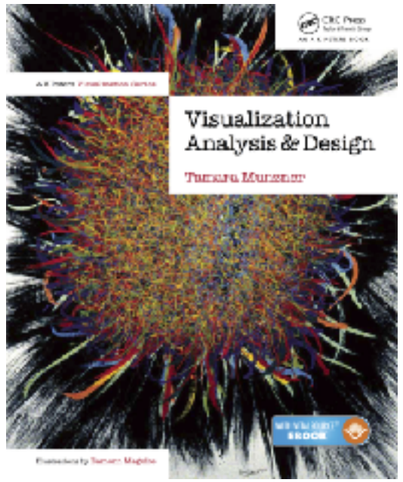
Visualization Analysis & Design



Network Data (Ch 9)

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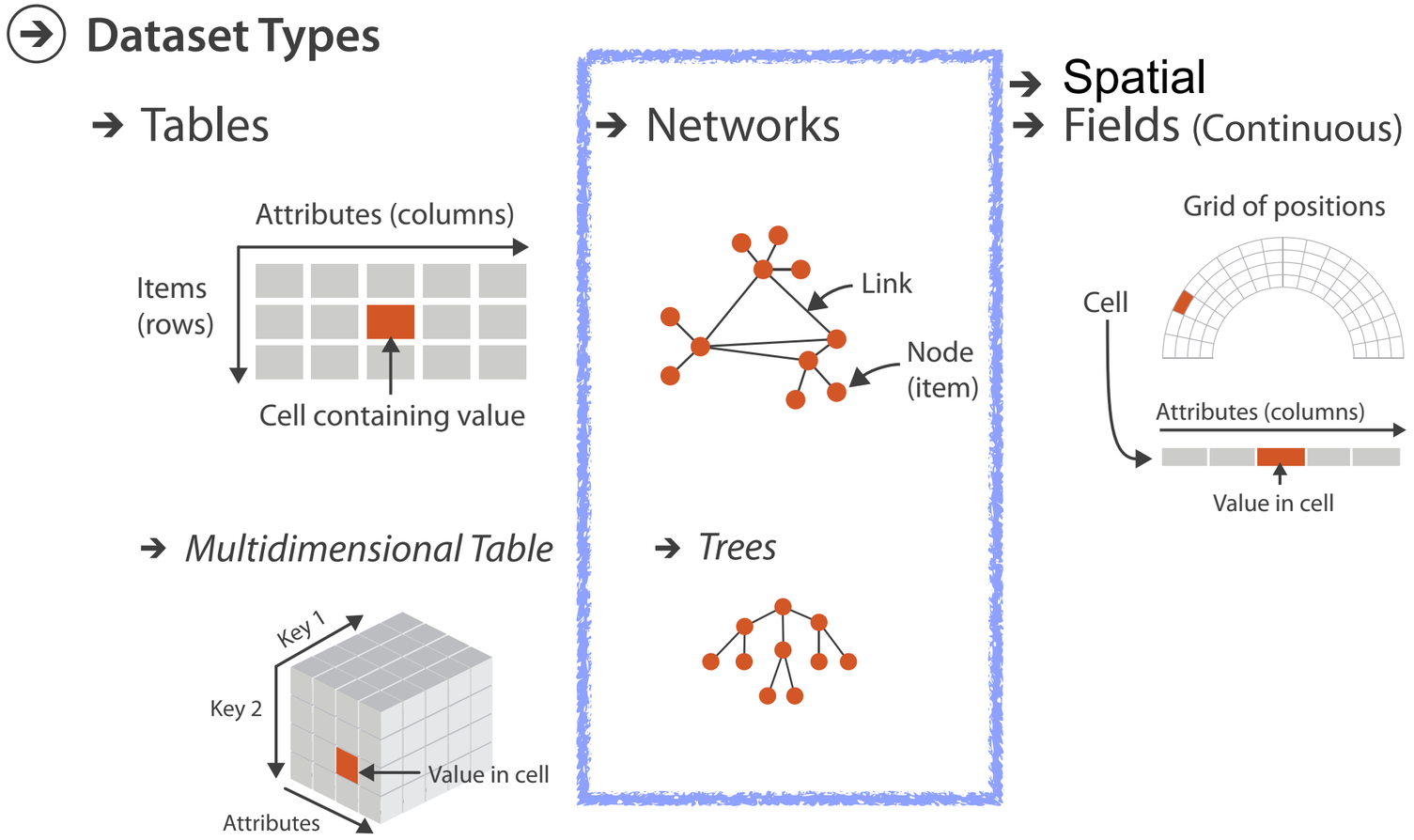
@tamaramunzner

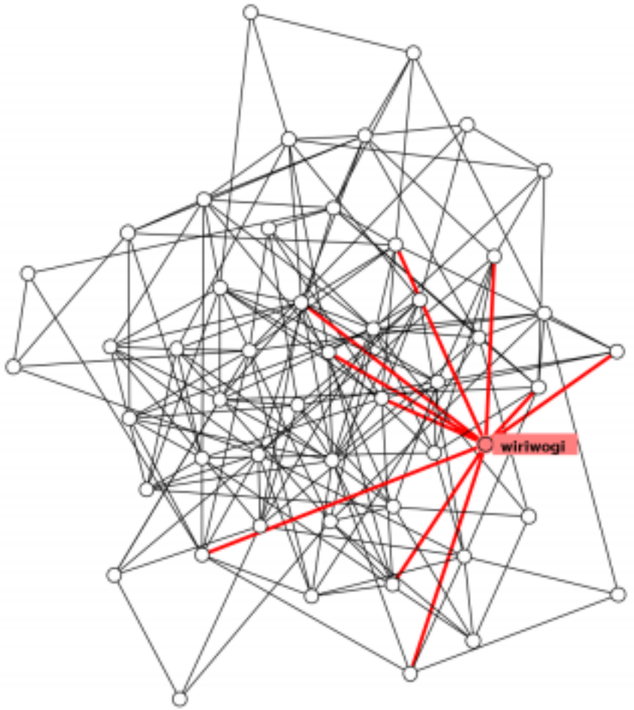
Network data

- 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



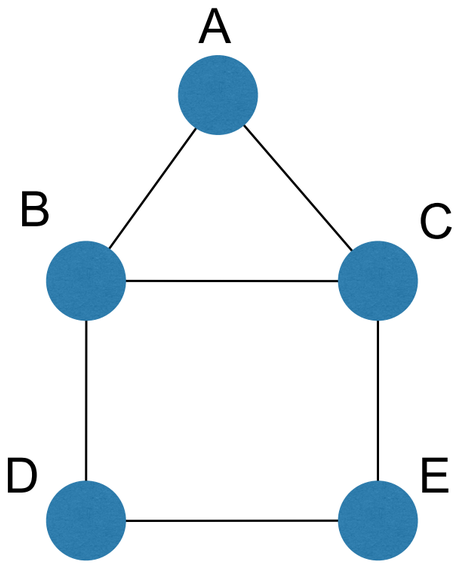
Network tasks: topology-based and attribute-based

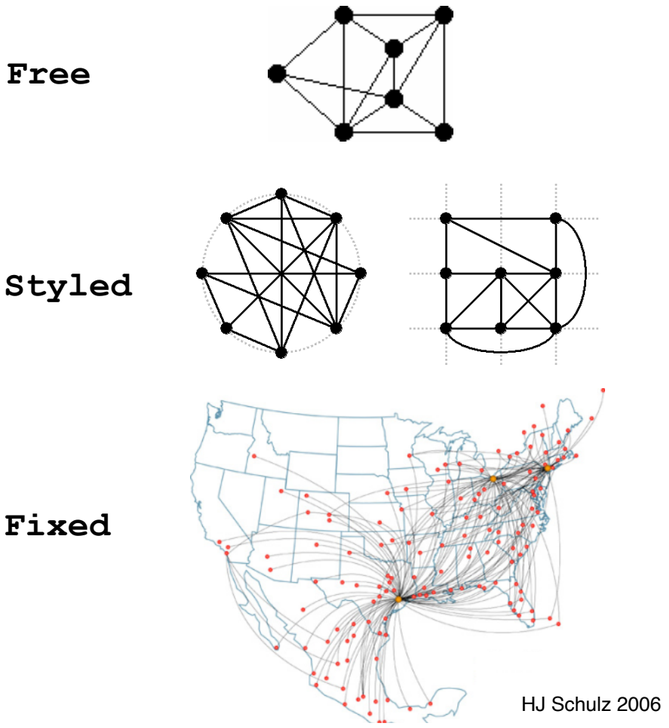
- topology based tasks
  - find paths
  - find (topological) neighbors
  - compare centrality/importance measures
  - identify clusters / communities
- attribute based tasks (similar to table data)
  - find distributions, ...
- combination tasks, incorporating both
  - example: find friends-of-friends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



Node-link diagrams

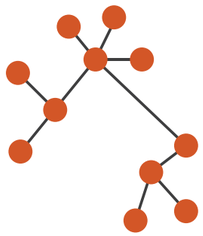
- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants





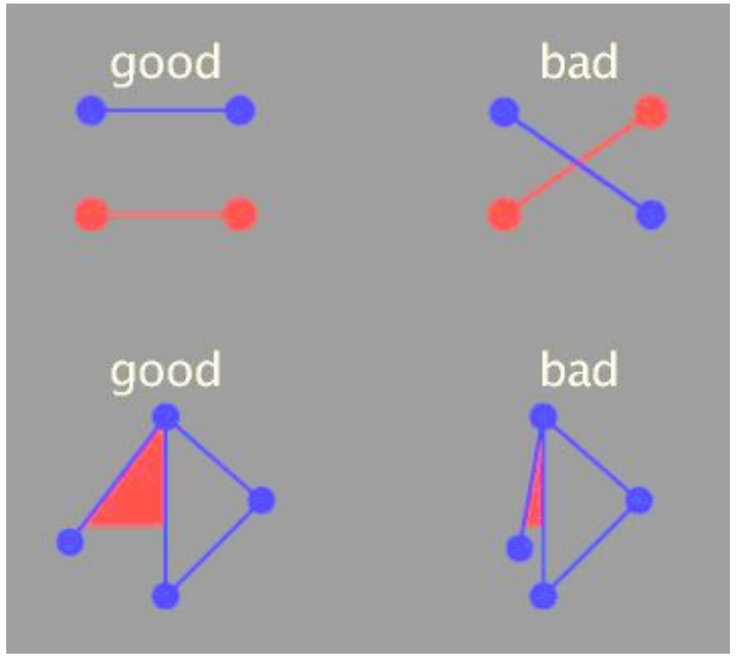
Node–Link Diagrams
Connection Marks

✔ NETWORKS ✔ TREES



Criteria for good node-link layouts

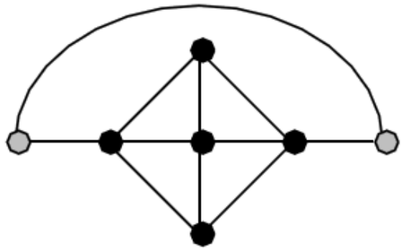
- minimize
  - edge crossings, node overlaps
  - distances between topological neighbor nodes
  - total drawing area
  - edge bends
- maximize
  - angular distance between different edges
  - aspect ratio disparities
- emphasize symmetry
  - similar graph structures should look similar in layout



Criteria conflict

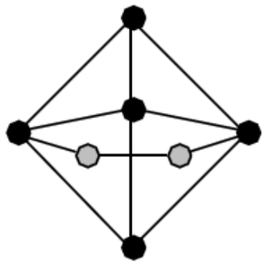
- most criteria NP-hard individually
- many criteria directly conflict with each other

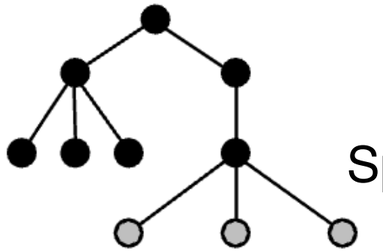
Minimum number of edge crossings



vs.

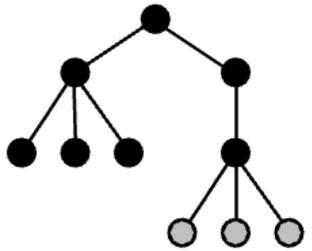
Uniform edge length





Space utilization

vs.



Symmetry

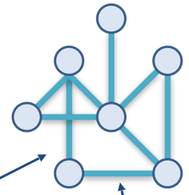
Schulz 2004

Optimization-based layouts

- formulate layout problem as optimization problem
- convert criteria into weighted cost function
  - F(layout) = a*[crossing counts] + b*[drawing space used]+...
- use known optimization techniques to find layout at minimal cost
  - energy-based physics models
  - force-directed placement
  - spring embedders

Force-directed placement

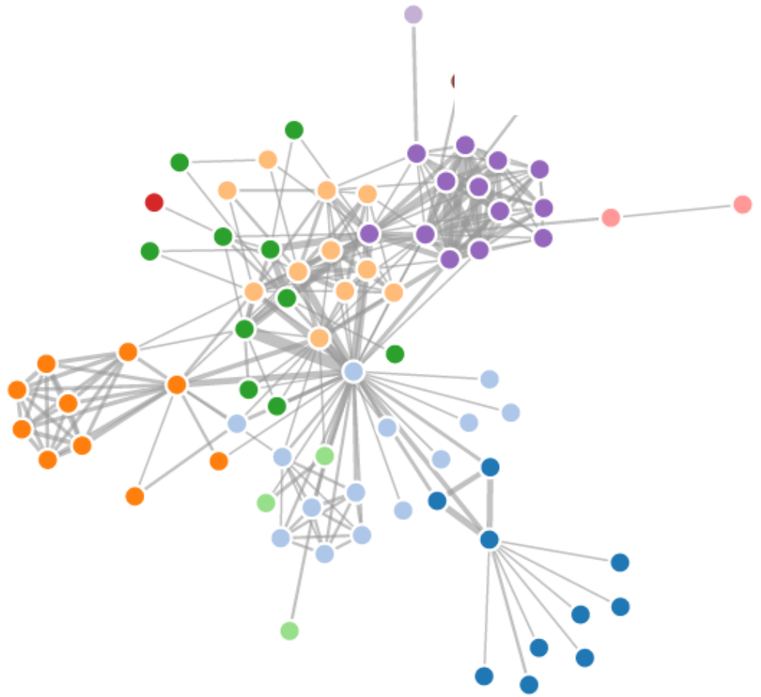
- physics model
  - links = springs pull together
  - nodes = magnets repulse apart



Expander
(pushing nodes apart)

Spring Coil
(pulling nodes together)

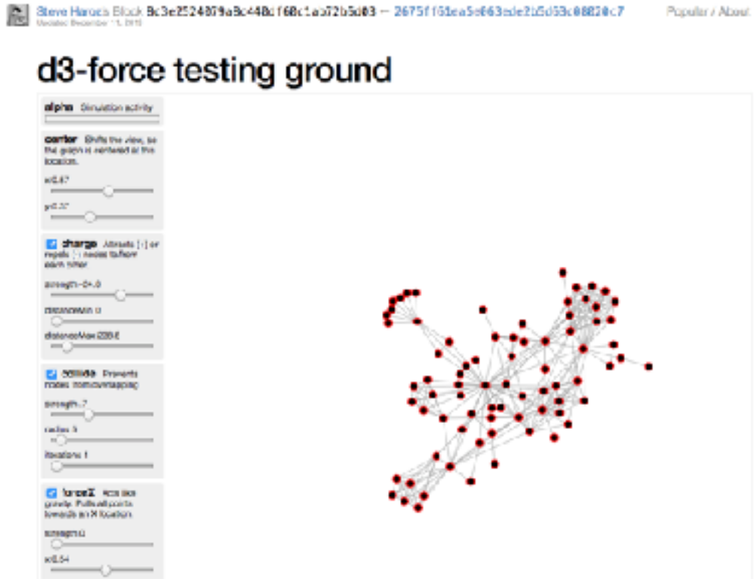
- algorithm
  - place vertices in random locations
  - while not equilibrium
    - calculate force on vertex
      - sum of
        - » pairwise repulsion of all nodes
        - » attraction between connected nodes
    - move vertex by c * vertex_force



http://mbostock.github.com/d3/ex/force.html

Force-directed placement properties

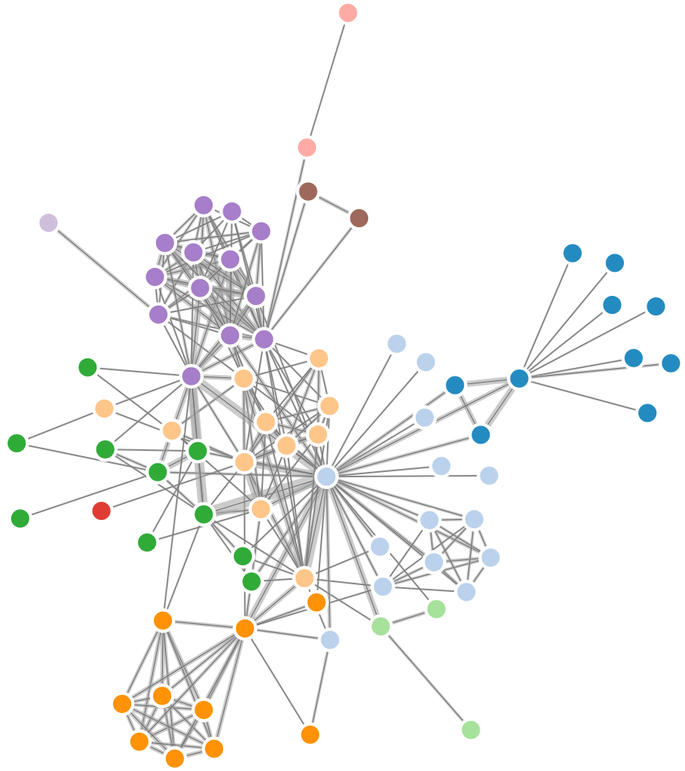
- strengths
  - reasonable layout for small, sparse graphs
  - clusters typically visible
  - edge length uniformity
- weaknesses
  - nondeterministic
  - computationally expensive: O(n^3) for n nodes
    - each step is n^2, takes ~n cycles to reach equilibrium
  - naive FD doesn't scale well beyond 1K nodes
  - iterative progress: engaging but distracting



https://bl.ocks.org/steveharoz/8c3e2524079a8c440df60c1ab72b5d03

Idiom: **force-directed placement**

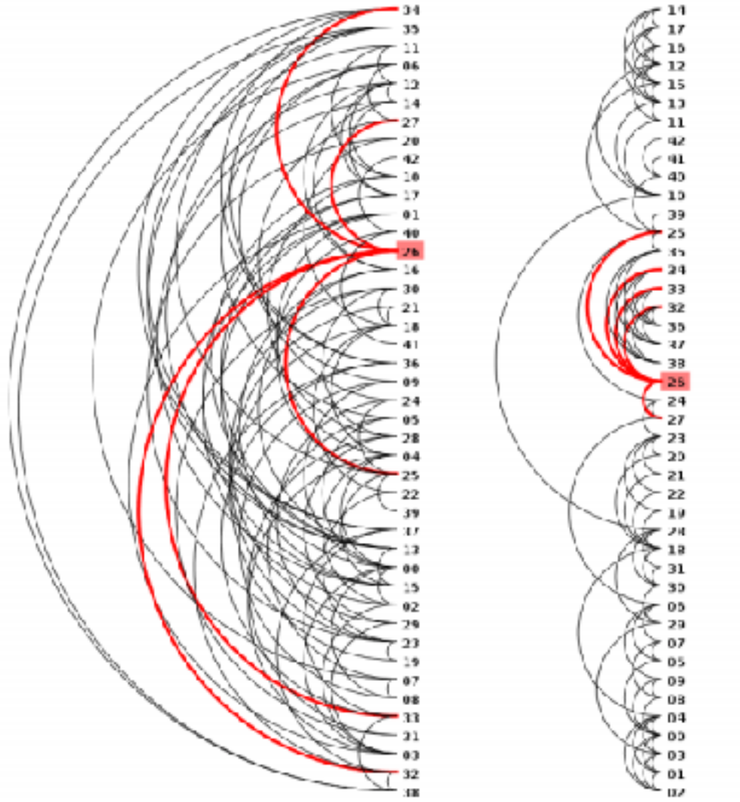
- visual encoding
  - link connection marks, node point marks
- considerations
  - spatial position: no meaning directly encoded
    - left free to minimize crossings
  - proximity semantics?
    - sometimes meaningful
    - sometimes arbitrary, artifact of layout algorithm
    - tension with length
      - long edges more visually salient than short
- tasks
  - explore topology; locate paths, clusters
- scalability
  - node/edge density E < 4N

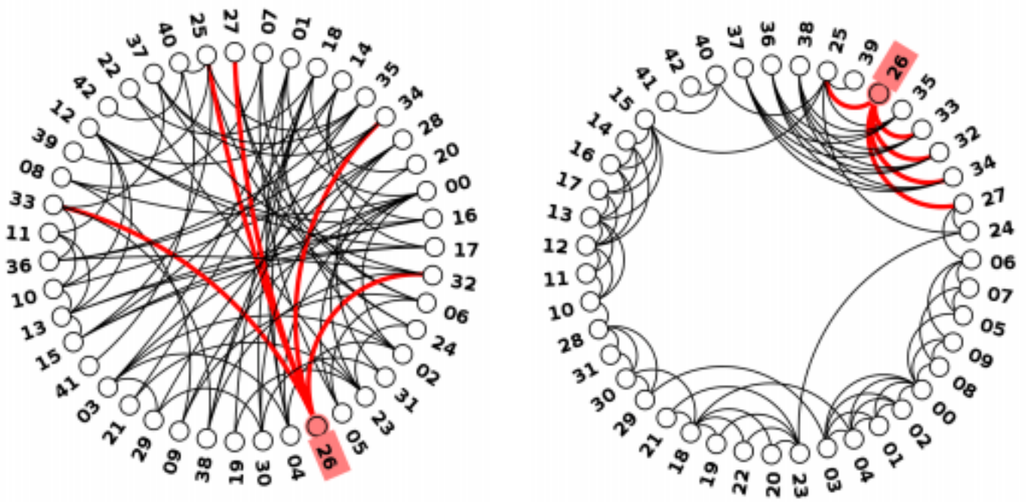


http://mbostock.github.com/d3/ex/force.html

Idiom: **circular layouts / arc diagrams (node-link)**

- restricted node-link layouts: lay out nodes around circle or along line
- data
  - original: network
  - derived: node ordering attribute (global computation)
- considerations: node ordering crucial to avoid excessive clutter from edge crossings
  - examples: before & after barycentric ordering

