Data Analytics and Decision Sciences

Part 3

Data and Results Visualization

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POLITECNICO
MILANO 1863

VISUALIZATION OF TABLES

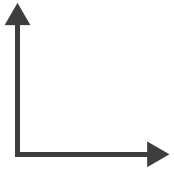
How to use space?

Space and quantitative attributes

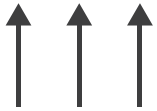
- Express values with position

- How to design the axis?

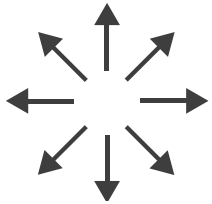
→ Rectilinear



→ Parallel

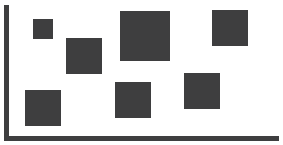


→ Radial



Space and categorical attributes

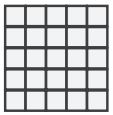
- Map categorical key(s) to separated regions



- Choose a proper alignment

→ *1 Key*
List

→ *2 Keys*
Matrix

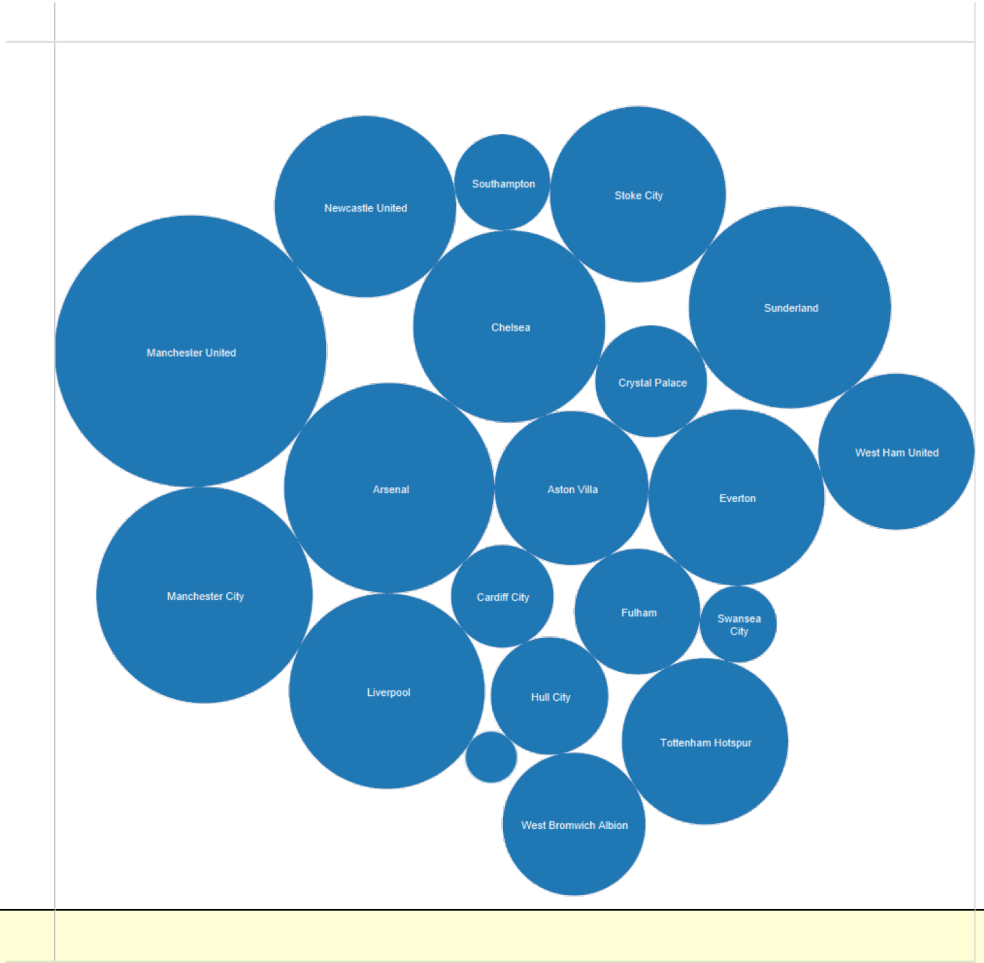


→ *3 Keys*
Volume

→ *Many Keys*
Recursive

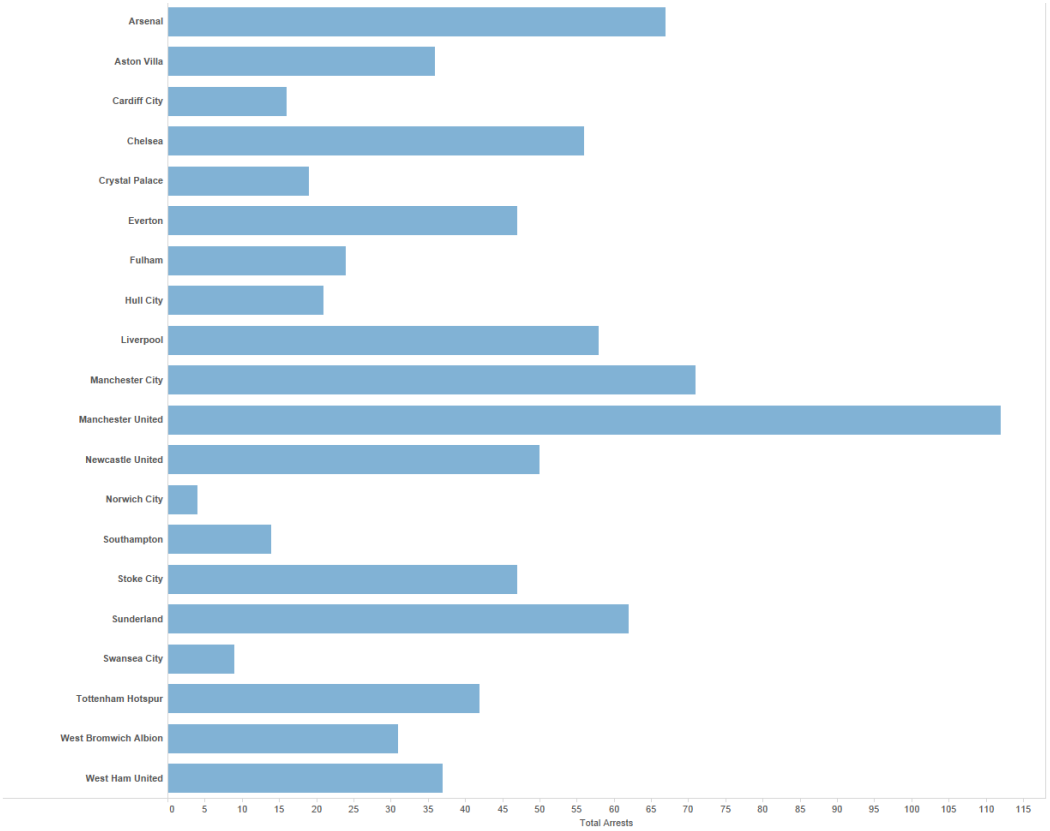
- Choose a proper ordering

Space and categorical attributes: example



Separated but not aligned/ordered: difficult to compare

Space and categorical attributes: example

