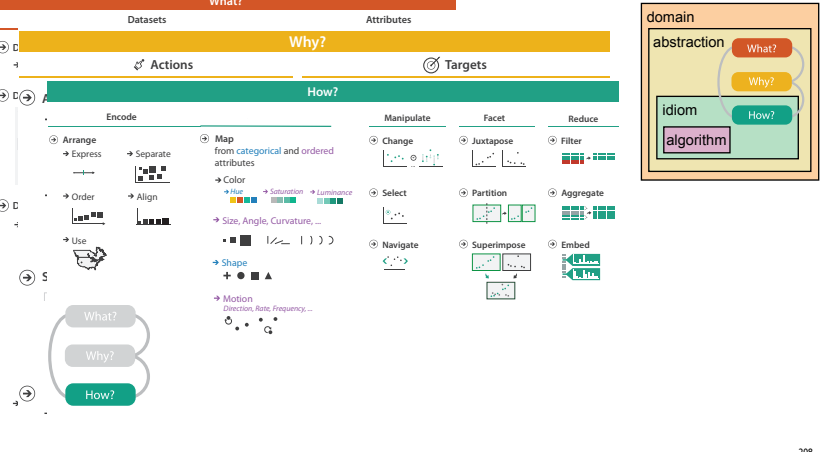


Idiom: Dimensionality reduction for documents



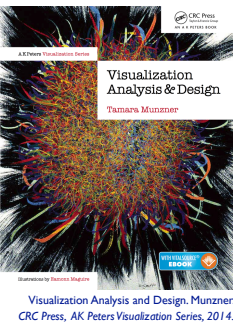
Further reading

- 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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch13reduce>



More information

- this tutorial
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25
- book
<http://www.cs.ubc.ca/~tmm/vadbook>
 - <https://www.routledge.com/Visualization-Analysis-and-Design/Munzner/p/book/9781466508910>
 - illustration acknowledgement: Eamonn Maguire
- full courses, papers, videos, software, talks
<http://www.cs.ubc.ca/group/infovis>
<http://www.cs.ubc.ca/~tmm>



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