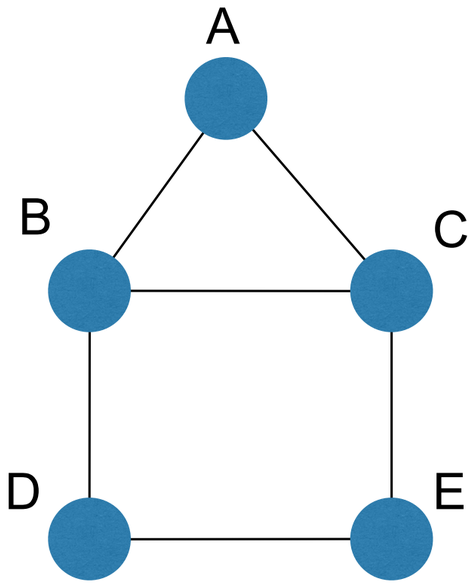


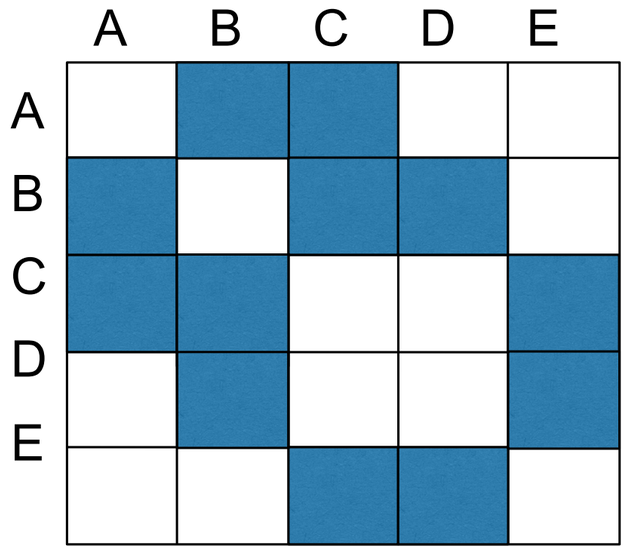


http://profs.etsmtl.ca/mmcguffin/research/2012-mcguffin-simpleNetVis/mcguffin-2012-simpleNetVis.pdf

Adjacency matrix representations

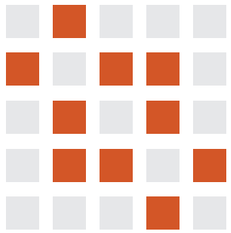
- derive adjacency matrix from network



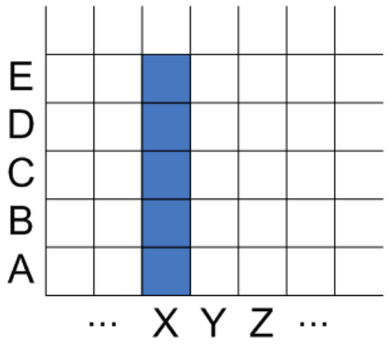


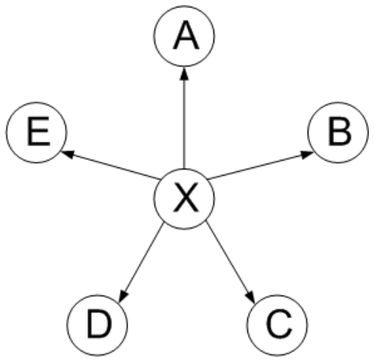
Adjacency Matrix
Derived Table

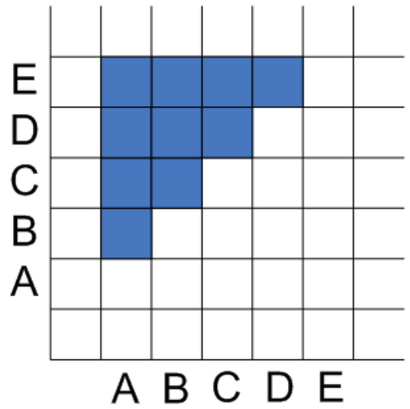
✔ NETWORKS ✔ TREES

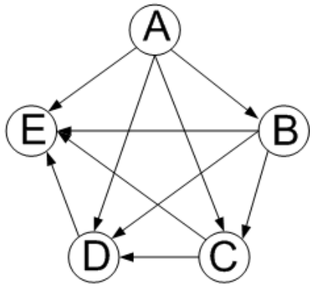


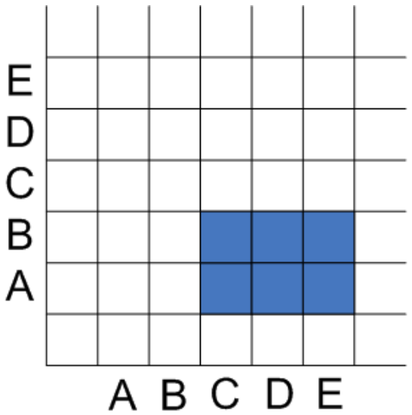
Adjacency matrix examples

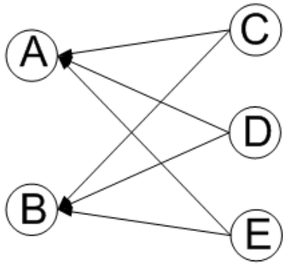


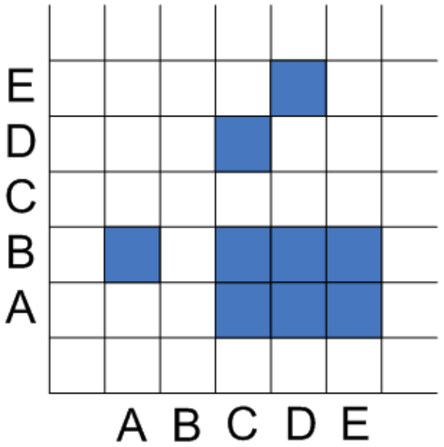


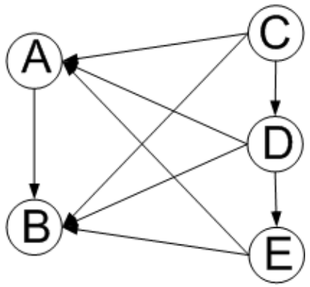






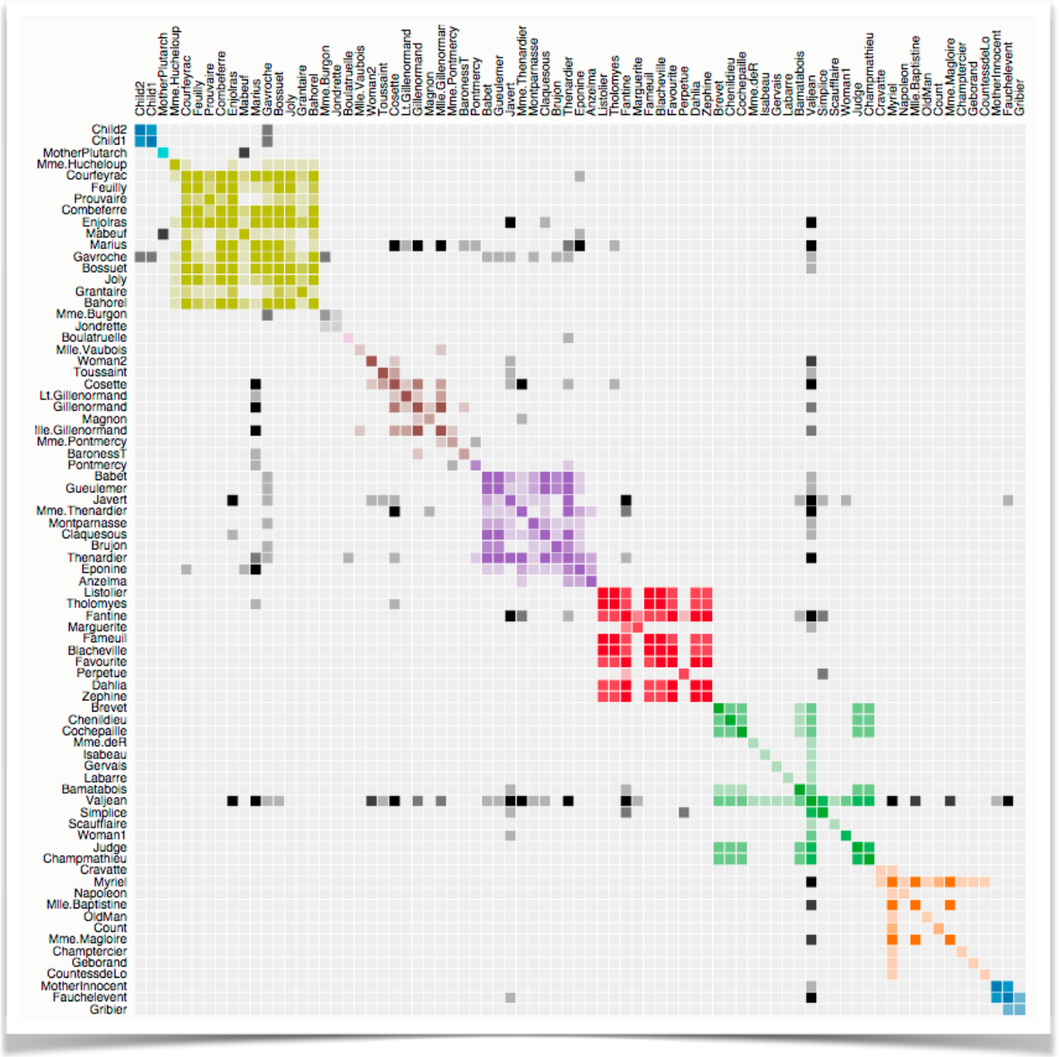






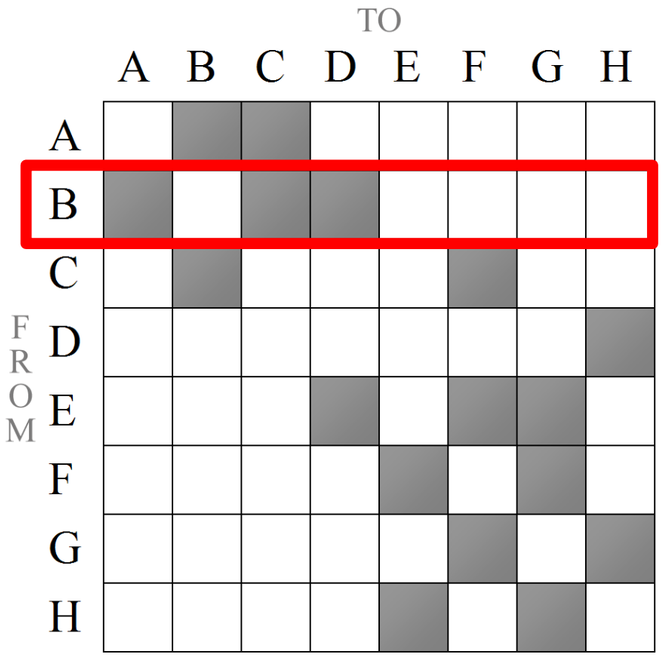
HJ Schulz 2007

Node order is crucial: Reordering

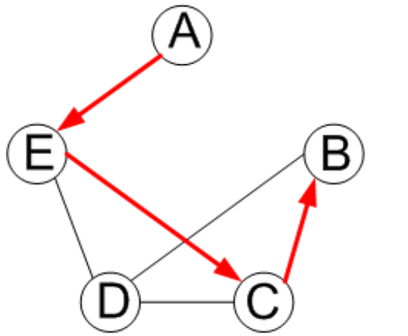


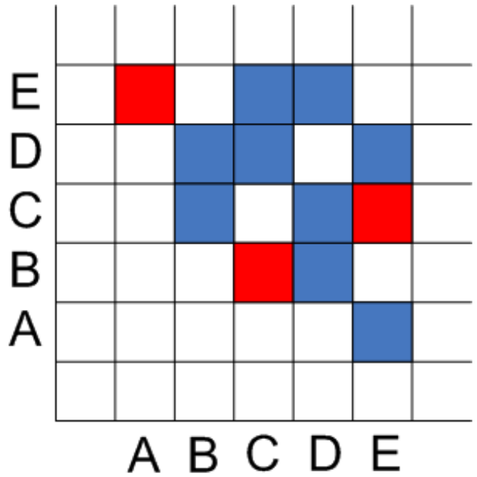
https://bost.ocks.org/mike/miserables/

Adjacency matrix



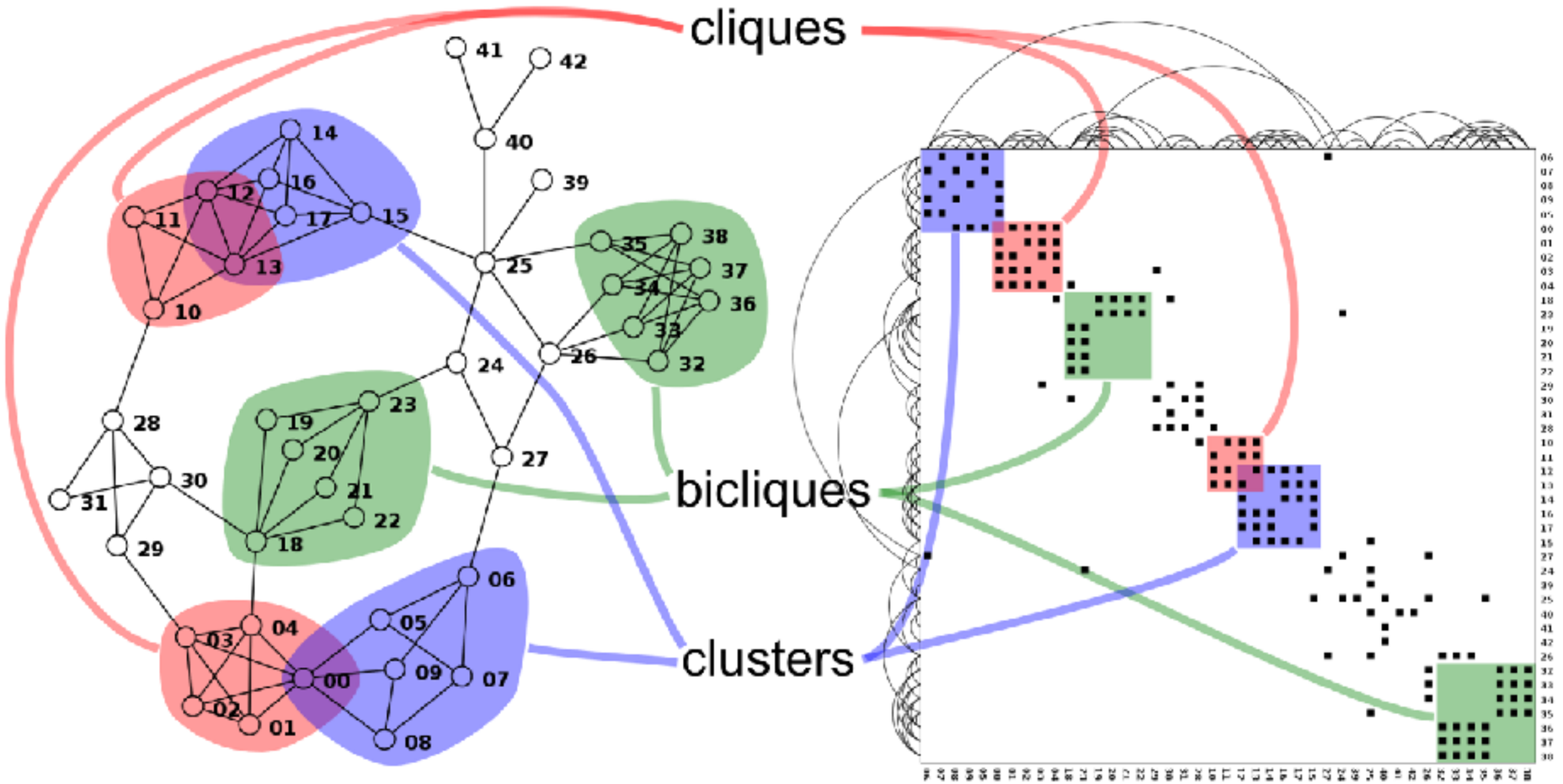
good for topology tasks
related to neighborhoods
(node 1-hop neighbors)





bad for topology tasks
related to paths

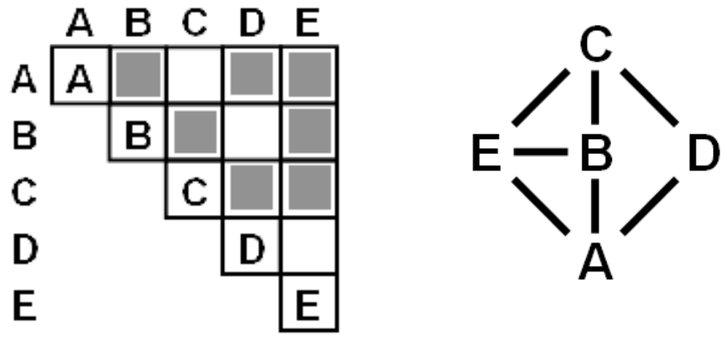
Structures visible in both



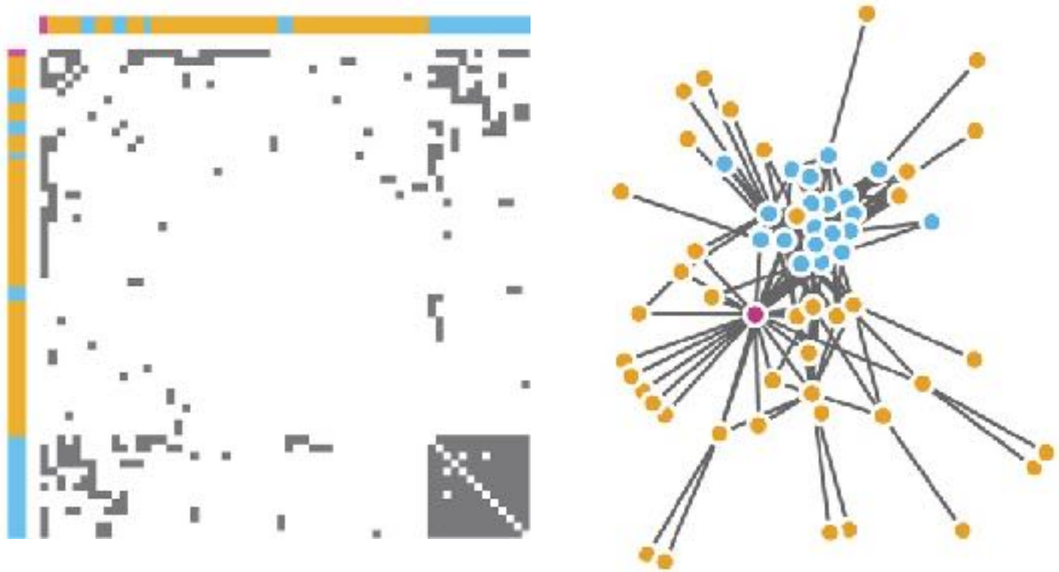
http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

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.]

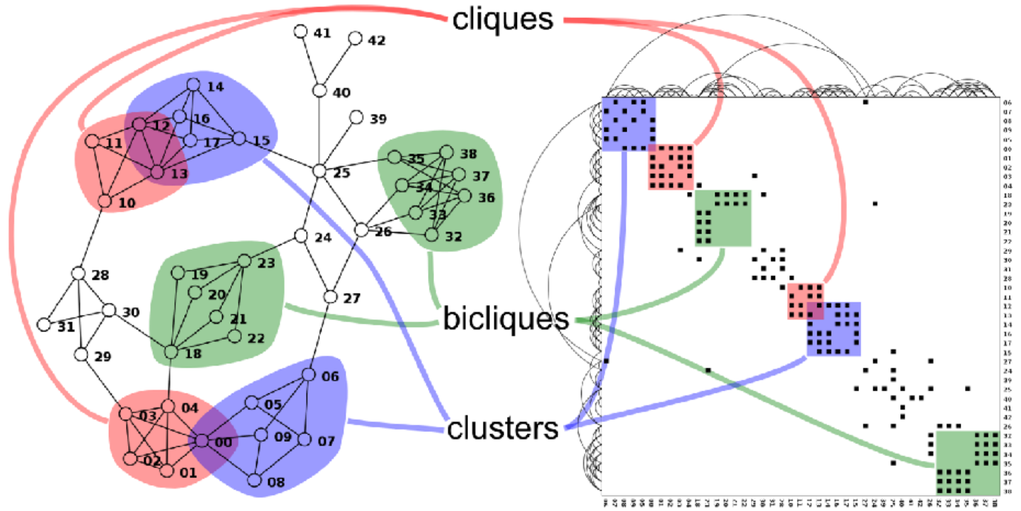


[Points of view: Networks. Gehlenborg and Wong. Nature Methods 9:115.]

Node-link vs. matrix comparison

- node-link diagram strengths
  - topology understanding, path tracing
  - intuitive, flexible, no training needed
- adjacency matrix strengths
  - focus on edges rather than nodes
  - layout straightforward (reordering needed)
  - predictability, scalability
  - some topology tasks trainable
- empirical study
  - node-link best for small networks
  - matrix best for large networks
    - if tasks don't involve path tracing!