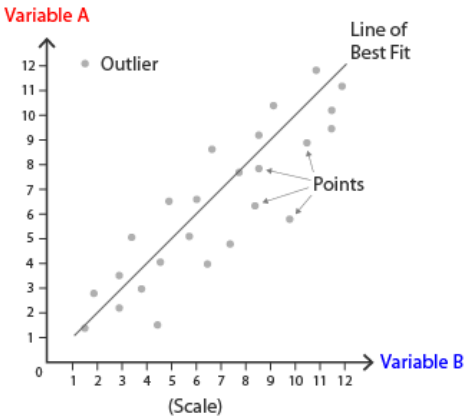


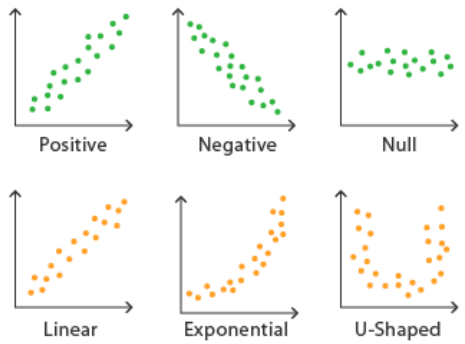
Separated and aligned but not ordered: which is the 4th largest?

Idioms for quantitative attributes

Scatter plot: anatomy

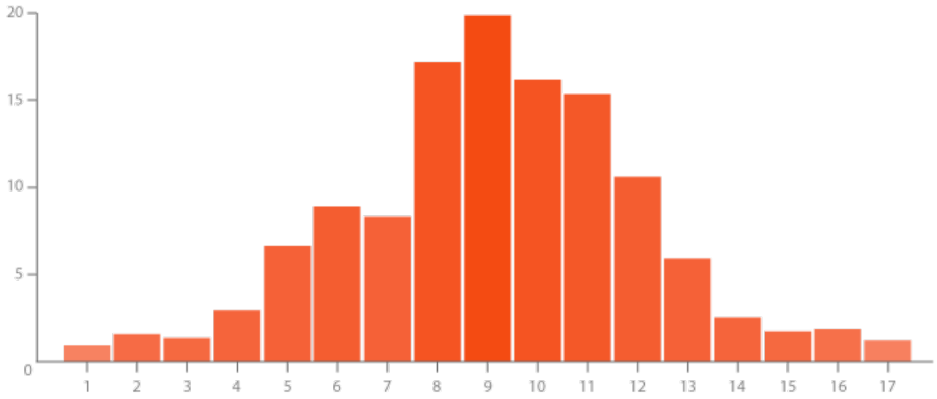
- What?
  - 2 quantitative attribute
- Why?
  - Correlation and distribution
  - Identify outliers, patterns, and clusters
- Remarks
  - Scale up to hundreds of items
  - Color and size can be used to encode two additional categorical attributes (bubble plot)