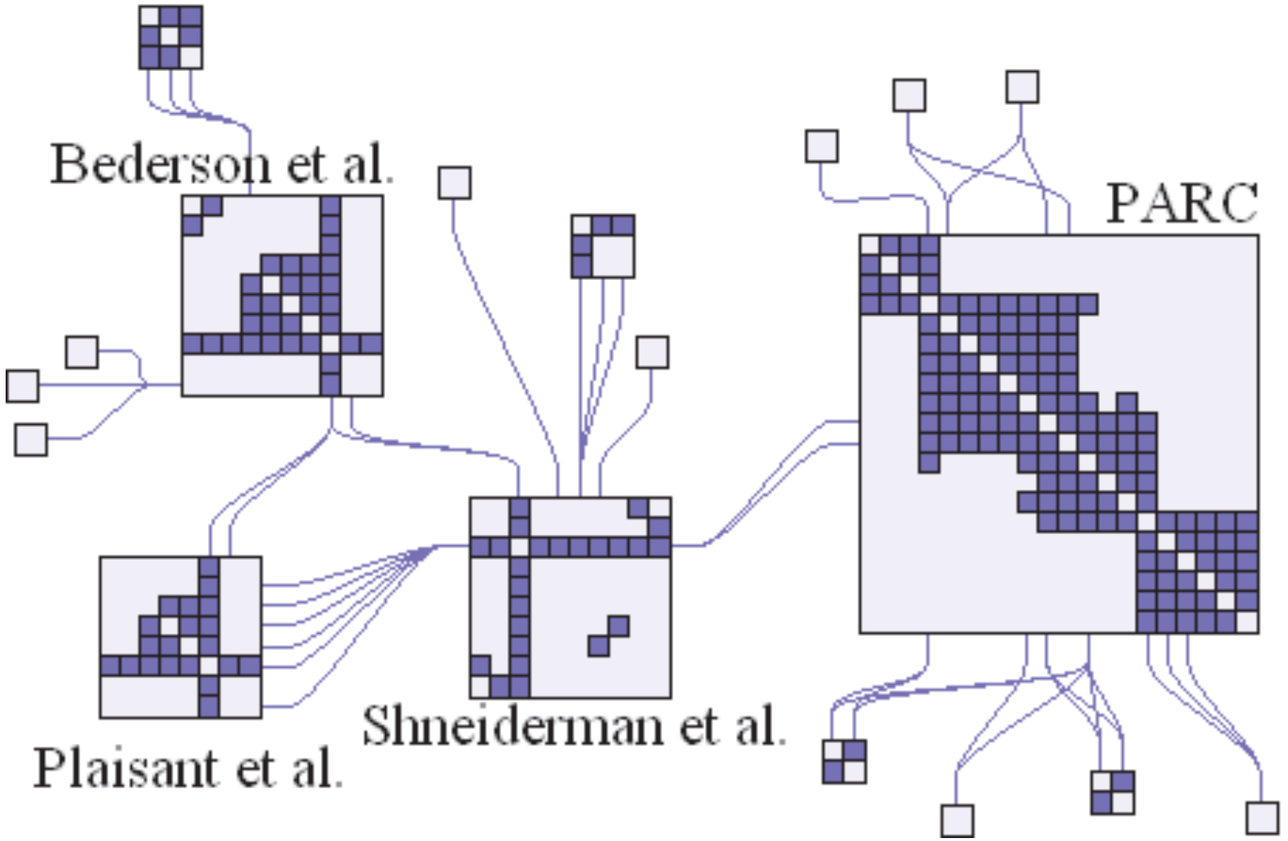
[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]



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

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.]

Trees

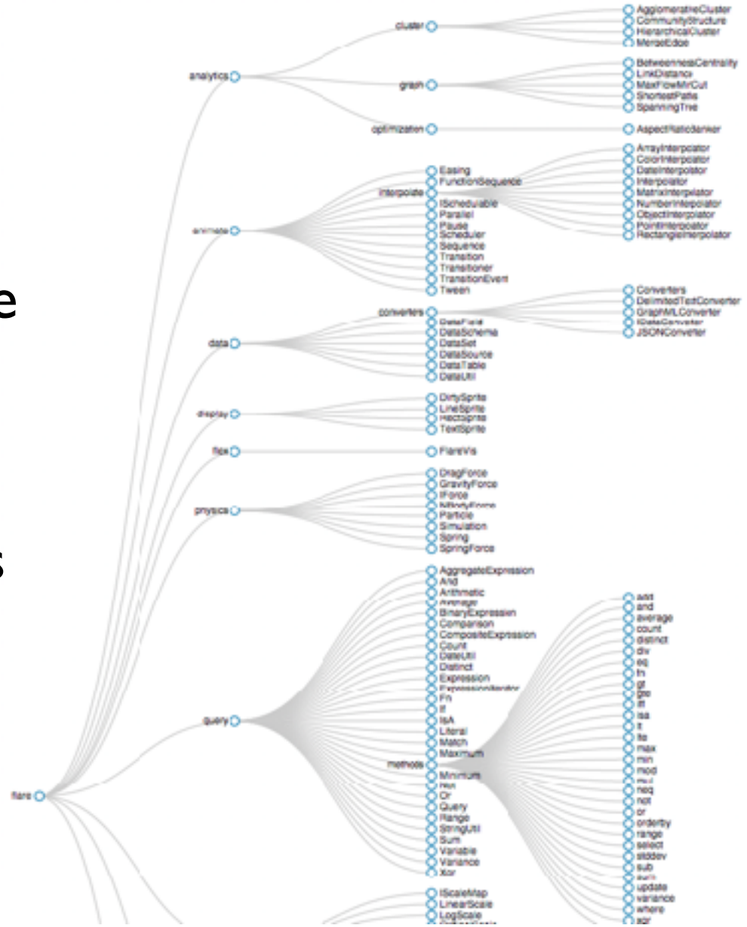
Node-link trees

- Reingold-Tilford
  - tidy drawings of trees
    - exploit parent/child structure
  - allocate space: compact but without overlap
    - rectilinear and radial variants

[Tidier drawing of trees. Reingold and Tilford. IEEE Trans. Software Eng., SE-7(2):223–228, 1981.]

  - nice algorithm writeup

http://billmill.org/pymag-trees/

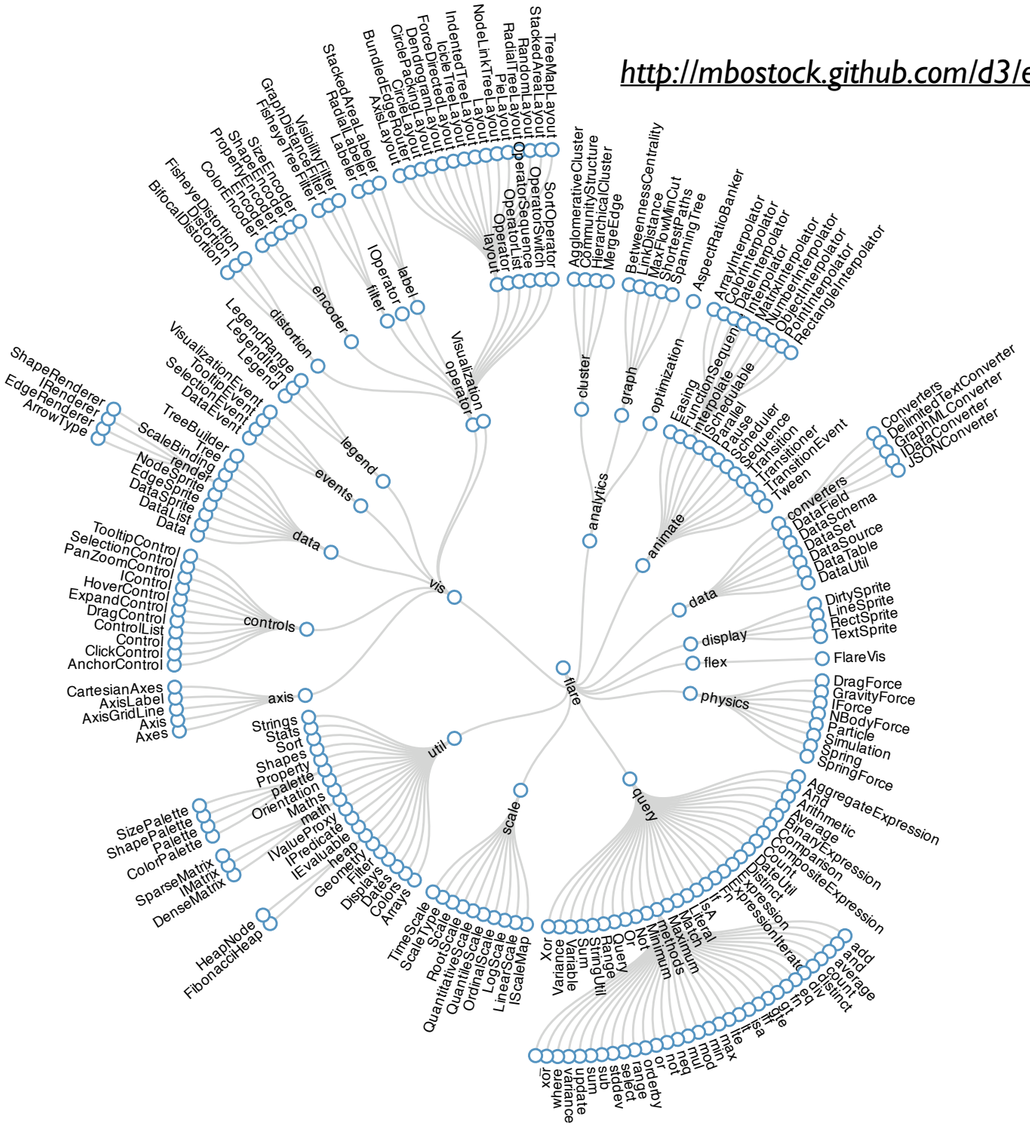


http://bl.ocks.org/mbostock/4339184

http://bl.ocks.org/mbostock/4063550

Idiom: **radial node-link tree**

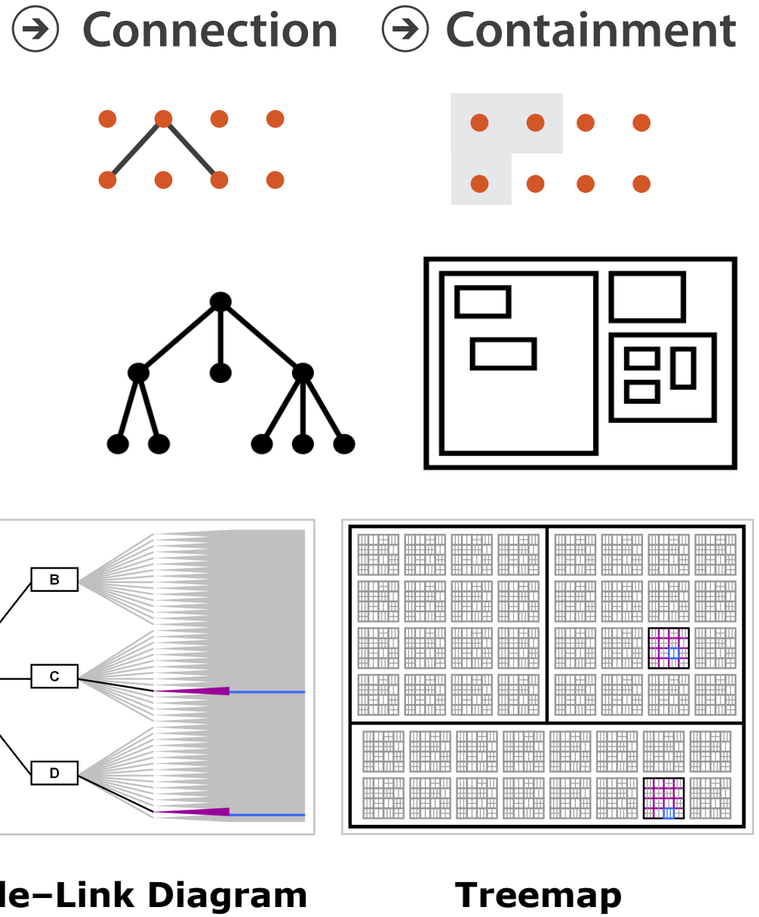
- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes (with/without labels)



http://mbostock.github.com/d3/ex/tree.html

Link marks: Connection and containment

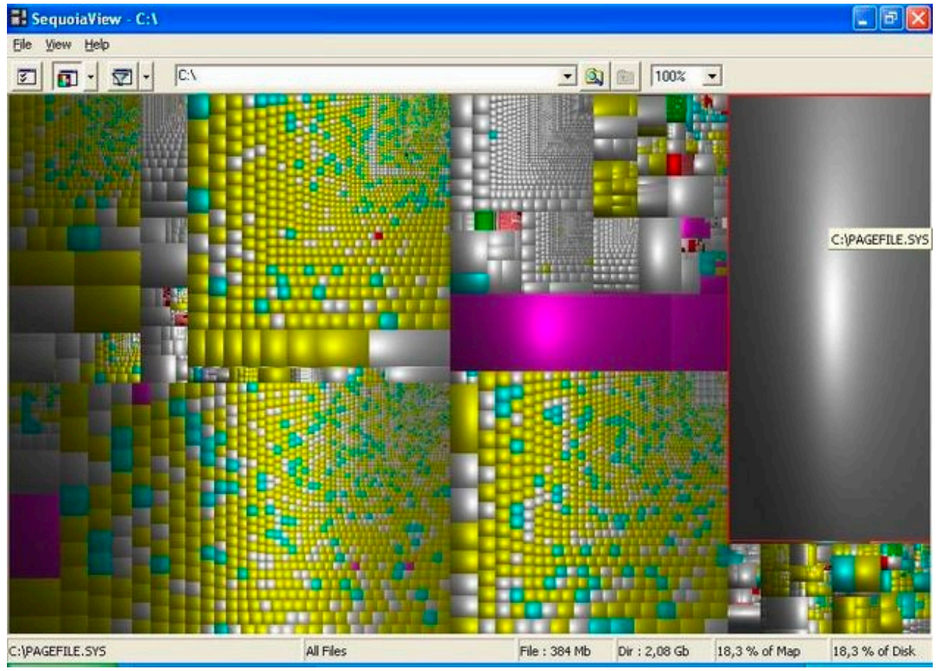
- marks as links (vs. nodes)
  - common case in network drawing
  - 1D case: connection
    - ex: all node-link diagrams
    - emphasizes topology, path tracing
    - networks and trees
  - 2D case: containment
    - ex: all treemap variants
    - emphasizes attribute values at leaves (size coding)
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



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

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
  - ex: disk space usage within filesystem
- scalability
  - 1M leaf nodes



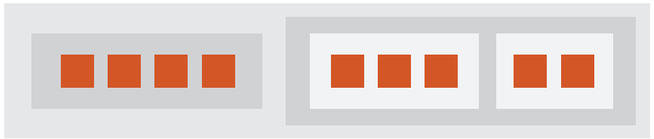
https://www.win.tue.nl/sequoiaview/

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

Enclosure

Containment Marks

✕ NETWORKS ✓ TREES

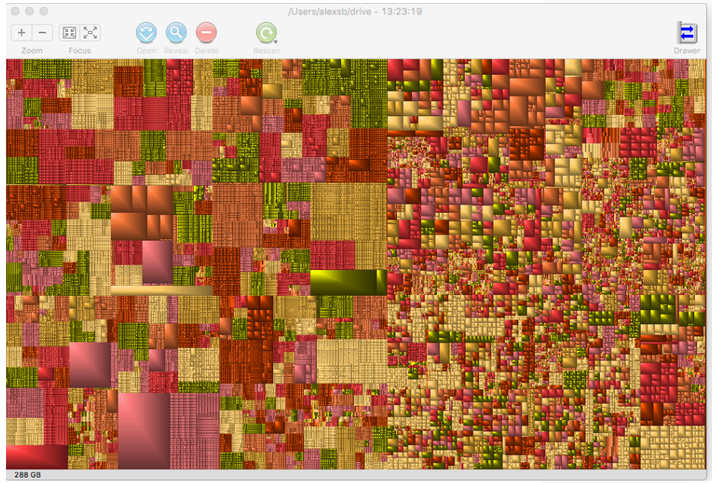


Idiom: implicit tree layouts (sunburst, icicle plot)

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

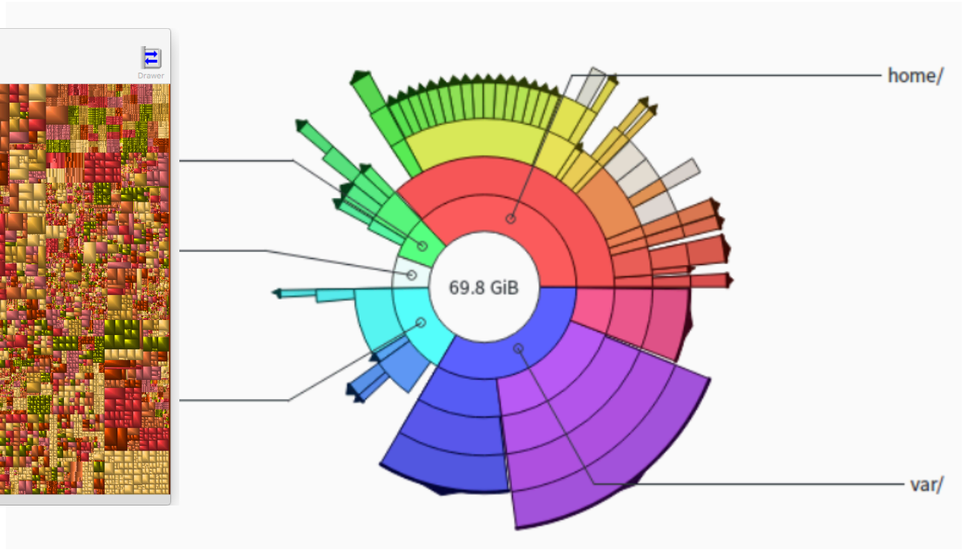
Treemap

containment



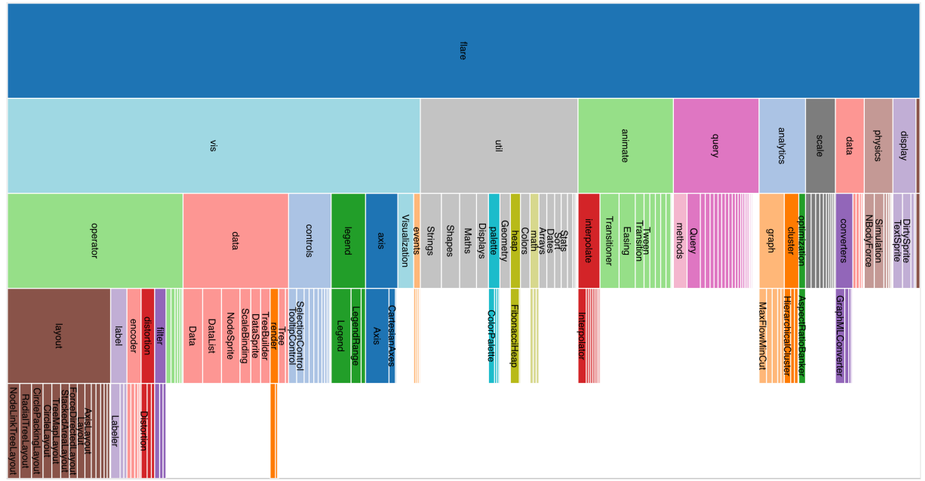
Sunburst

position (radial)



Icicle Plot

position (rectilinear)



Idiom: implicit tree layouts (sunburst, icicle plot)

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

Treemap

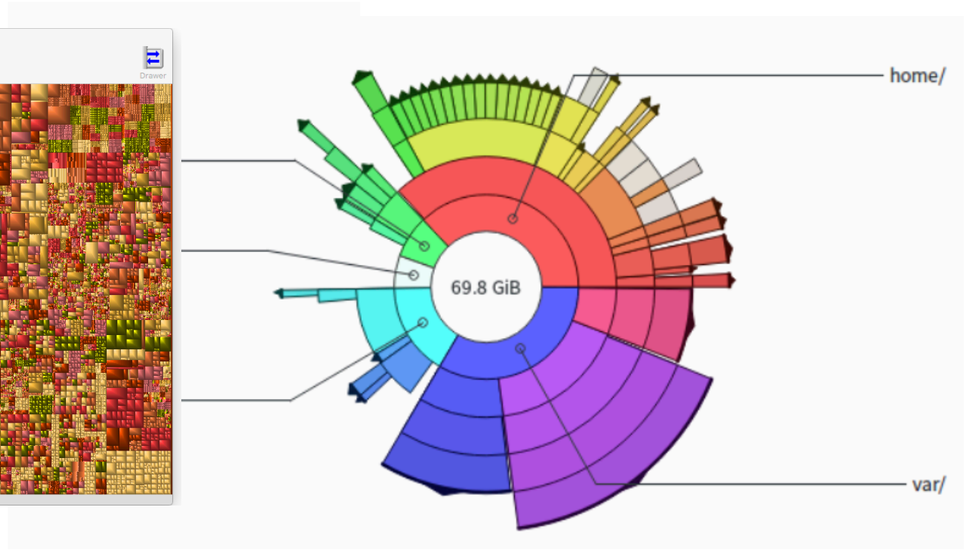
containment

only leaves visible

Sunburst

position (radial)