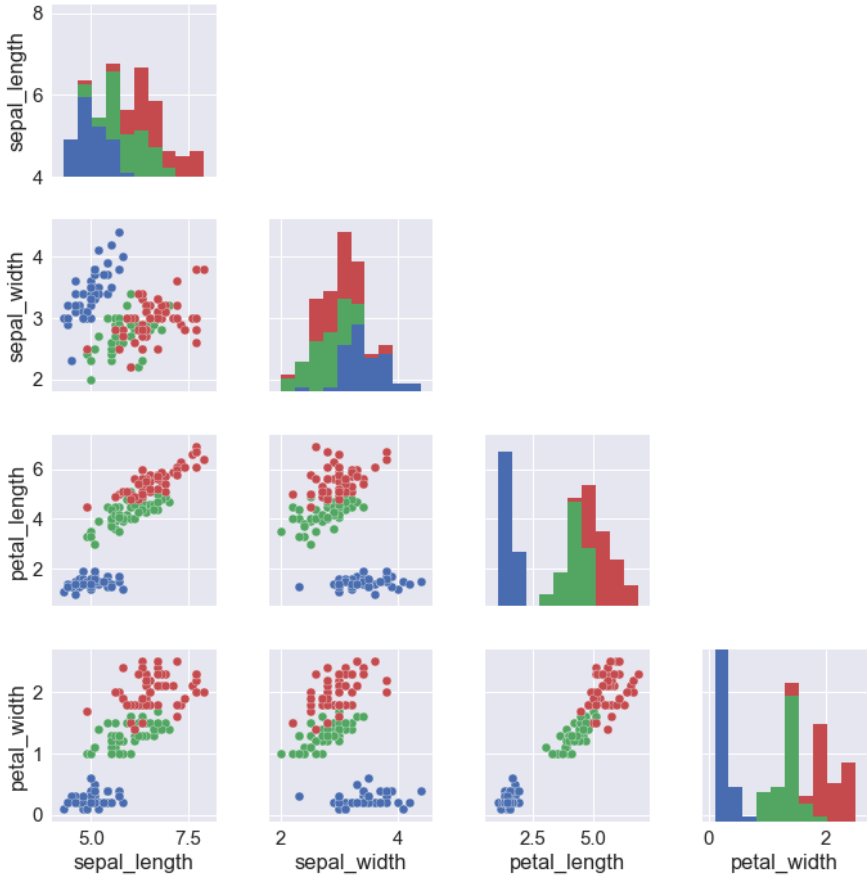
Histogram: anatomy

- What?
  - 1 quantitative attribute
- Why?
  - Identify distribution, patterns, and range
- Remarks
  - A line (or area) can plotted to show computed density function
  - Items can be plotted with dots



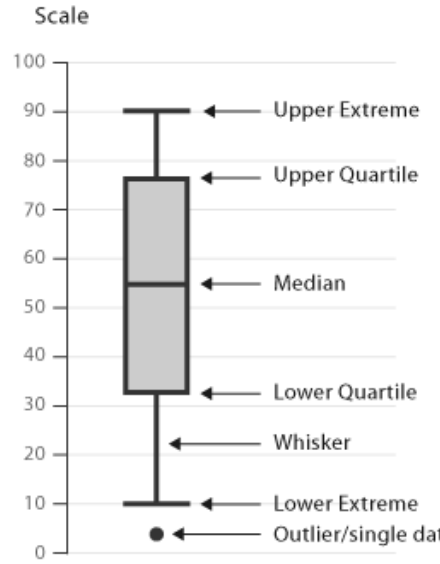
Scatter plot matrix: anatomy

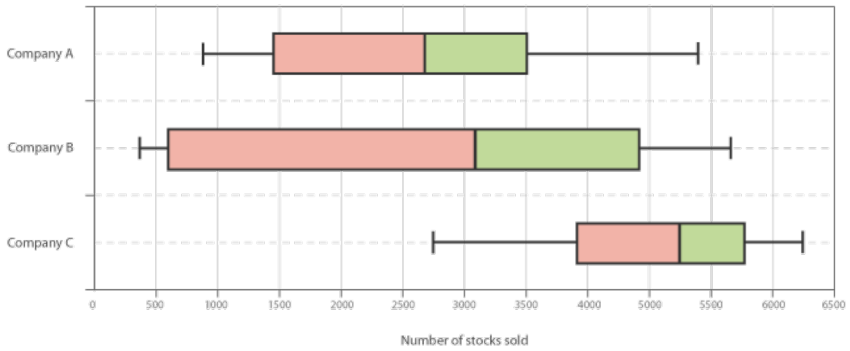
- What?
  - N quantitative attribute
- Why?
  - Correlation and distribution
  - Identify outliers, patterns, and clusters
- Remarks
  - Scale up one dozen of attributes and hundreds of items
  - Possible to remove upper triangle (or map to different plot)



Box plot: anatomy

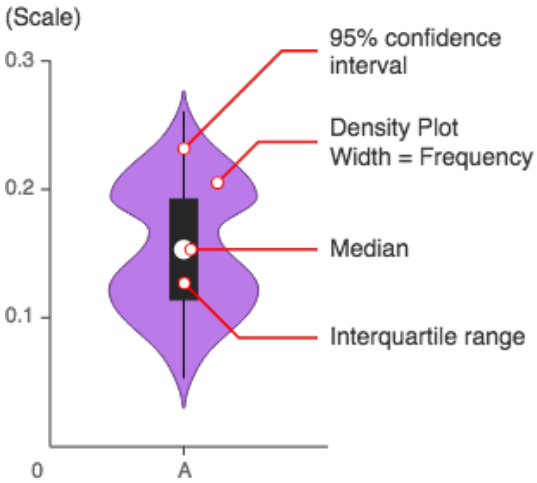
- What?
  - N quantitative attributes
  - (or 1 quantitative and 1 categorical key)
- Why?
  - Distribution
  - Identify outliers, extremes, etc.
- Remarks
  - Color can encode categorical attribute
  - Grouping possible
  - Alternative glyphs