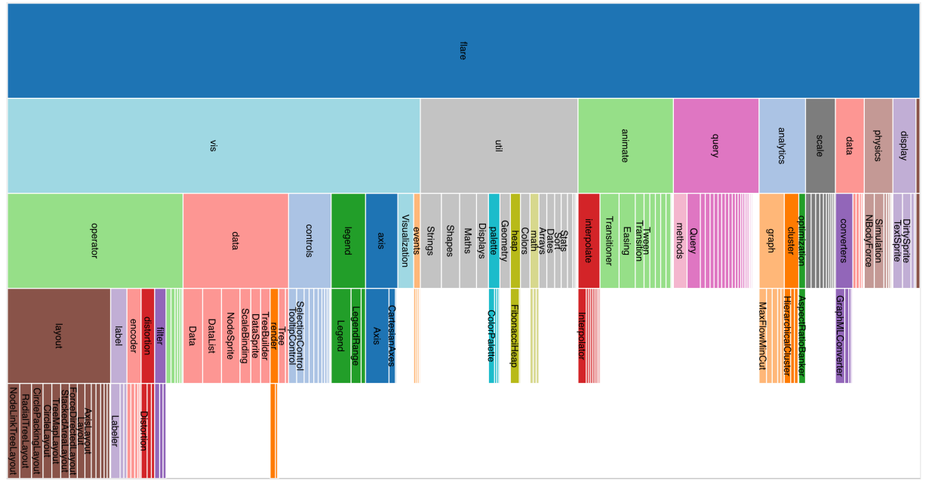
inner nodes & leaves visible



Icicle Plot

position (rectilinear)

inner nodes & leaves visible



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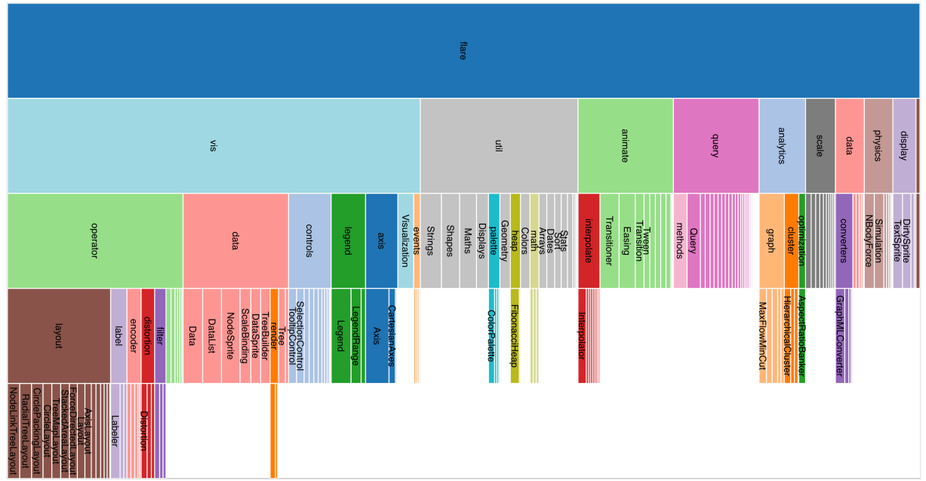
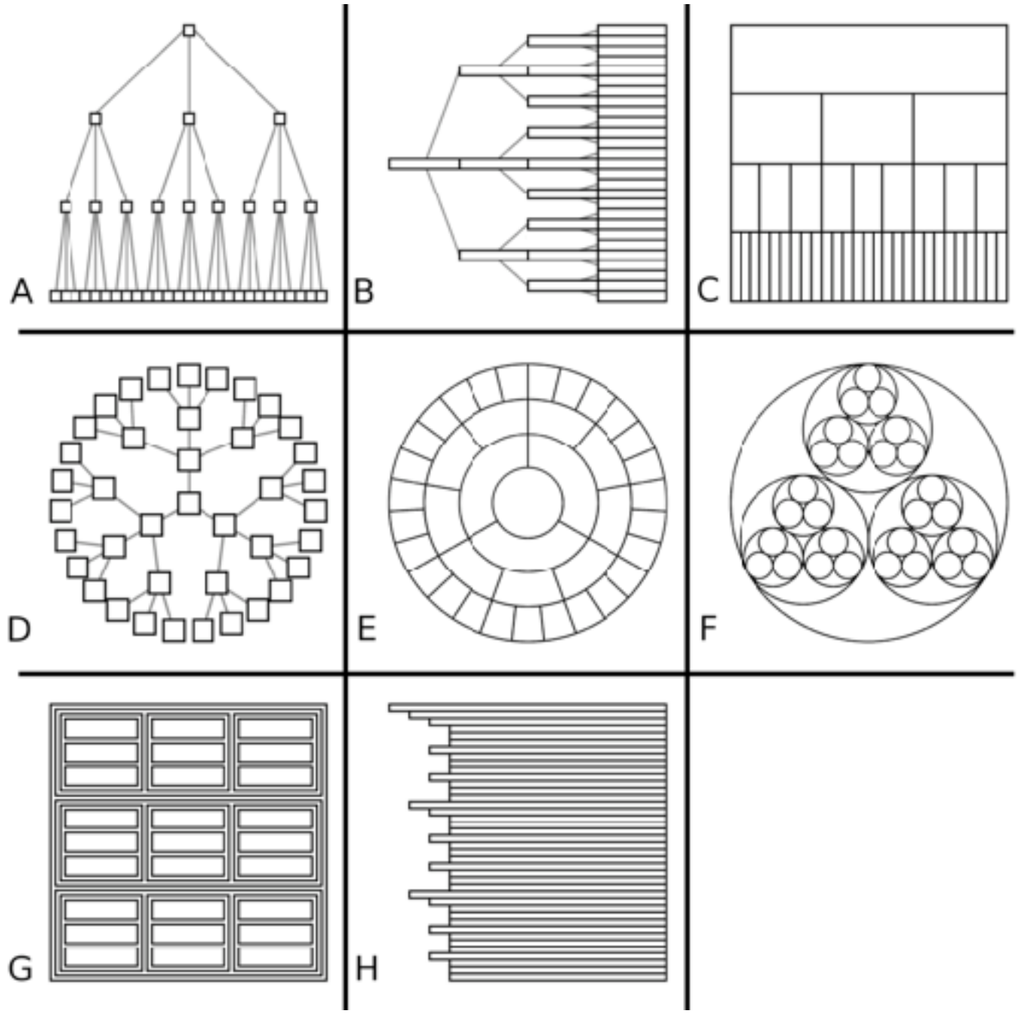


Implicit

Spatial Position

✕ NETWORKS ✓ TREES

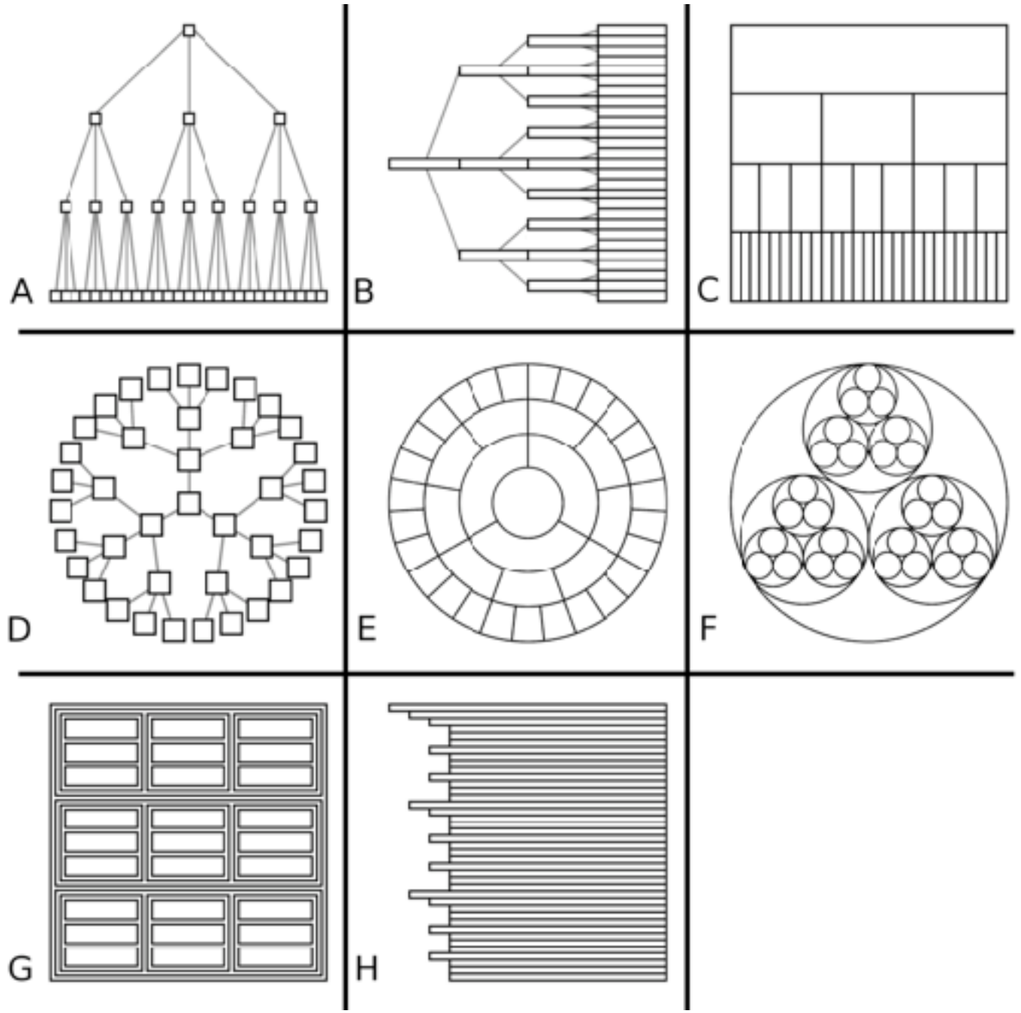
Tree drawing idioms comparison



[Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. McGuffin and Robert. Information Visualization 9:2 (2010), 115–140.]

Comparison: tree drawing idioms

- data shown
  - link relationships
  - tree depth
  - sibling order



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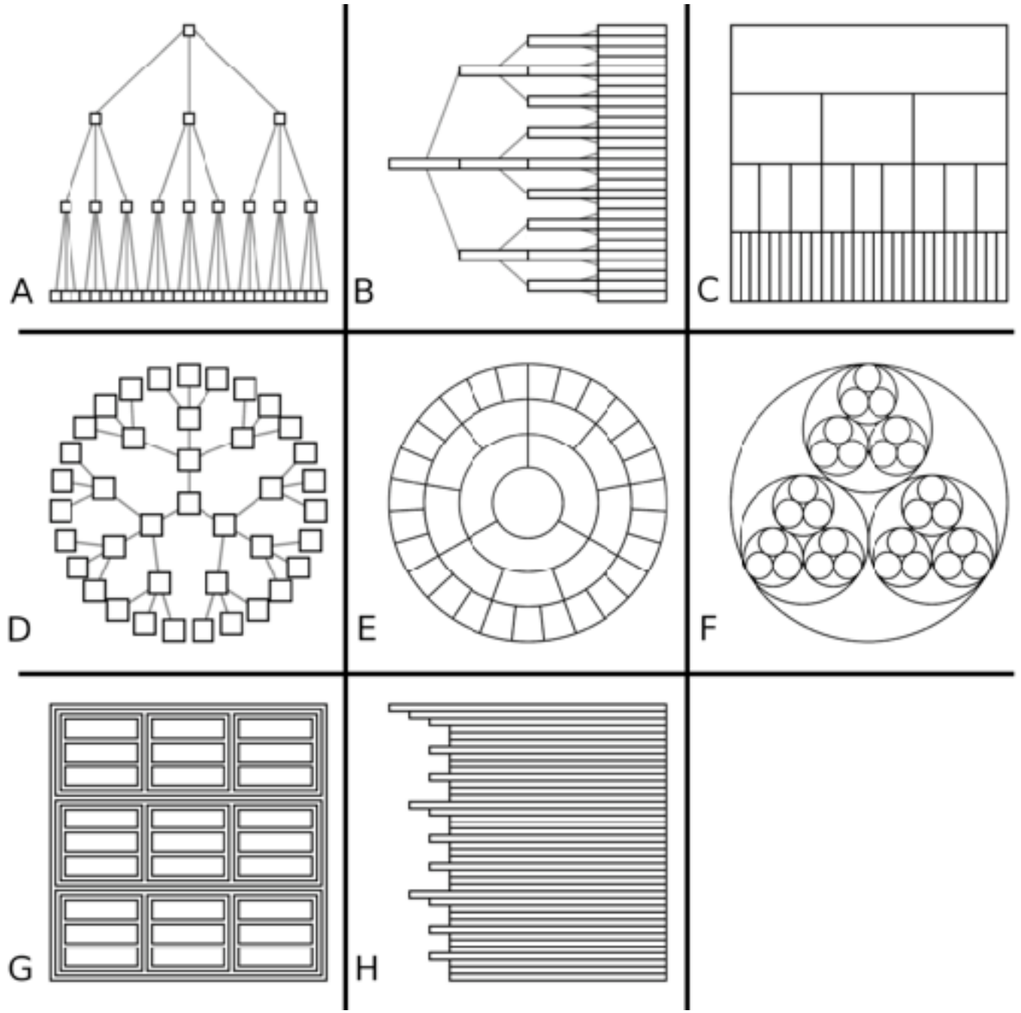
  - connection vs containment link marks
  - rectilinear vs radial layout
  - spatial position channels



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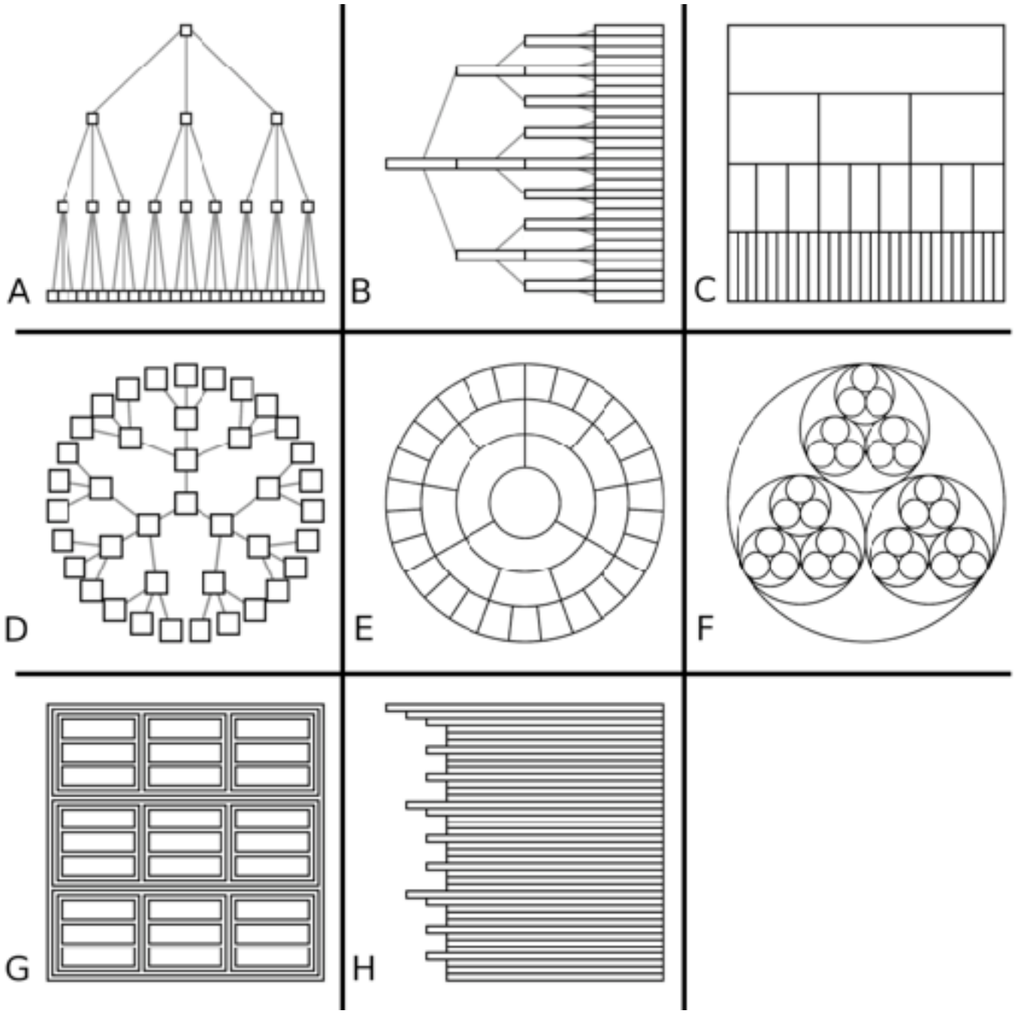
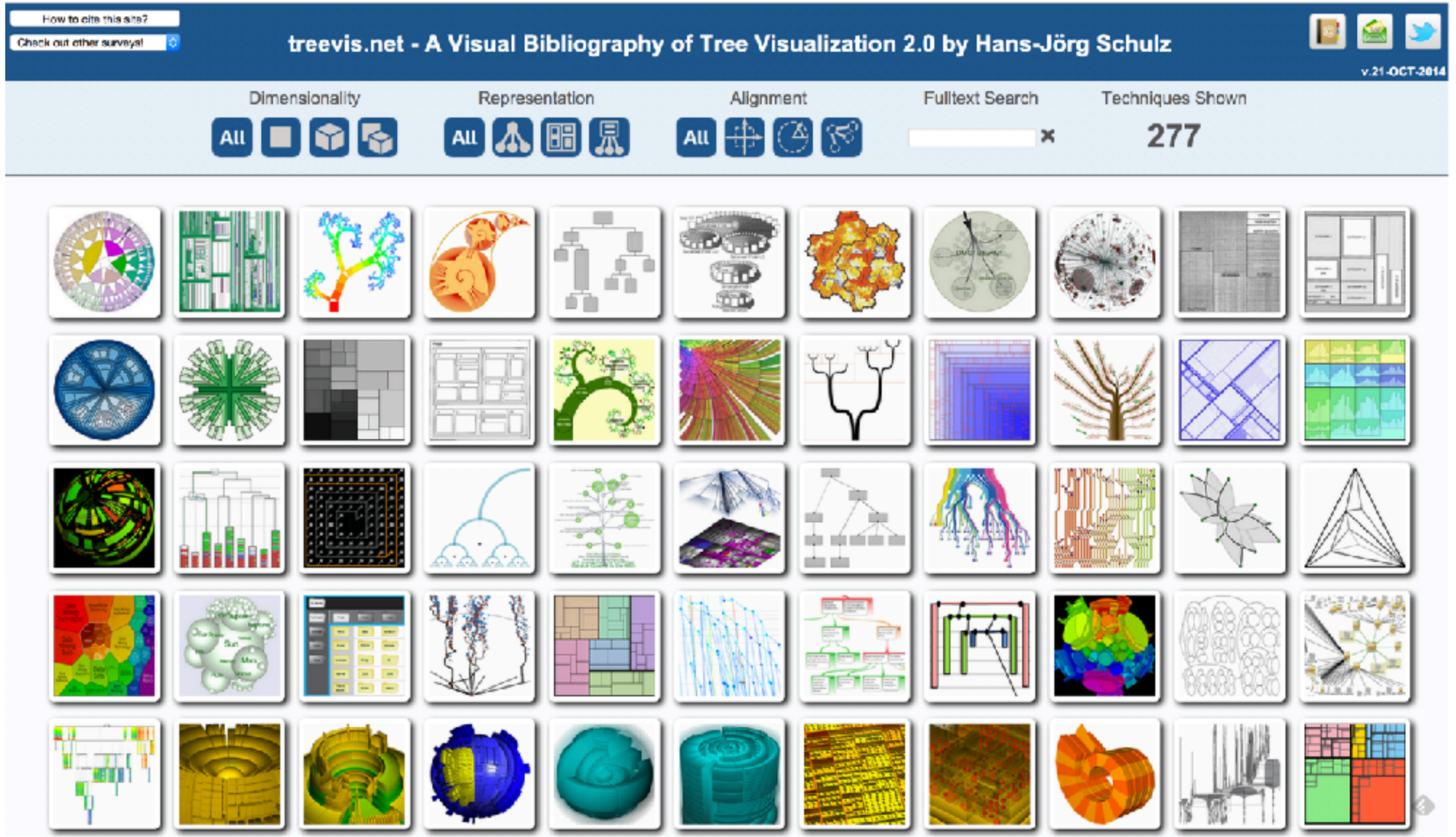
Comparison: tree drawing idioms

- data shown
  - link relationships
  - tree depth
  - sibling order
- design choices
  - connection vs containment link marks
  - rectilinear vs radial layout
  - spatial position channels
- considerations
  - redundant? arbitrary?
  - information density?
    - avoid wasting space
    - consider where to fit labels!



[Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. McGuffin and Robert. Information Visualization 9:2 (2010), 115–140.]

treevis.net: Many, many options!



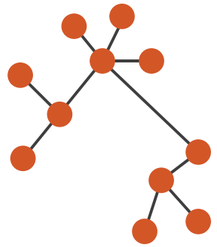
https://treevis.net/

Arrange networks and trees

Node–Link Diagrams

Connection Marks

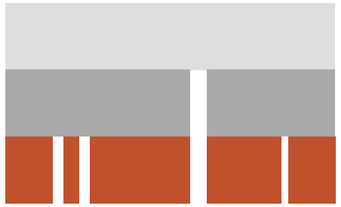
✔ NETWORKS ✔ TREES



Implicit

Spatial Position

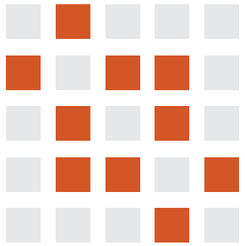
✘ NETWORKS ✔ TREES



Adjacency Matrix

Derived Table

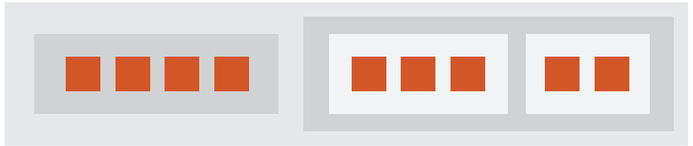
✔ NETWORKS ✔ TREES



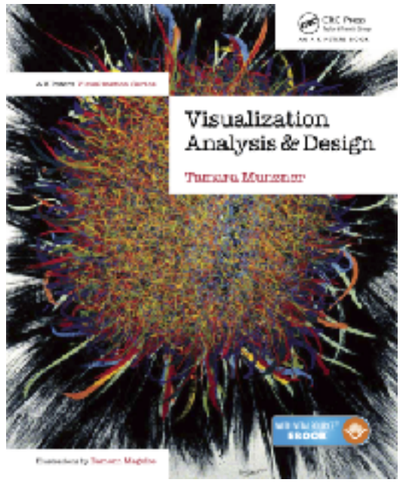
Enclosure

Containment Marks

✘ NETWORKS ✔ TREES



Visualization Analysis & Design

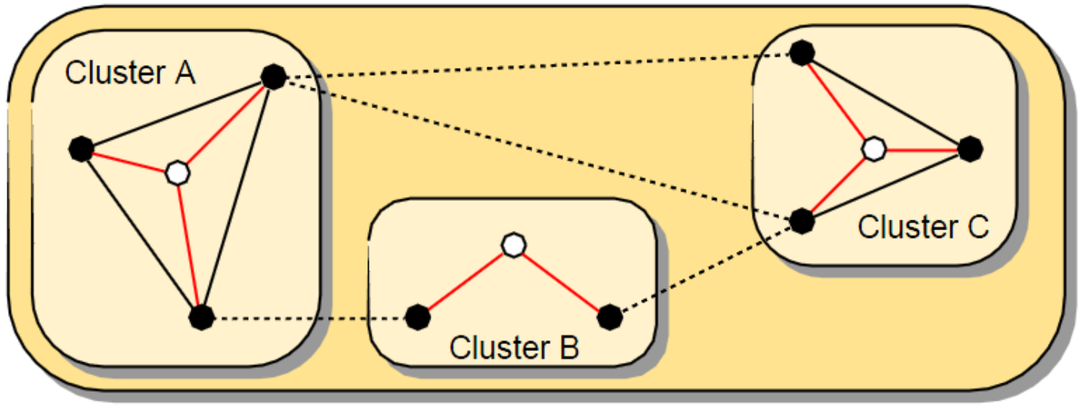


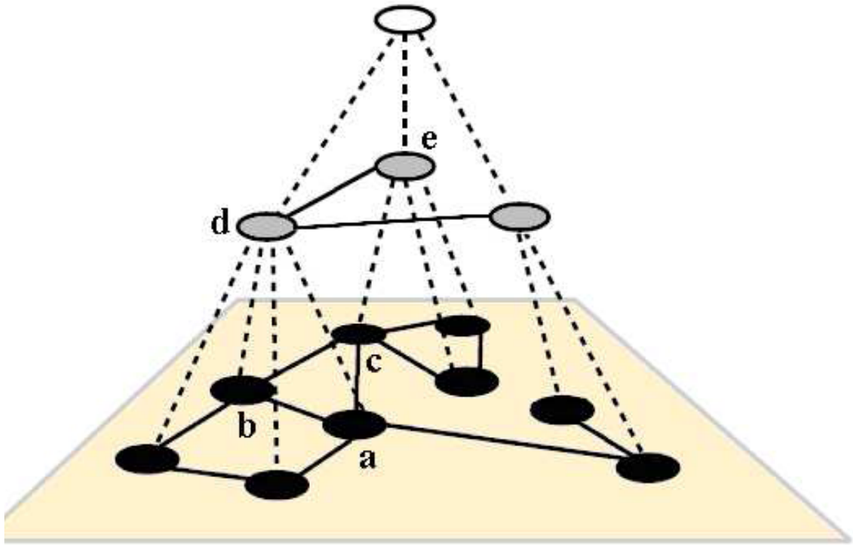
Network Data (Ch 9) II

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

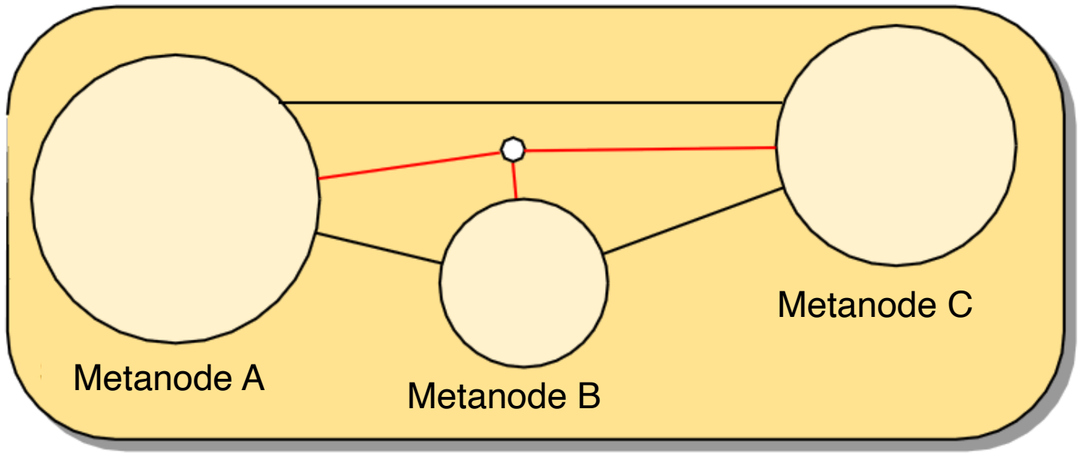
Multilevel networks

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





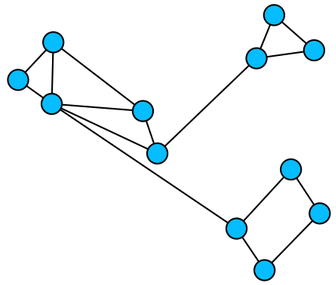
real vertex
virtual vertex
internal spring
virtual spring
external spring

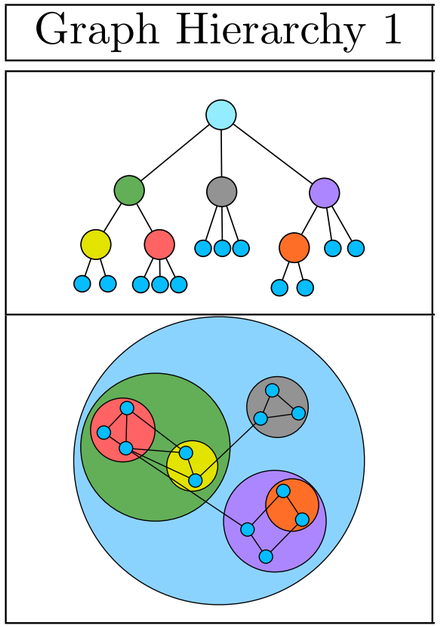


[Schulz 2004]

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

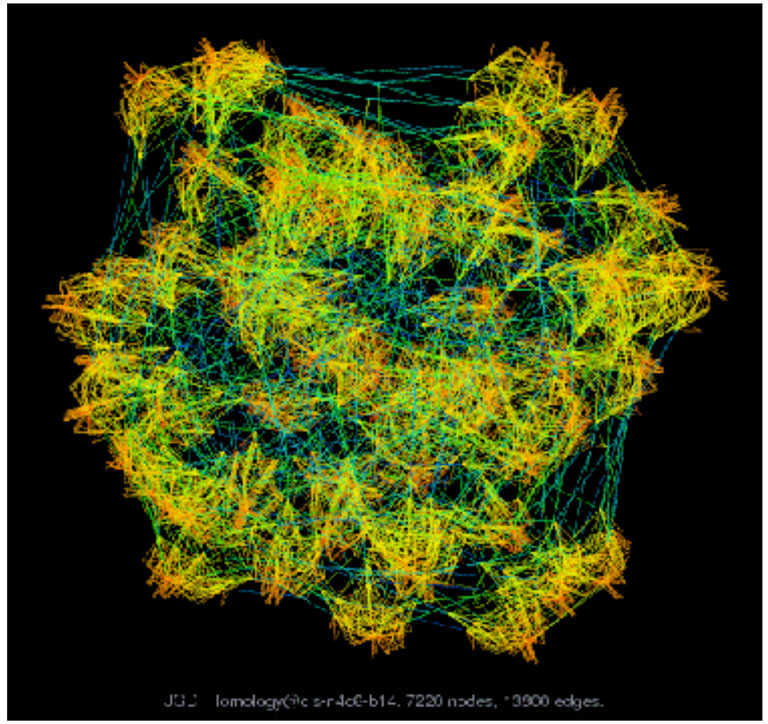




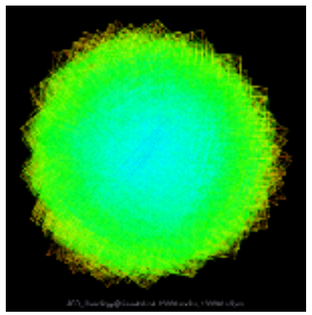
[GrouseFlocks: Steerable Exploration of Graph Hierarchy Space. Archambault, Munzner, and Auber. IEEE TVCG 14(4):900-913, 2008.]

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

- data: compound graph
  - 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



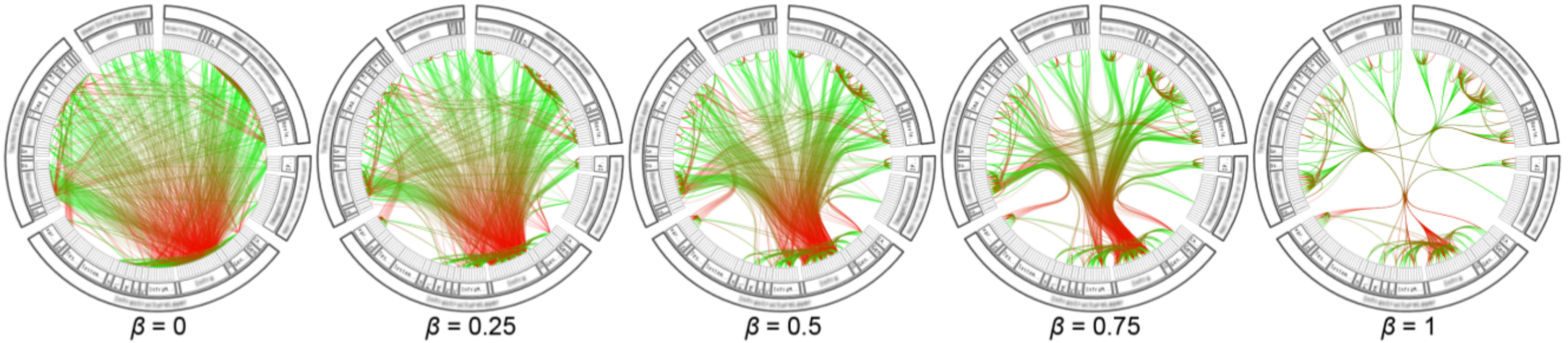
[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]



http://www.research.att.com/yifanhu/GALLERY/GRAPHS/index1.html

Idiom: **hierarchical edge bundling**

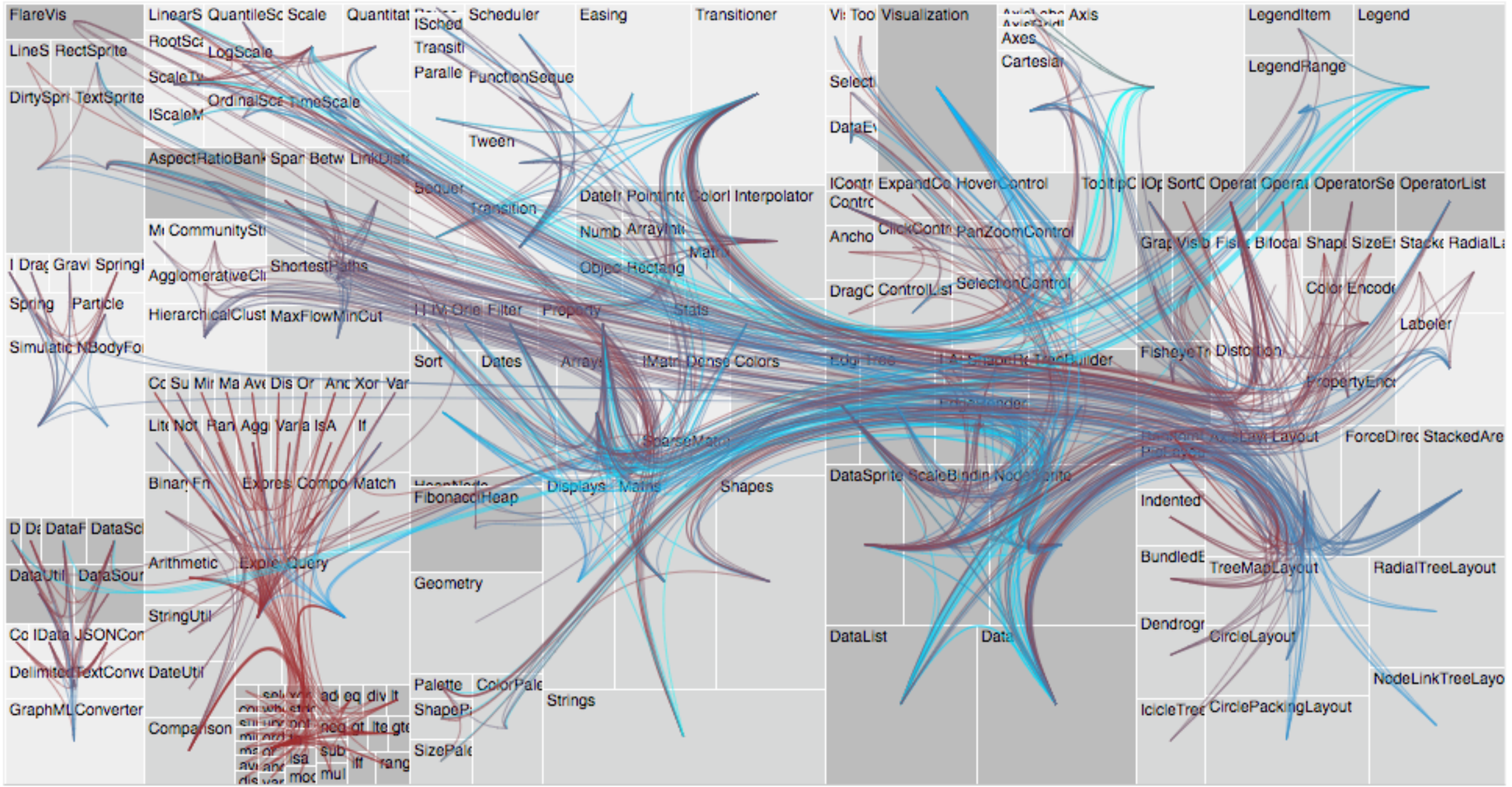
- data
  - any layout of compound network
    - network: software classes (nodes), import/export between classes (links)
    - cluster hierarchy: class package structure
  - derived: bundles of edges with same source/destination (multi-level)
- idiom: curve edge routes according to bundles
- task: edge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

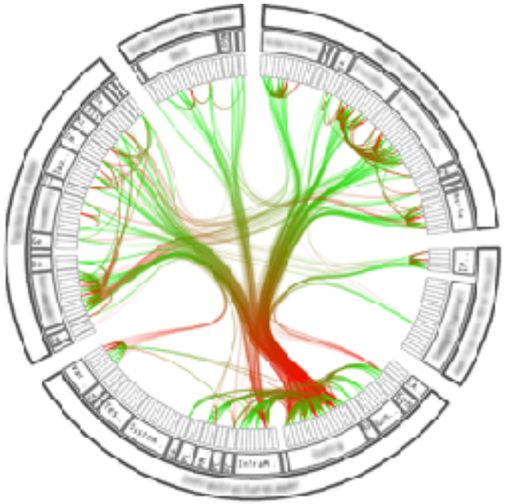


[Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data. Danny Holten. TVCG 12(5):741-748 2006]

Hierarchical edge bundling

- works for any layout: treemap vs radial





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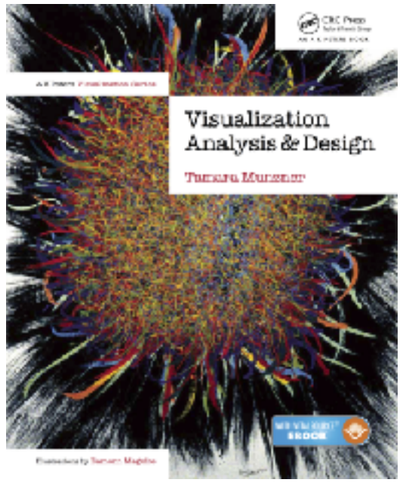

Spatial Data (Ch 9)

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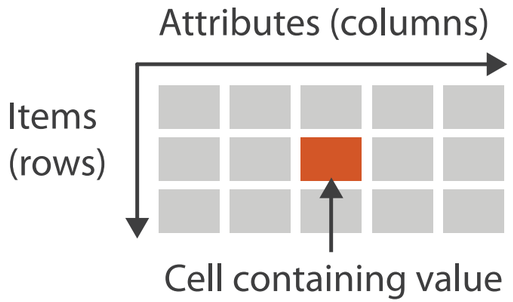
University of British Columbia
@tamaramunzner

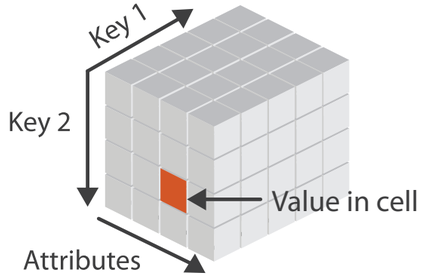
Focus on Spatial

Dataset Types

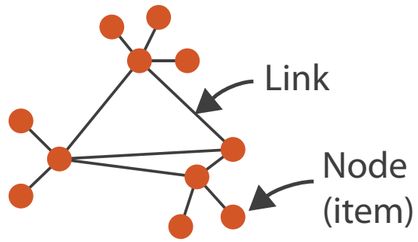
Tables



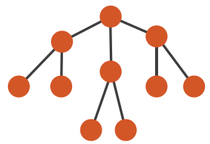
Multidimensional Table



Networks

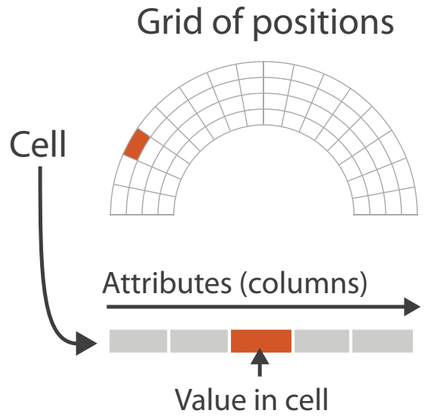


Trees

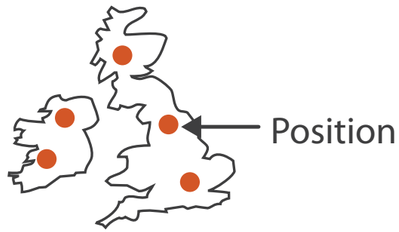


Spatial

Fields (Continuous)



Geometry (Spatial)



How?

Encode

Arrange

- Express
- Separate
- Order
- Align
- Use

Map

from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*
- Size, Angle, Curvature, ...
- Shape
- Motion

Direction, Rate, Frequency, ...

Manipulate

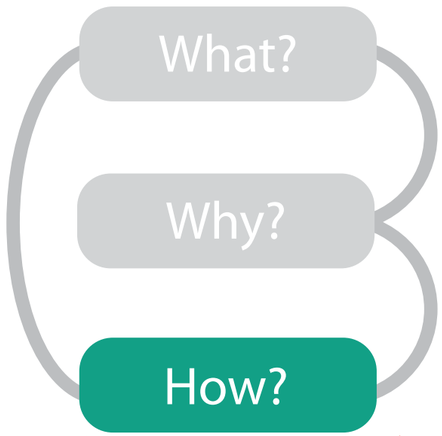
- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed



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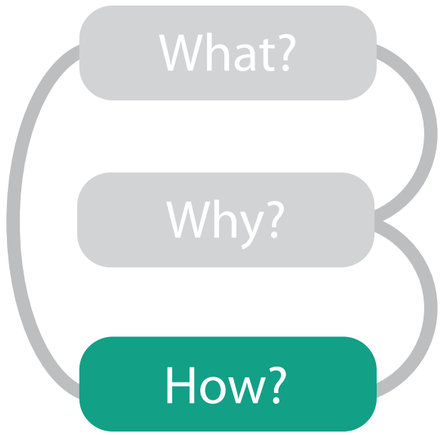

Manipulate

Change

Select

Navigate

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Juxtapose

Partition

Superimpose

Reduce

Filter

Aggregate

Embed

Spatial data

- use given spatial position
- when?
  - dataset contains spatial attributes and they have primary importance
  - central tasks revolve around understanding spatial relationships

- examples
  - geographical/cartographic data
  - sensor/simulation data

Geographic Maps

Geographic Map

Interlocking marks

- **shape** coded
- **area** coded
- **position** coded

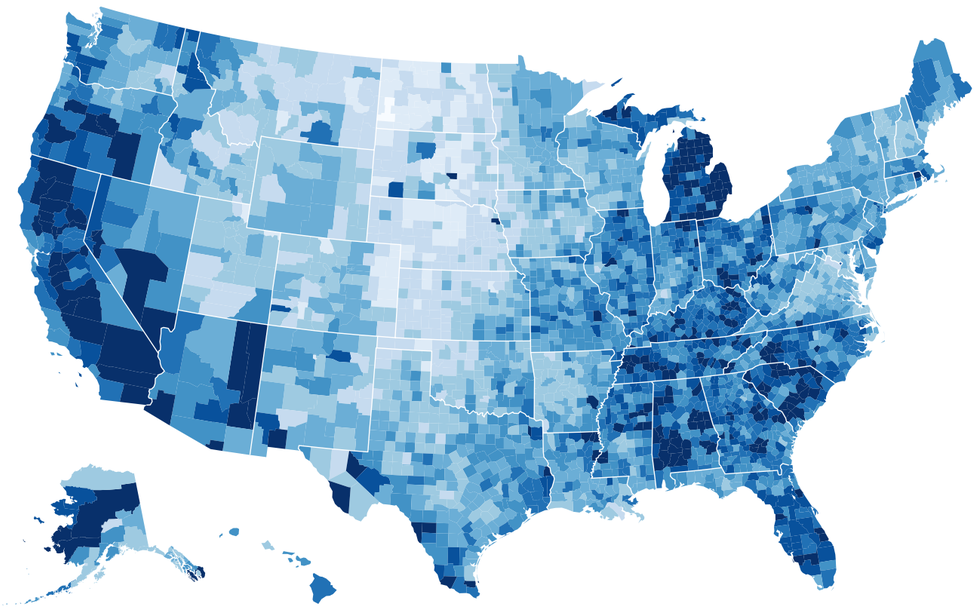
- cannot encode another attribute with these channels, they're "taken"

Thematic maps

- show spatial variability of attribute ("theme")
  - combine geographic / reference map with (simple, flat) tabular data
  - join together
    - region: interlocking area marks (provinces, countries with outline shapes)
      - also could have point marks (cities, locations with 2D lat/lon coords)
    - region: categorical key attribute in table
      - use to look up value attributes
- major idioms
  - choropleth
  - symbol maps
  - cartograms
  - dot density maps

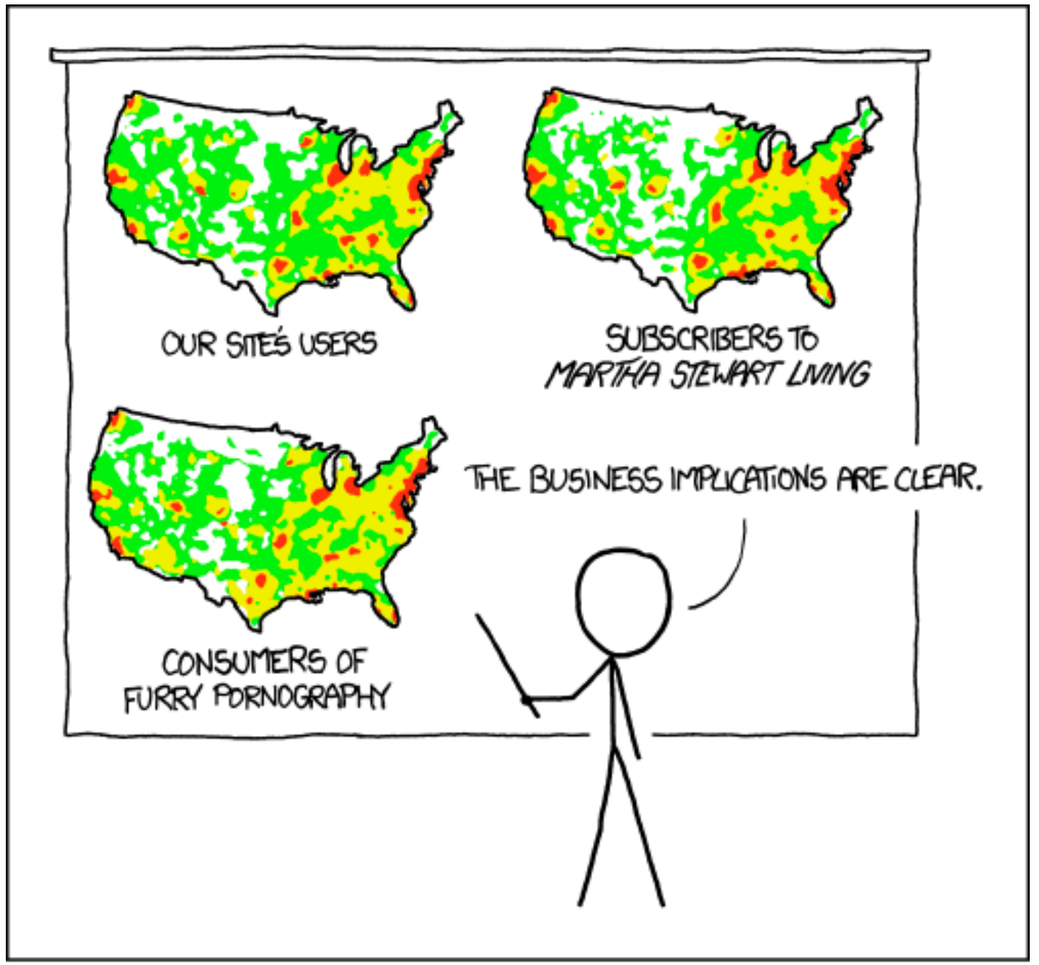
Idiom: **choropleth map**

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



http://bl.ocks.org/mbostock/4060606

Beware: Population maps trickiness!