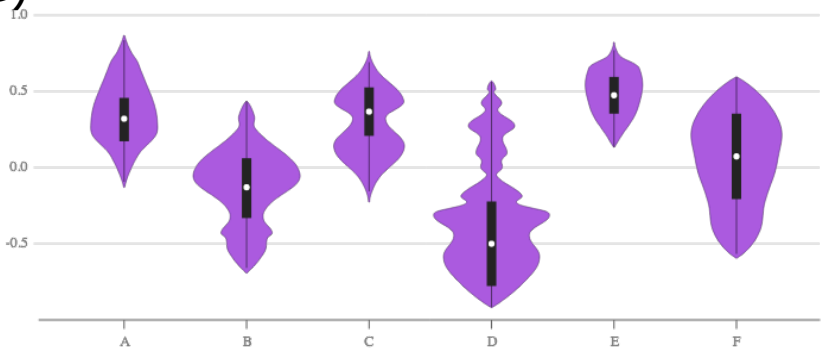




Violin plot: anatomy

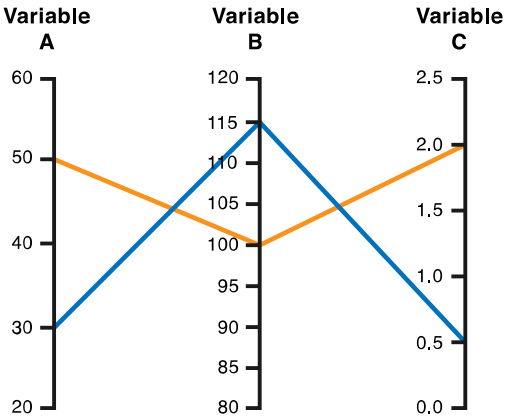
- What?
  - N quantitative attributes
  - (or 1 quantitative and 1 categorical key)
- Why?
  - Distribution
  - Identify range
- Remarks
  - Color can encode categorical attribute (if binary split is possible)
  - Similar to letter-value plot



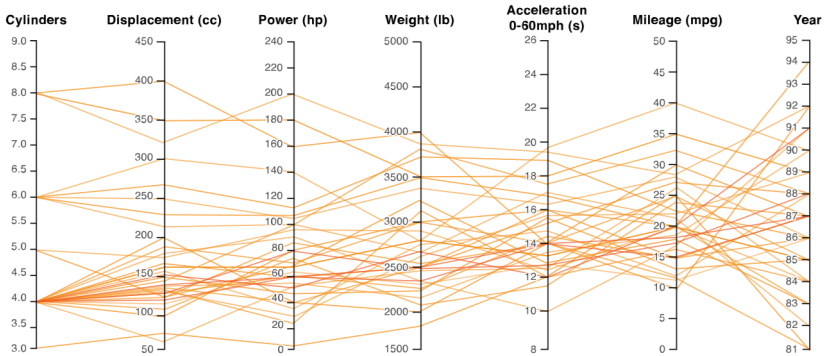


Parallel coordinates: anatomy

- What?
  - N quantitative/ordered attributes
- Why?
  - Correlation
  - Identify outliers, range and patterns
- Remarks
  - Scale up to hundreds of items and a dozen of attributes
  - Color(hue) can encode additional categorical attribute

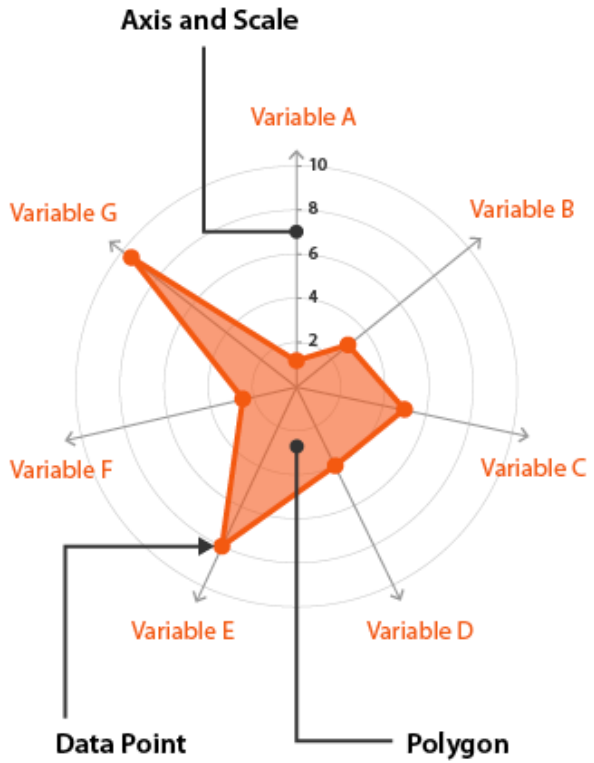


Data			
	Variable A	Variable B	Variable C
Item 1	50	100	2.0
Item 2	30	115	0.5



Radar chart: anatomy

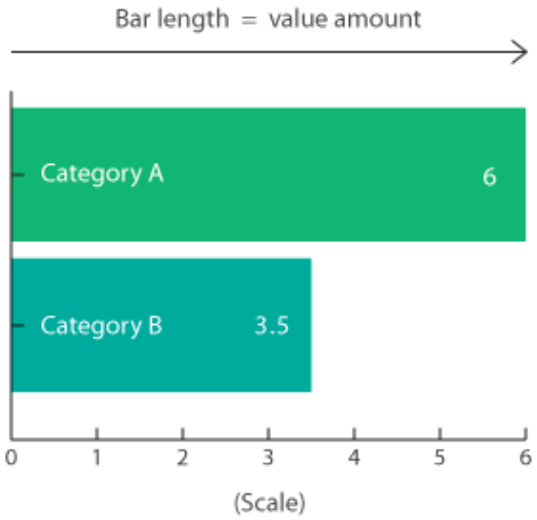
- What?
  - N quantitative attribute
- Why?
  - Identify patterns
  - Compares values
- Remarks
  - Scale up to a dozen attributes
  - Color (hue) can encode an additional categorical key (up to 3-4 values)
  - Not filled version to improve readability