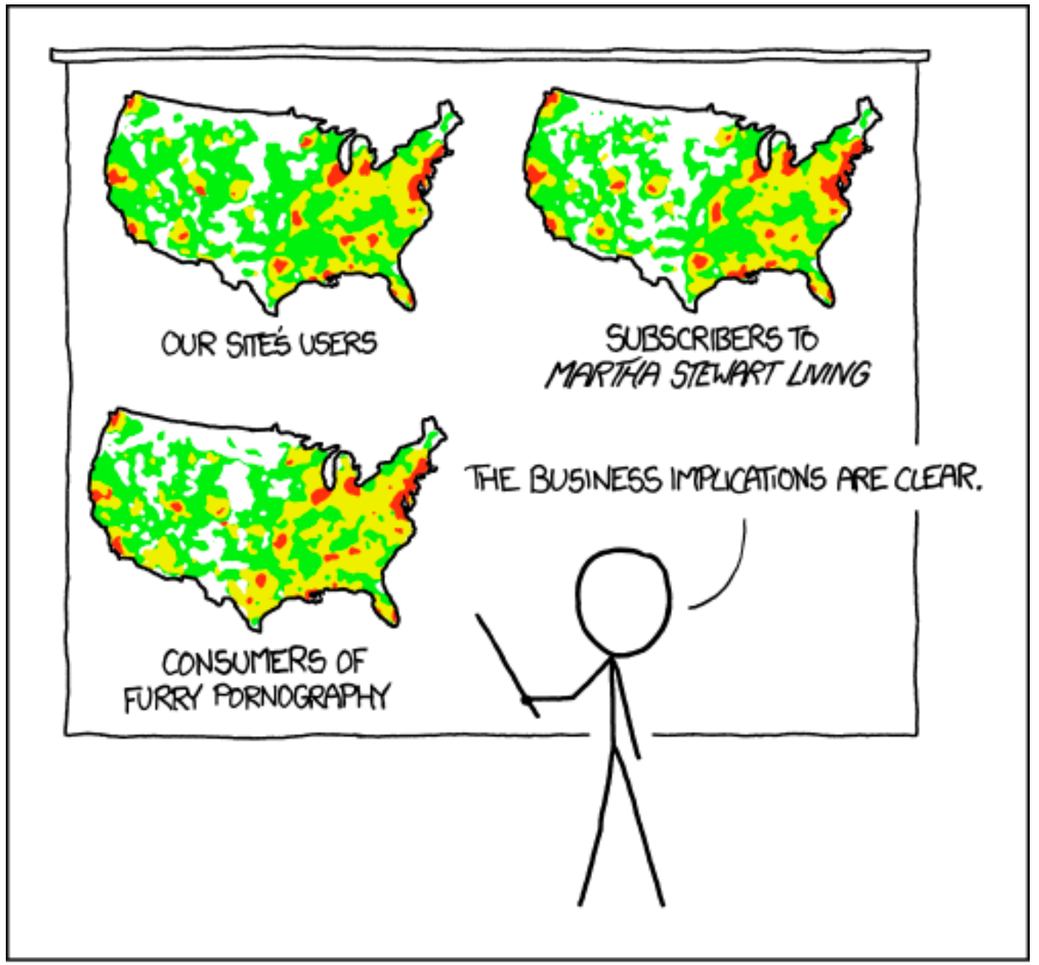


PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

[https://xkcd.com/1138]

Beware: Population maps trickiness!

- spurious correlations: most attributes just show where people live



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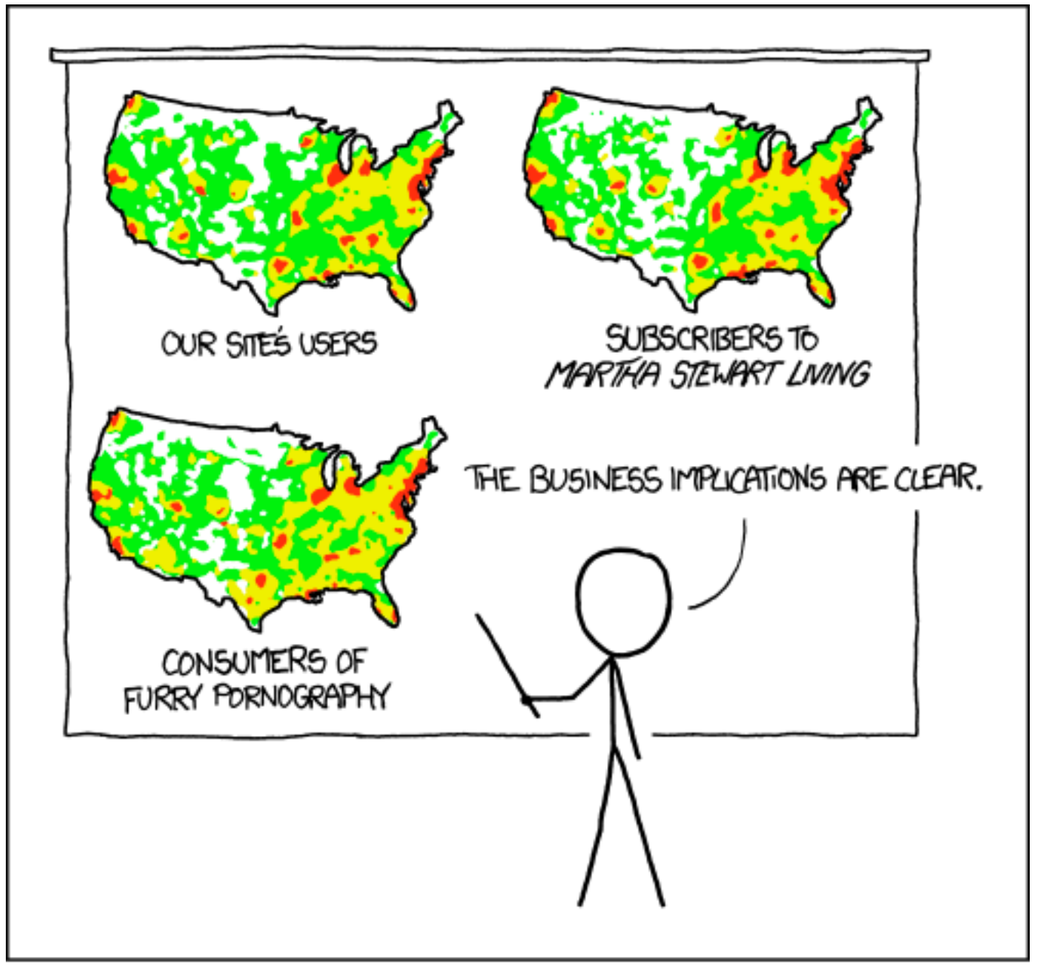
Beware: Population maps trickiness!

- 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
    - unemployed people per 100 citizens, mean family income



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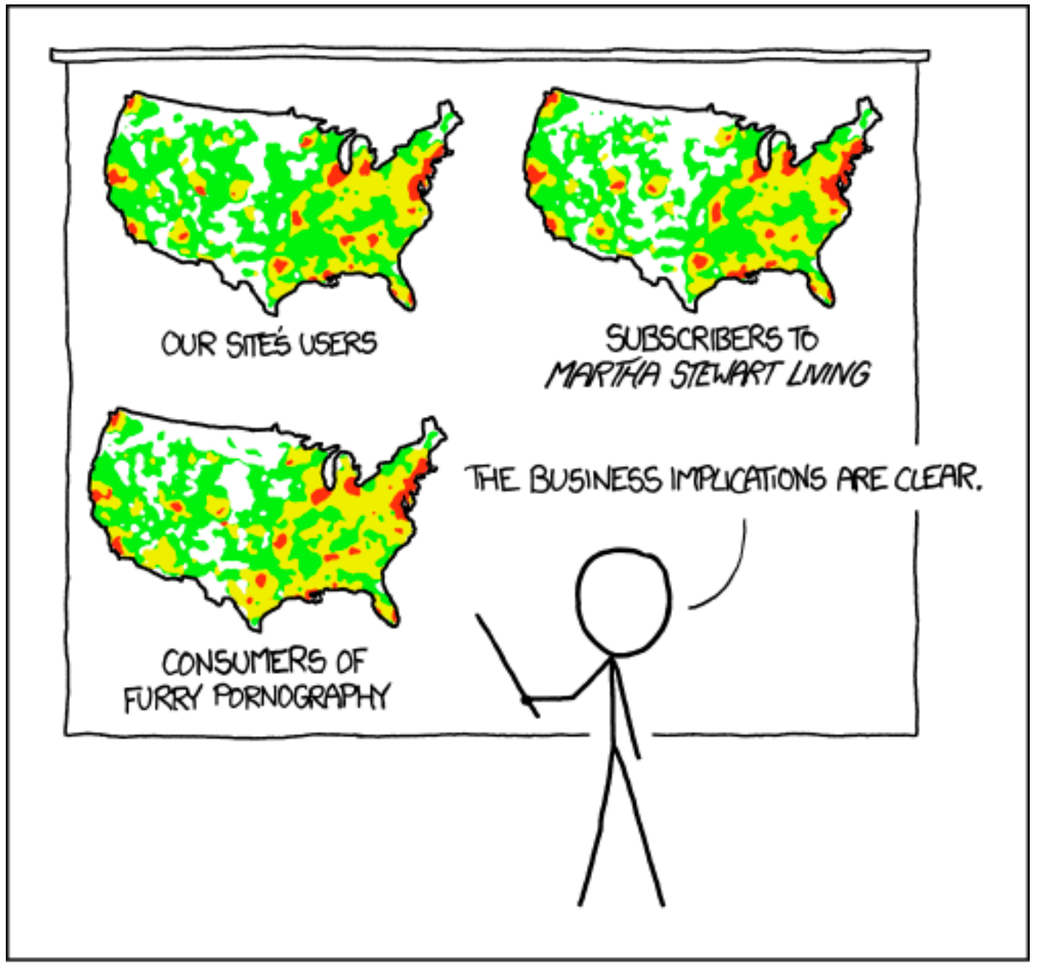
Beware: Population maps trickiness!

- 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
    - unemployed people per 100 citizens, mean family income
- general issue
  - absolute counts vs relative/normalized data
  - failure to normalize is common error



[https://xkcd.com/1138]

Choropleth maps: Recommendations

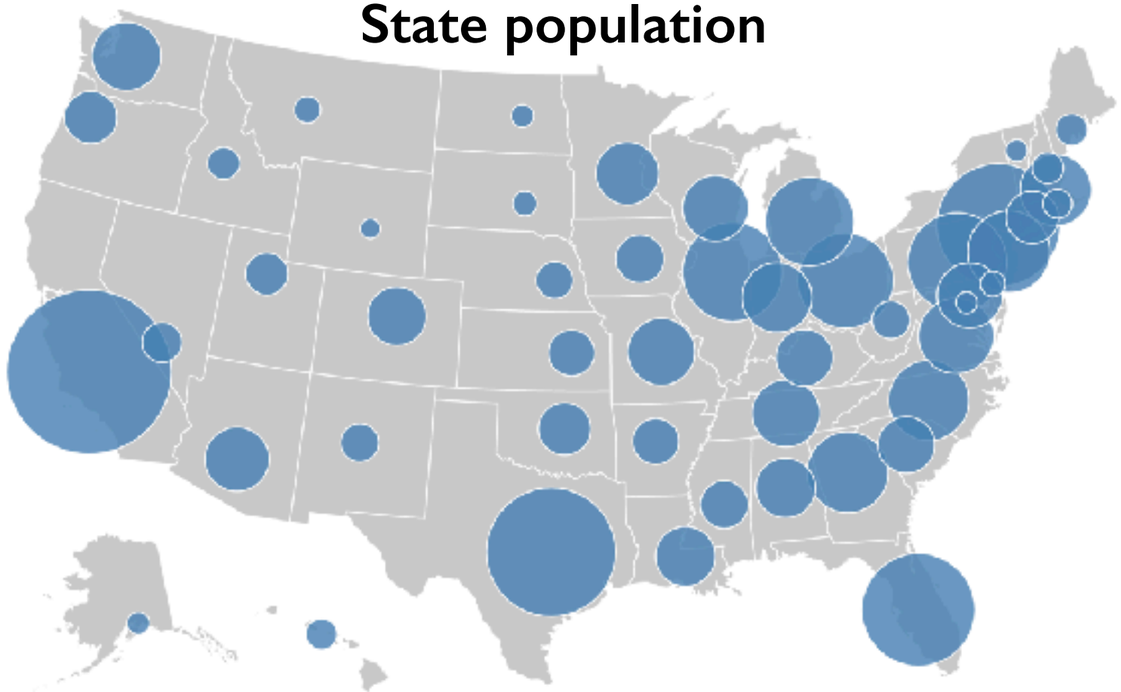
- only use when central task is understanding spatial relationships
- show only one variable at a time
- normalize when appropriate
- be careful when choosing colors & bins
- best case: regions are roughly equal sized

Choropleth map: Pros & cons

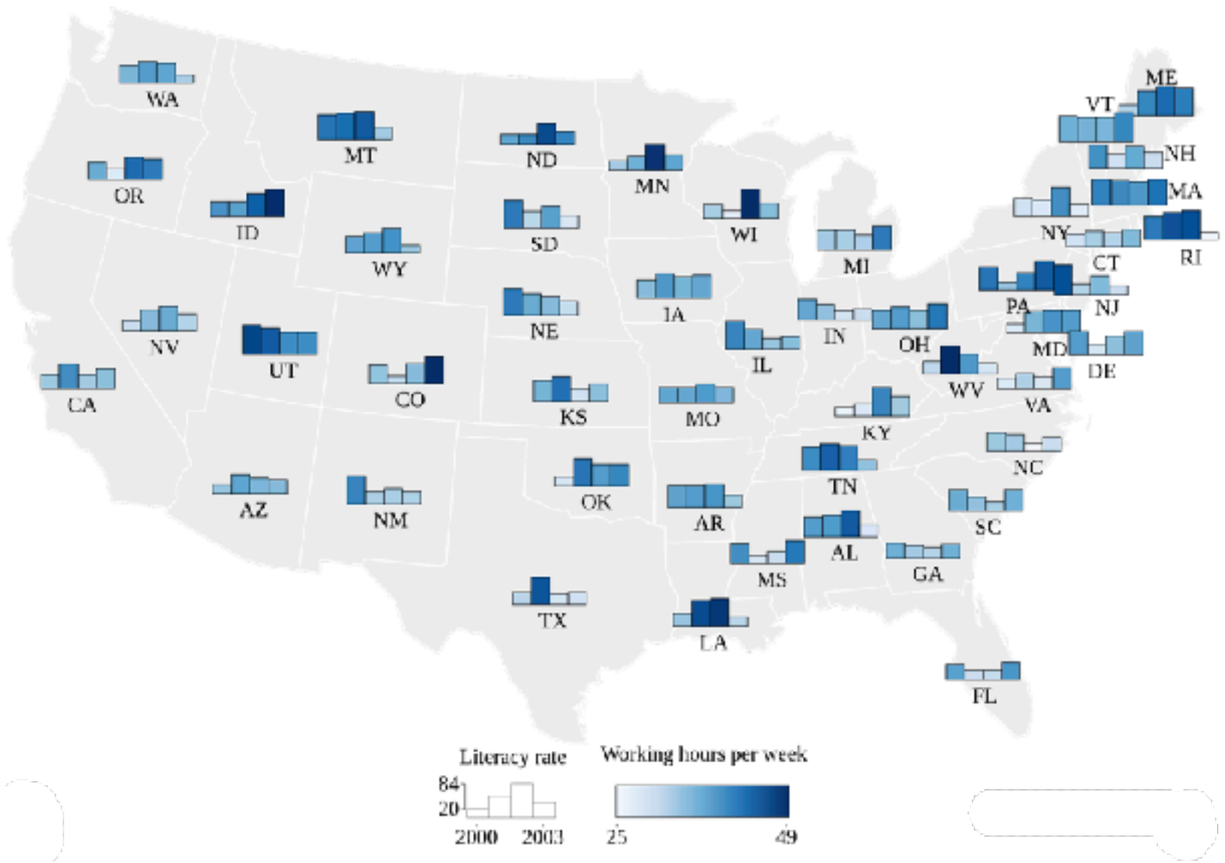
- pros
  - easy to read and understand
  - well established visualization (no learning curve)
  - data is often collected and aggregated by geographical regions
- cons
  - most effective visual variable used for geographic location
  - visual salience depends on region size, not true importance wrt attribute value
    - large regions appear more important than small ones
  - color palette choice has a huge influence on the result

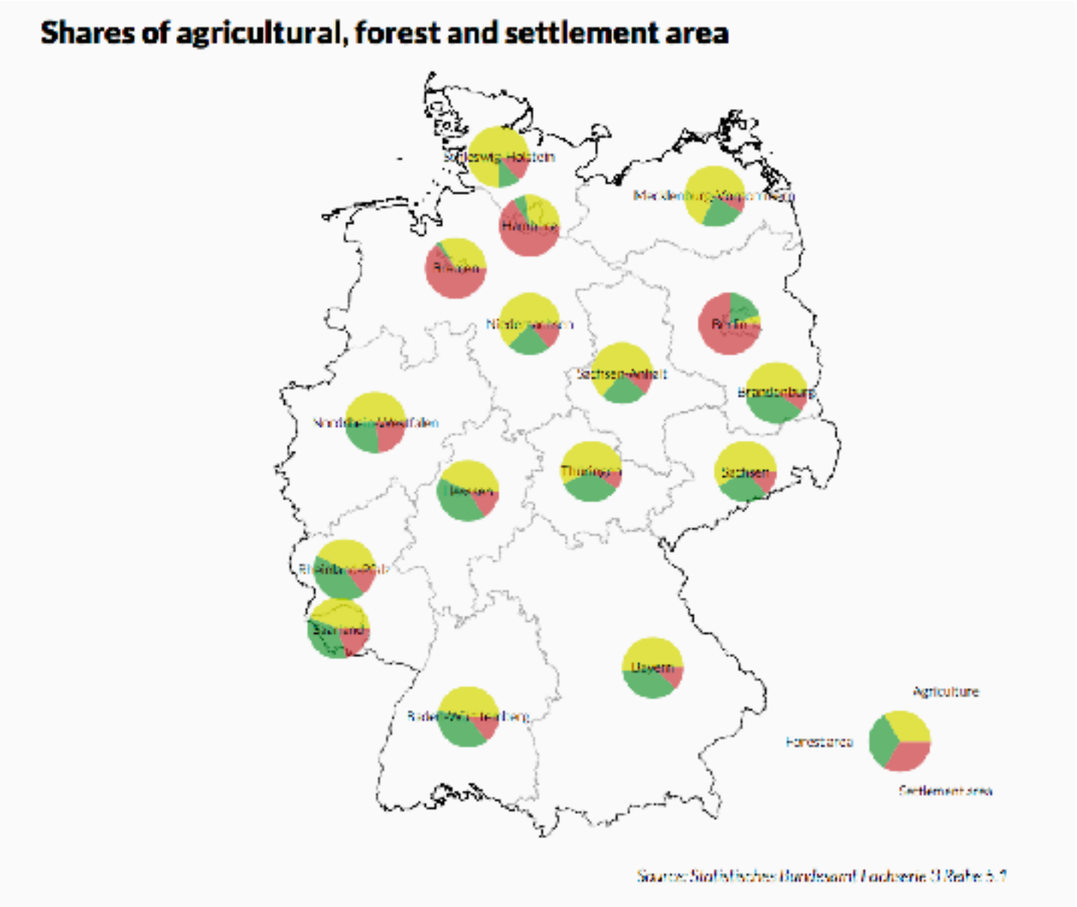
Idiom: **Symbol maps**

- symbol is used to represent aggregated data (mark or glyph)
  - allows use of size and shape and color channels
    - aka proportional symbol maps, graduated symbol maps
- keep original spatial geometry in the background
- often a good alternative to choropleth maps