Idioms for one categorical key

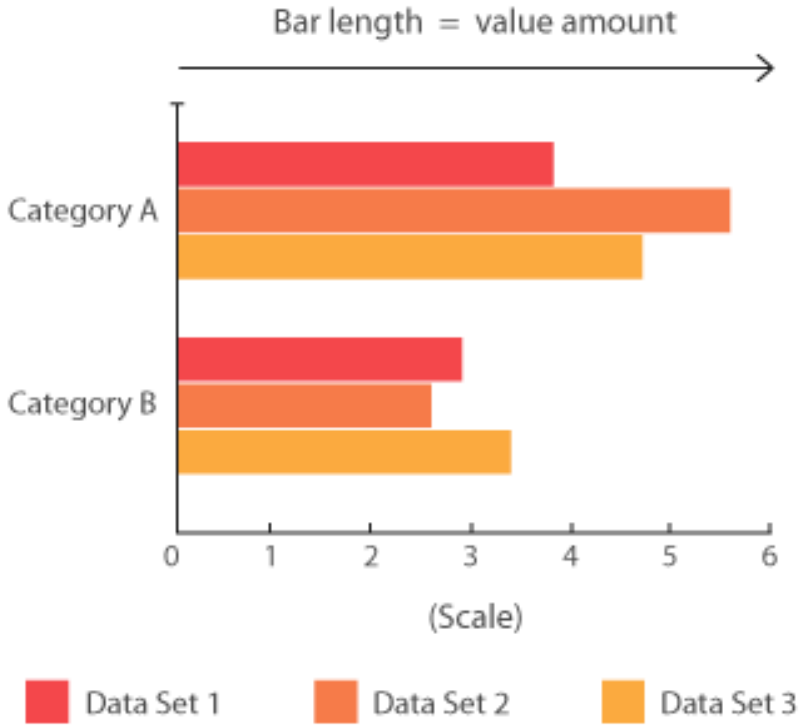
Bar: anatomy

- What?
  - 1 quantitative attribute
  - 1 categorical key
- Why?
  - Compare/Lookup values
  - Identify extremes
- Remarks
  - Scale up to ~100 bars
  - Key vs values ordering
  - Not suitable for trends



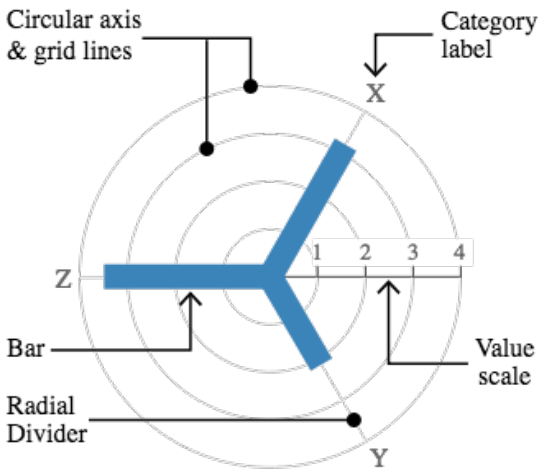
Multi-set bar: anatomy

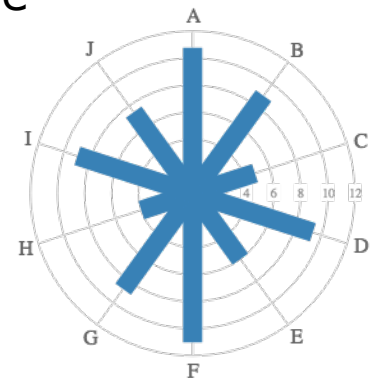
- What?
  - 1 quantitative attribute
  - 2 categorical keys
- Why?
  - Compare values
  - Identify patterns
- Remarks
  - Scale up to ~100 bars
  - The grouping key affects patterns/comparison focus

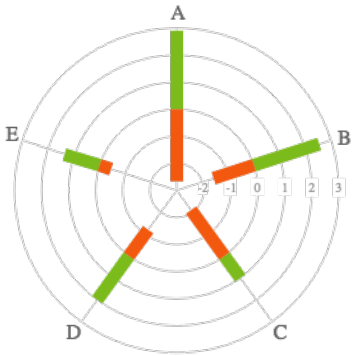


Radial Column bar: anatomy

- What?
  - 1 quantitative attribute
  - 1 categorical key
- Why?
  - Compare/Lookup values
  - Identify pattern
- Remarks
  - Allow stacked design
  - Less dense than linear layout (scale up to ~20 bars)
  - Less accuracy to compare values