Symbol maps with glyphs



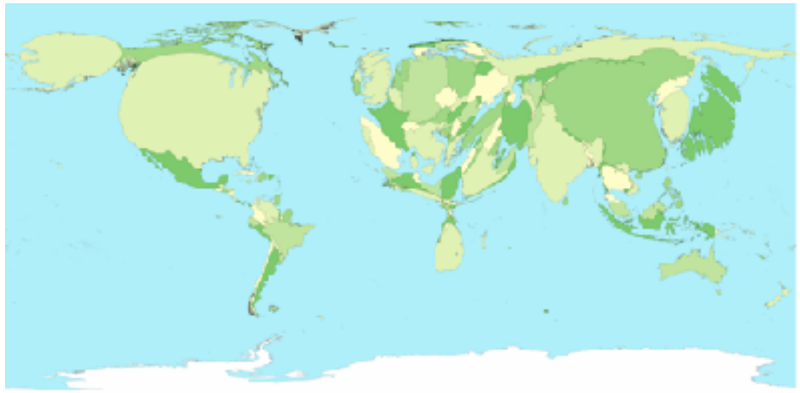


Symbol map: Pros & cons

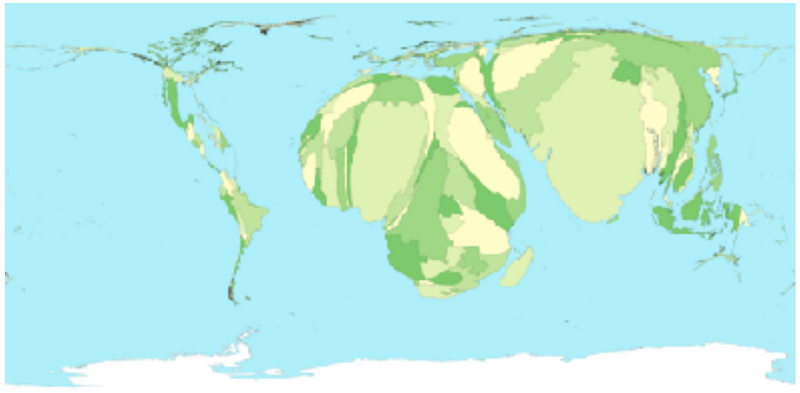
- pros
  - somewhat intuitive to read and understand
  - mitigate problems with region size vs data salience
    - marks: symbol size follows attribute value
    - glyphs: symbol size can be uniform
- cons
  - possible occlusion / overlap
    - symbols could overlap each other
    - symbols could occlude region boundaries
  - complex glyphs may require explanation / training

Idiom: **Contiguous cartogram**

- interlocking marks:
  shape, area, and position coded
- derive new interlocking marks
  - based on combination of original interlocking marks and new quantitative attribute
- algorithm to create new marks
  - input: target size
  - goal: shape as close to the original as possible
  - requirement: maintain constraints
    - relative position
    - contiguous boundaries with their neighbours

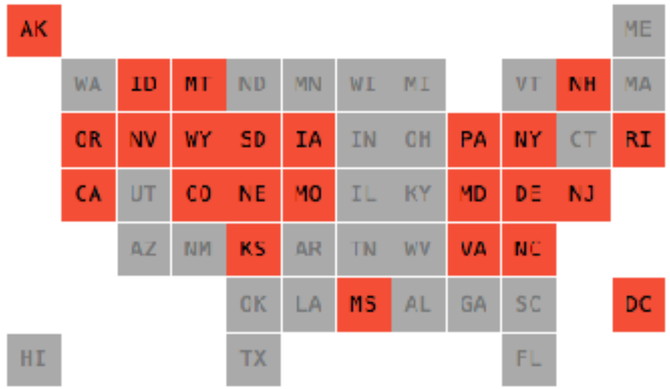


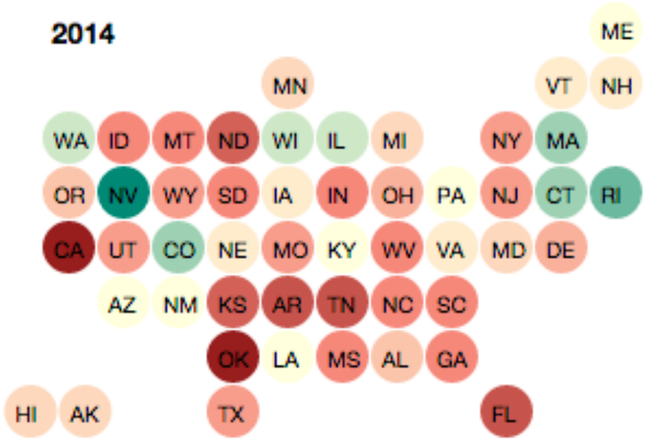
Greenhouse Emissions



Child Mortality

Idiom: **Grid Cartogram**





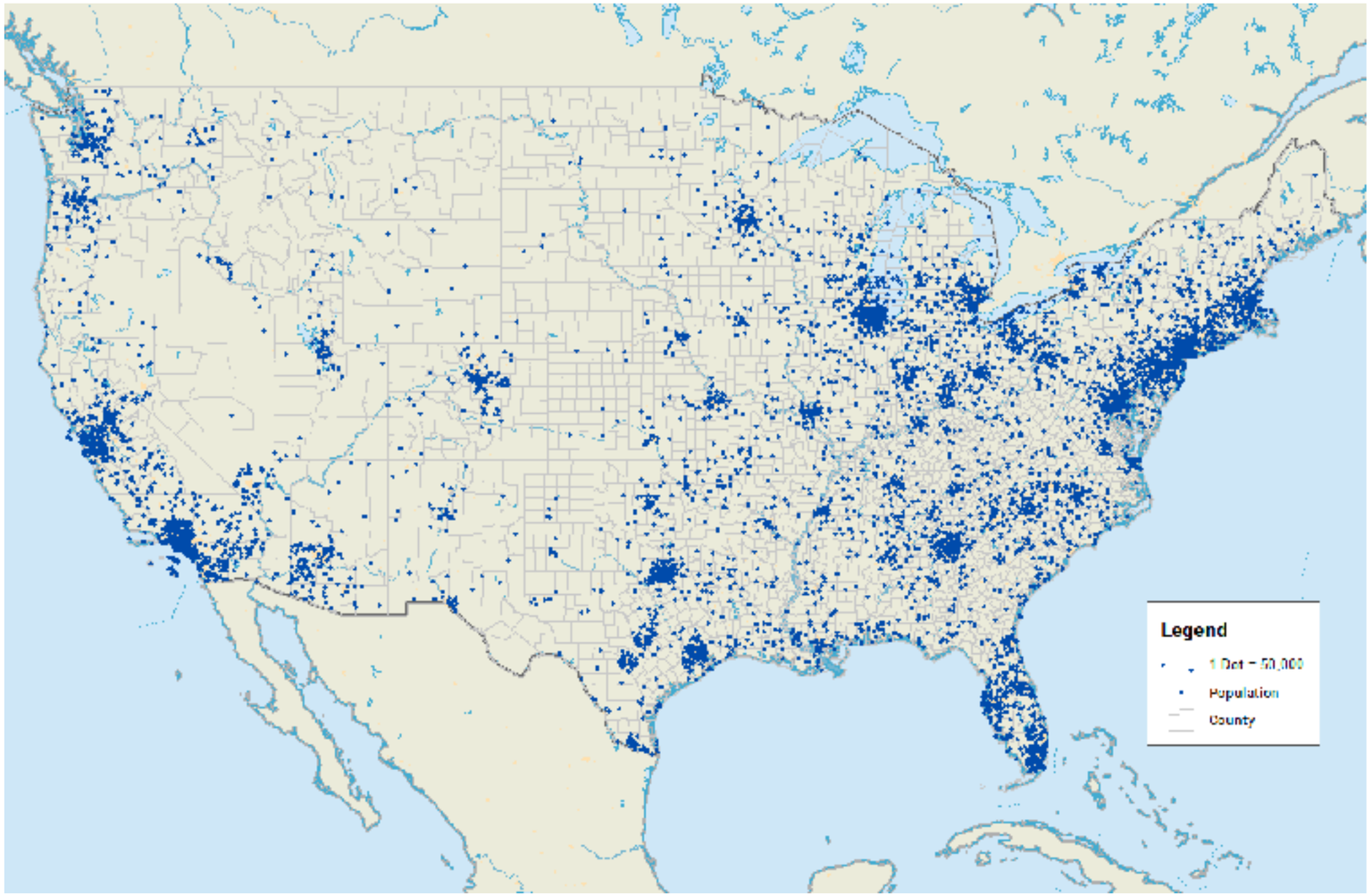
- uniform-sized shapes arranged in rectilinear grid
- maintain approximate spatial position and arrangement

Cartogram: Pros & cons

- pros
  - can be intriguing and engaging
  - best case: strong and surprising size disparities
  - non-contiguous cartograms often easier to understand
- cons
  - require substantial familiarity with original dataset & use of memory
    - compare distorted marks to memory of original marks
    - mitigation strategies: transitions or side by side views
  - major distortion is problematic
    - may be aesthetically displeasing
    - may result in unrecognizable marks
  - difficult to extract exact quantities

Idiom: **Dot density maps**

- visualize distribution of a phenomenon by placing dots
- one symbol represents a constant number of items
  - dots have uniform size & shape
  - allows use of color channel
- task:
  show spatial patterns, clusters

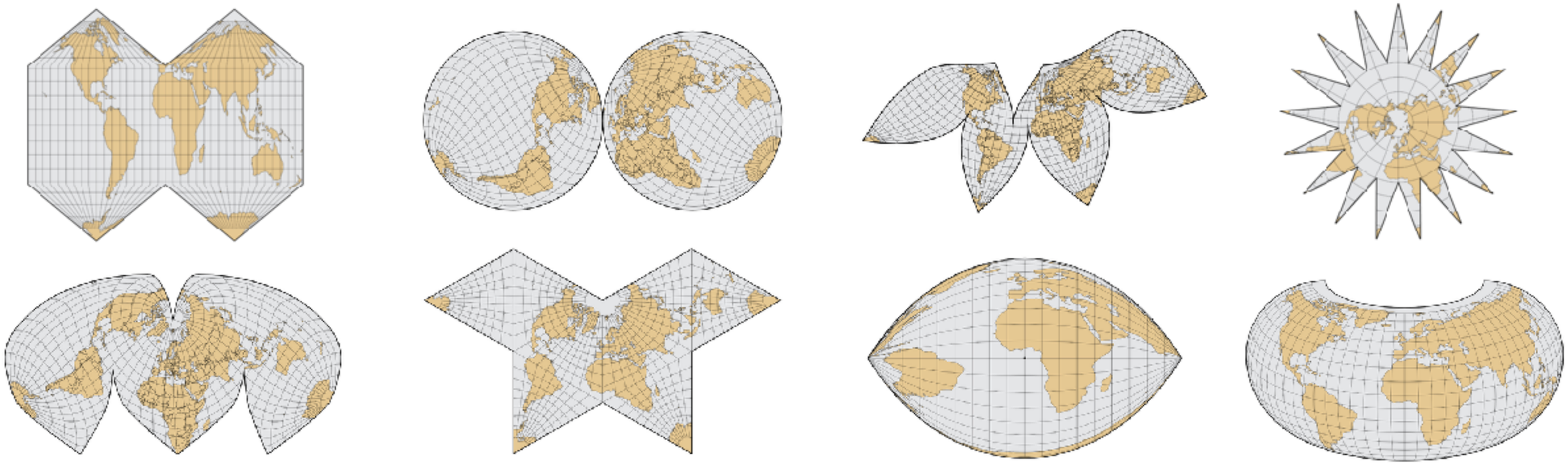


Dot density maps: Pros and cons

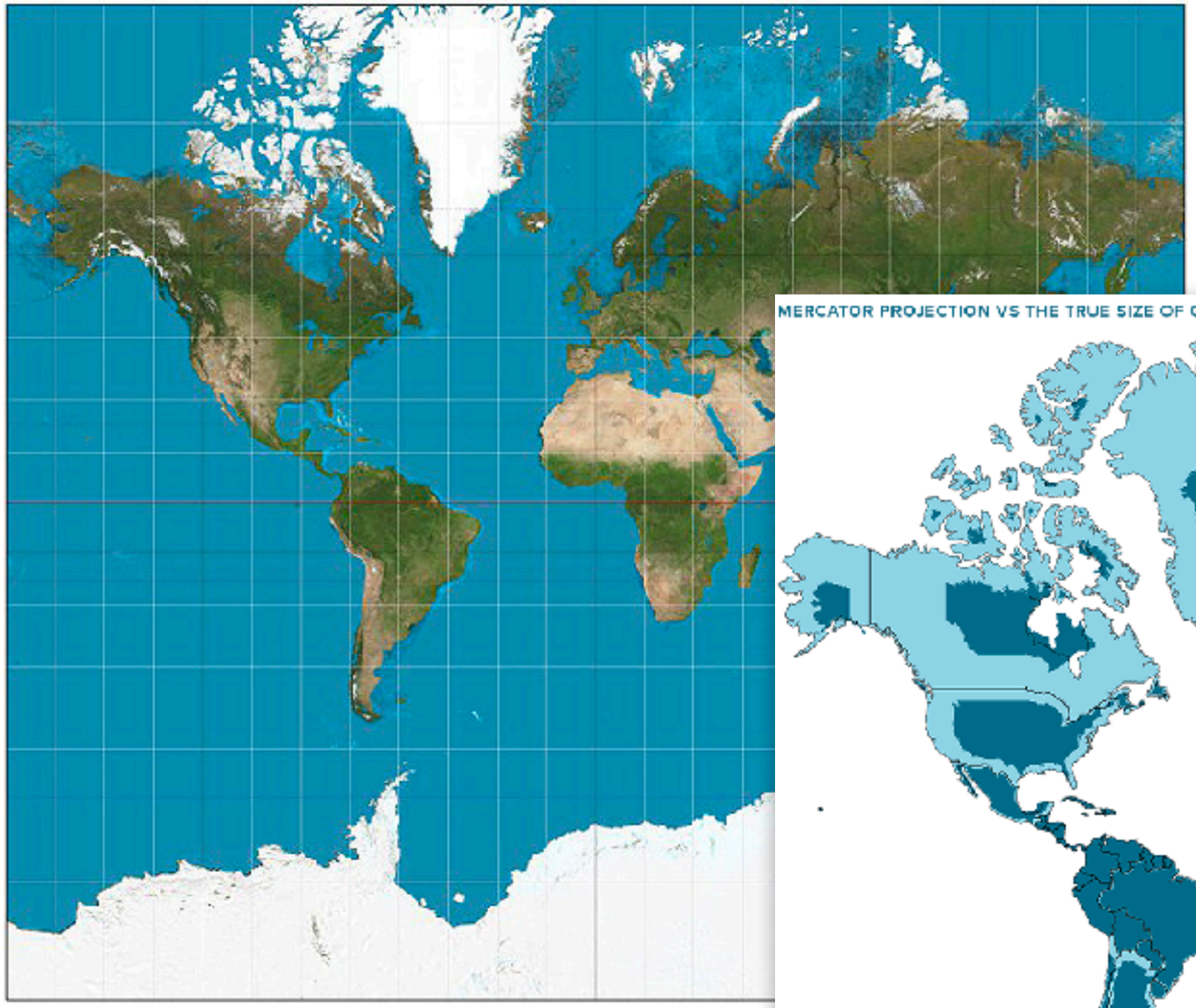
- pros
  - straightforward to understand
  - avoids choropleth non-uniform region size problems
- cons
  - challenge: normalization, just like choropleths
    - show population density (correlated with attribute), not effect of interest
  - perceptual disadvantage:
    difficult to extract quantities
  - performance disadvantage:
    rendering many dots can be slow

Map Projections

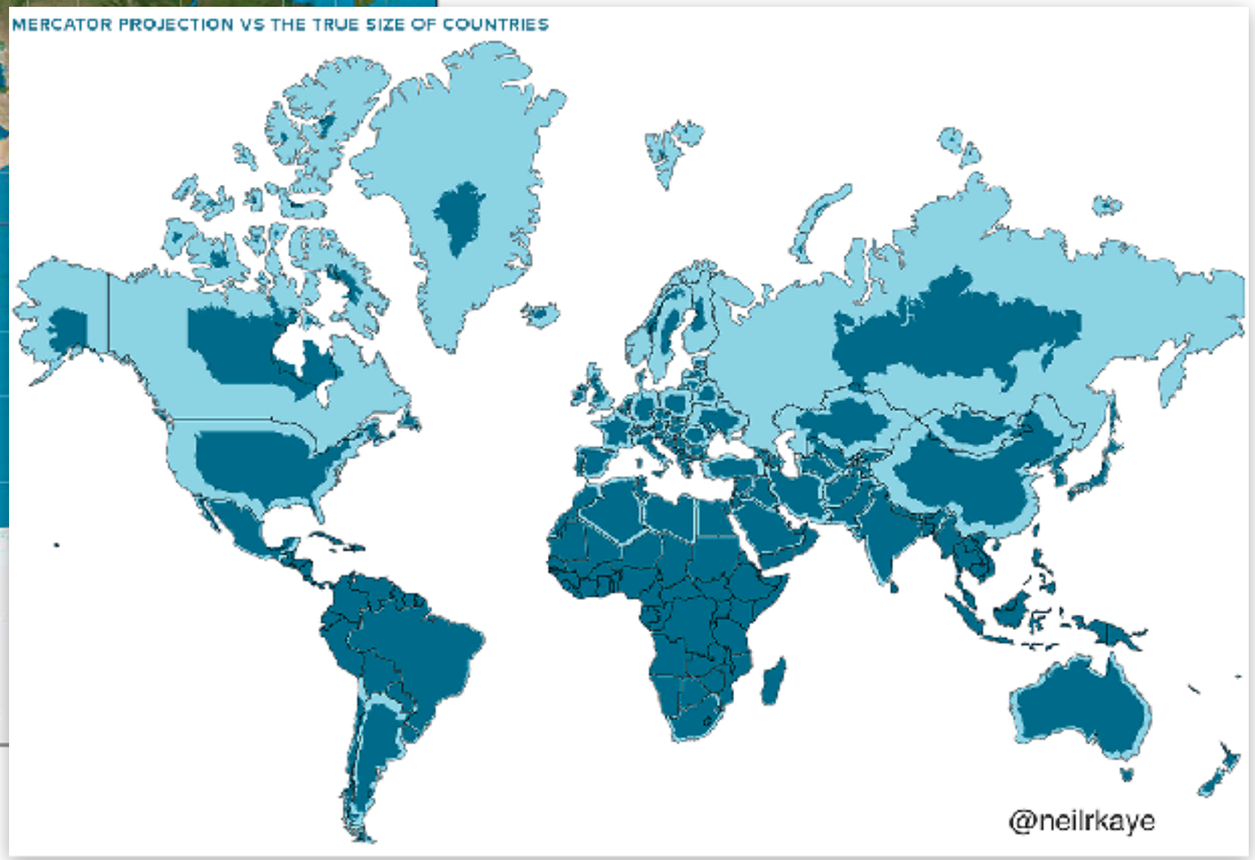
- mathematical functions that map 3D surface geometry of the Earth to 2D maps
- all projections of sphere on plane necessarily distort surface in some way
- interactive: philogb.github.io/page/myriahedral/ and jasondavies.com/maps/



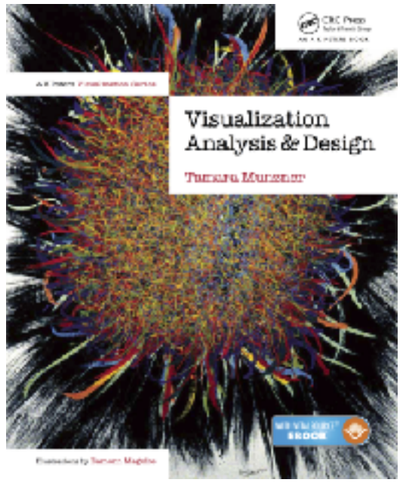
Mercator Projection



» Heavily distorts country sizes; particularly close to the poles.



Visualization Analysis & Design



Spatial Data (Ch 9) II

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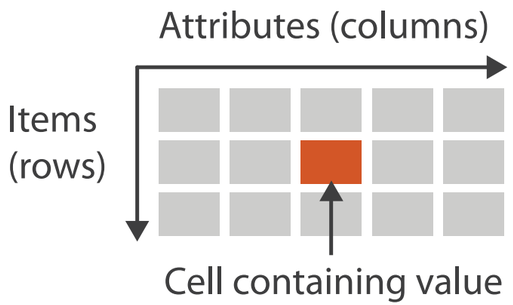
University of British Columbia
@tamaramunzner

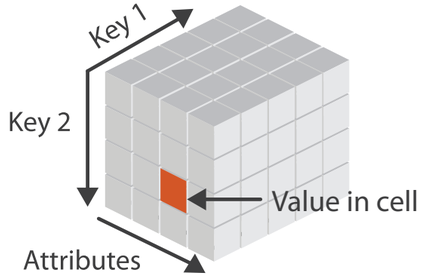
Focus on Spatial

Dataset Types

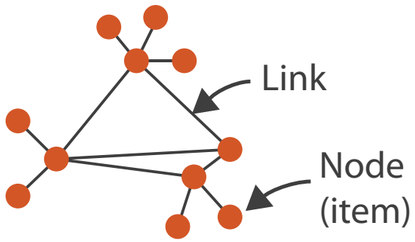
Tables



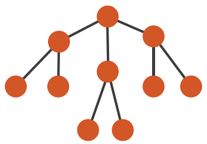
Multidimensional Table



Networks

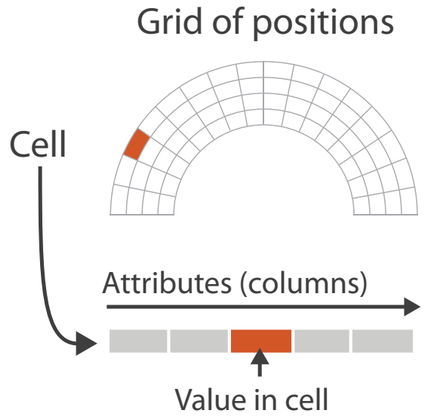


Trees

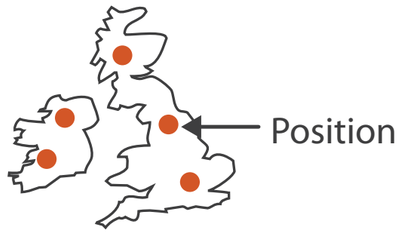


Spatial

Fields (Continuous)



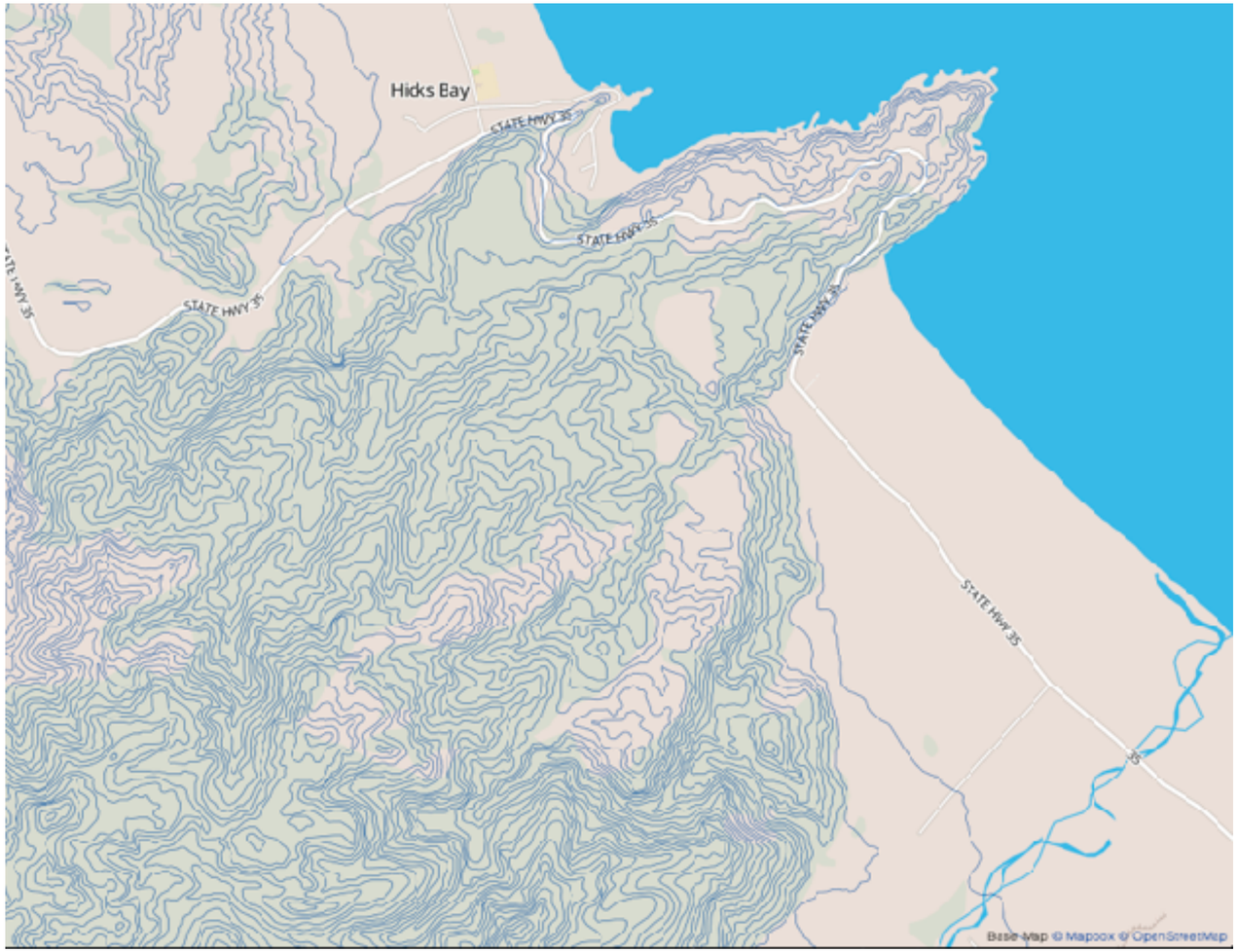
Geometry (Spatial)



Spatial Fields

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
- task
  - understanding terrain shape
    - densely lined regions = steep
- pros
  - use only 2D position, avoid 3D challenges
  - color channel available for other attributes
- cons
  - significant clutter from additional lines



Land Information New Zealand Data Service

Idioms: **isosurfaces, direct volume rendering**

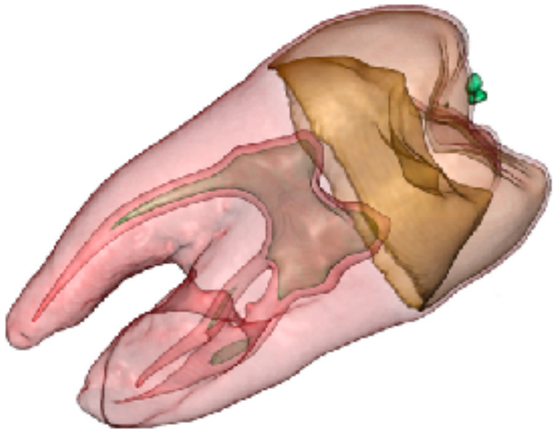
- data
  - scalar spatial field (3D volume)
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships

[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.]

Idioms: **isosurfaces, direct volume rendering**

- data
  - scalar spatial field (3D volume)
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships
- isosurface
  - derived data: isocontours computed for specific levels of scalar values



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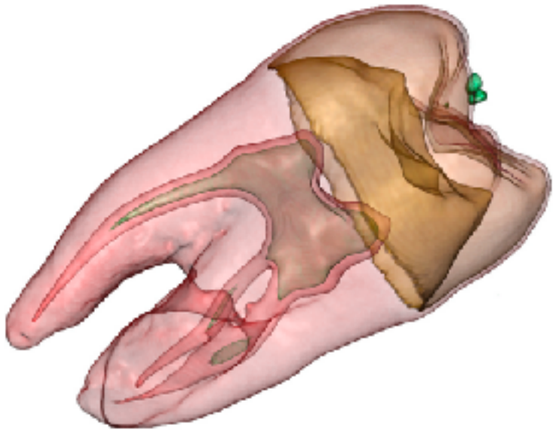
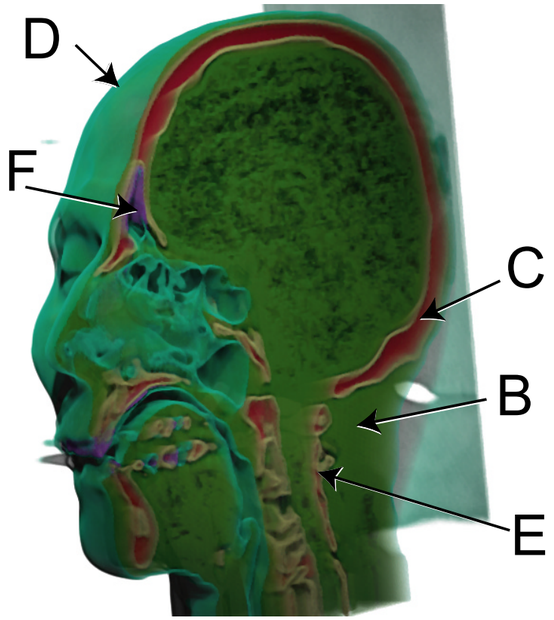
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Idioms: **isosurfaces, direct volume rendering**

- data
  - scalar spatial field (3D volume)
    - 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





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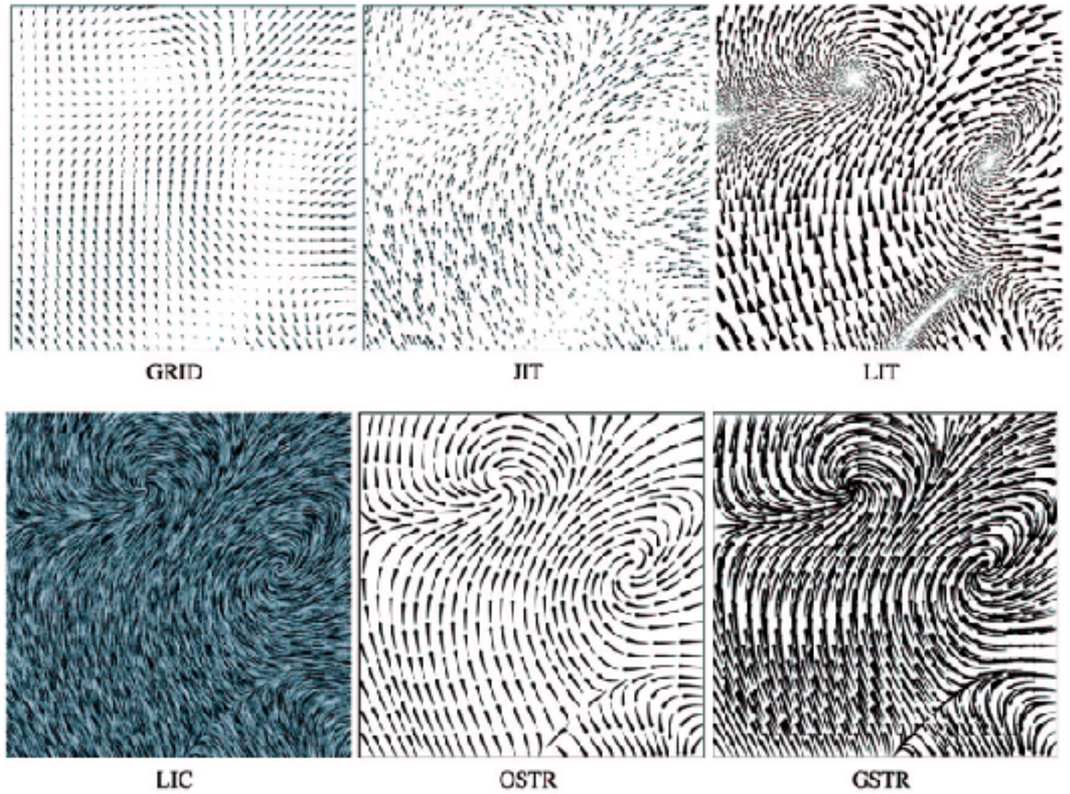
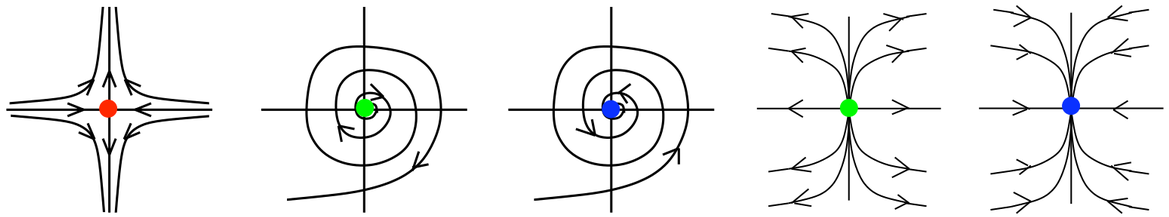
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Vector and tensor fields

- data
  - multiple attribs per cell (vector: 2)
- 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



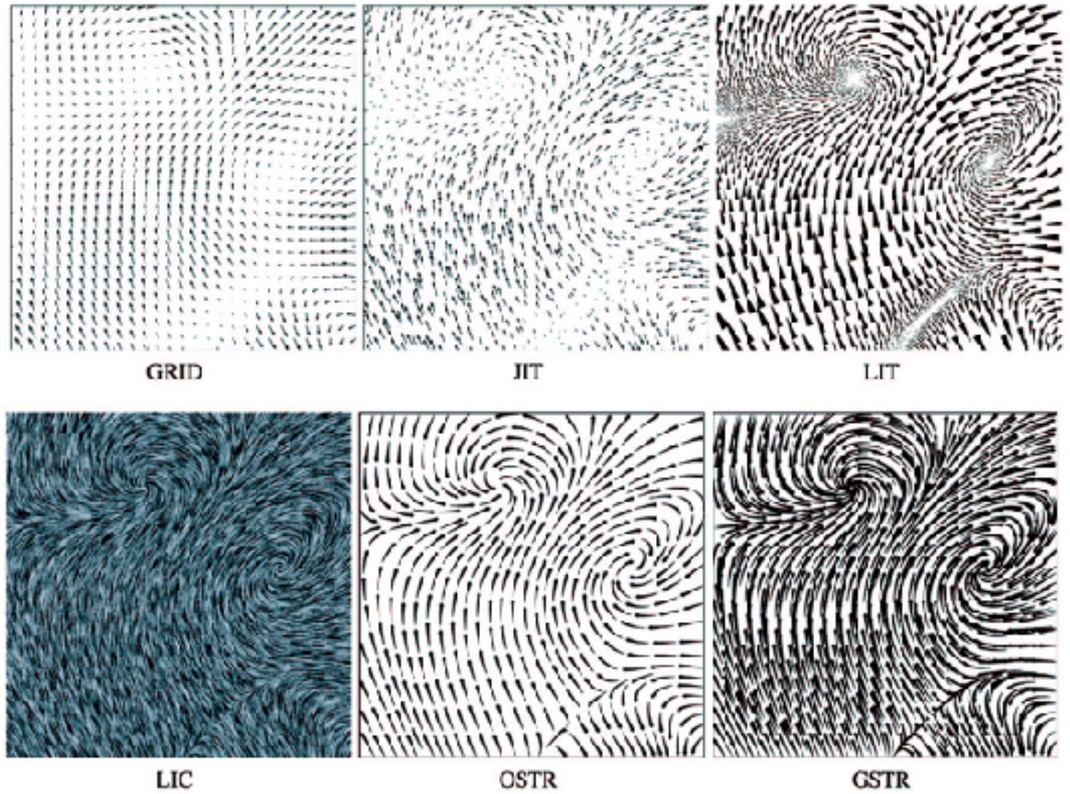
[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]



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

Vector fields

- empirical study tasks
  - finding critical points, identifying their types
  - identifying what type of critical point is at a specific location
  - predicting where a particle starting at a specified point will end up (advection)



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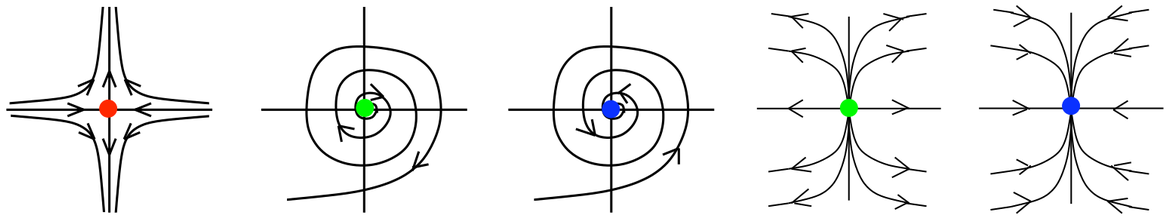
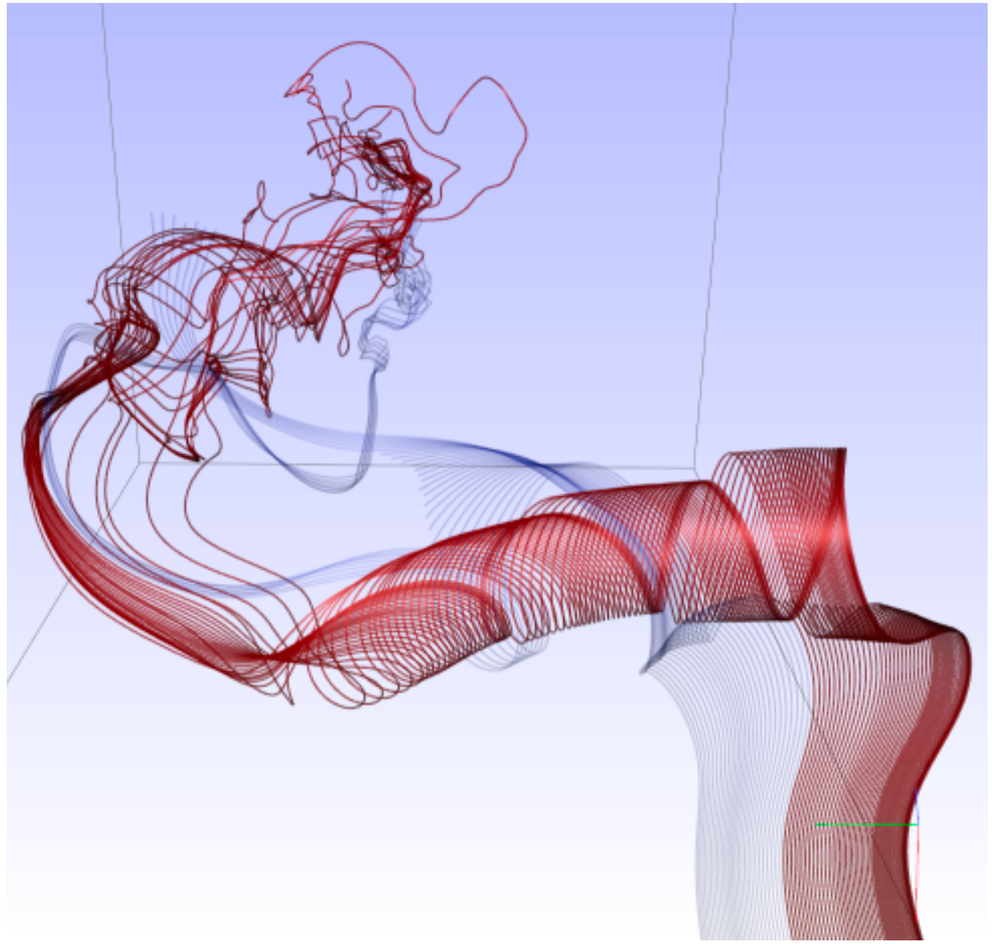


[Topology tracking for the visualization of time-dependent two-dimensional flows. Tricoche, Wischgoll, Scheuermann, and Hagen. Computers & Graphics 26:2 (2002), 249–257.]

Idiom: **similarity-clustered streamlines**

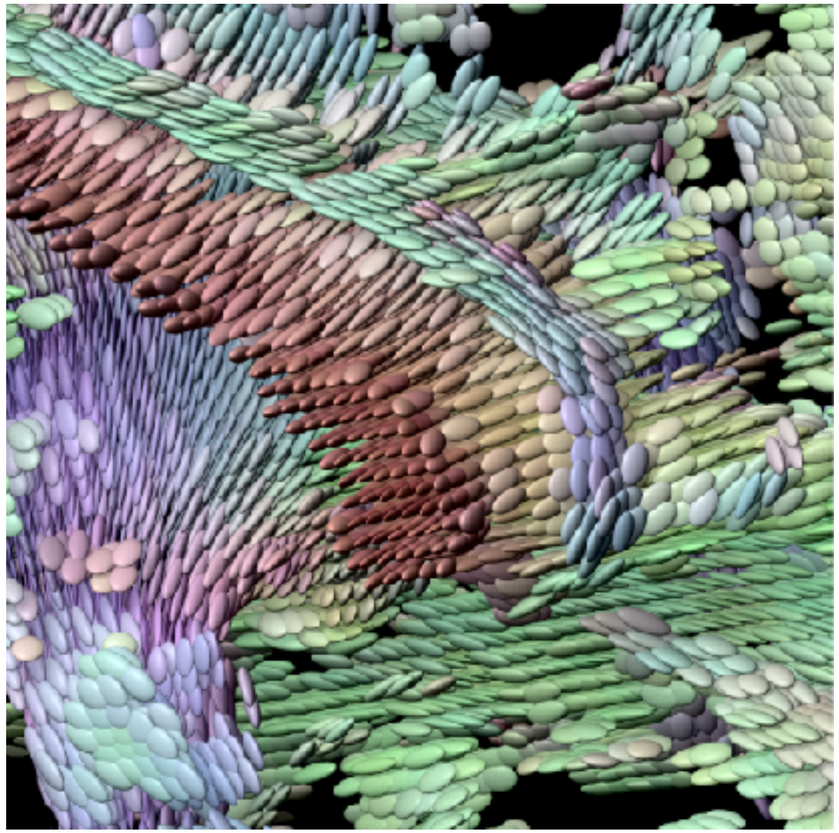
- data
  - 3D vector field
- derived data (from field)
  - streamlines: trajectory particle will follow
- derived data (per streamline)
  - curvature, torsion, tortuosity
  - signature: complex weighted combination
  - compute cluster hierarchy across all signatures
  - encode: color and opacity by cluster
- 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.]

Idiom: Ellipsoid Tensor Glyphs

- data
  - tensor field: multiple attributes at each cell (entire matrix)
    - stress, conductivity, curvature, diffusivity...
  - derived data:
    - shape (eigenvalues)
    - orientation (eigenvectors)
- visual encoding
  - glyph: 3D ellipsoid

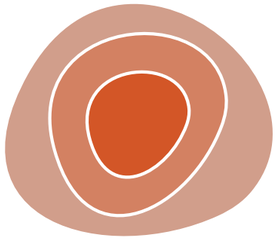


[Superquadric Tensor Glyphs. Kindlmann. Proc. VisSym04, p147-154, 2004.]

Arrange spatial data

- **Use Given**
  - Geometry
    - *Geographic*

  - 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)*