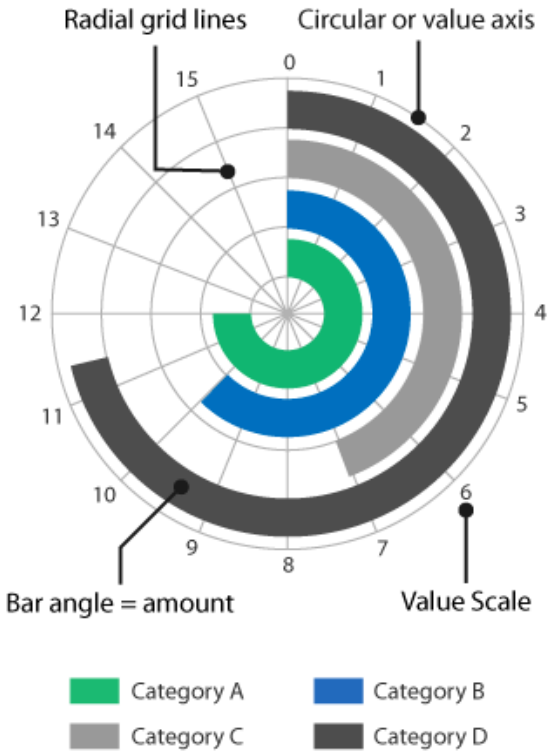






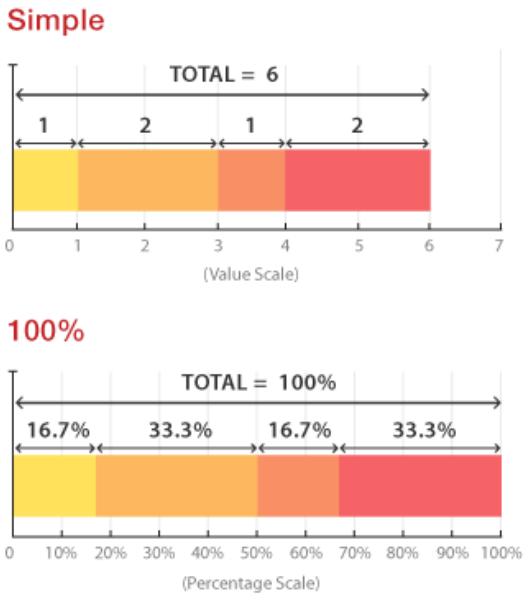
Radial bar: anatomy

- What?
  - 1 quantitative attribute
  - 1 categorical key
- Why?
  - Compare/Lookup values
- Remarks
  - Much less dense than linear layout (max 10 bars)
  - Can be used for intervals (from a start value to an end value)



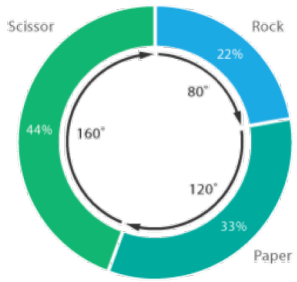
Stacked bar: anatomy

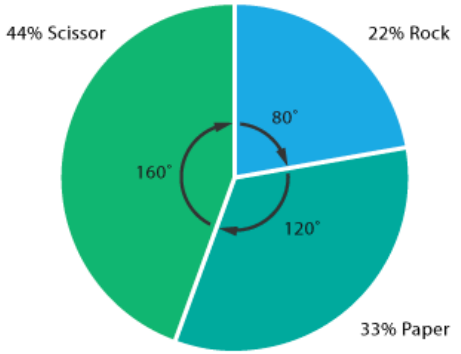
- What?
  - 2 categorical keys
  - 1 quantitative attribute
- Why?
  - Part-to-whole
  - Compare/lookup values
  - Identify patterns
- Remarks
  - Absolute vs Normalized
  - Ordering of secondary key affect accuracy



Pie chart: anatomy

- What?
  - 1 quantitative attribute
  - 1 categorical key
- Why?
  - Part-to-whole
- Remarks
  - Less dense and accurate than linear layout
  - Central area can be removed (donut chart)

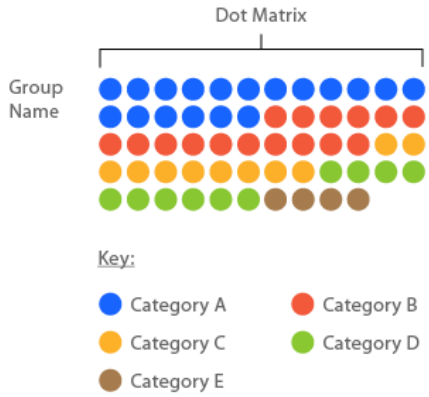




Data			
Rock	Paper	Scissor	TOTAL
2	3	4	9
To calculate percentages			
2/9=22%	3/9=33%	4/9=44%	100%
Degrees for each "pie slice"			
(2/9) x 360 = 80°	(3/9) x 360 = 120°	(4/9) x 360 = 160°	360°

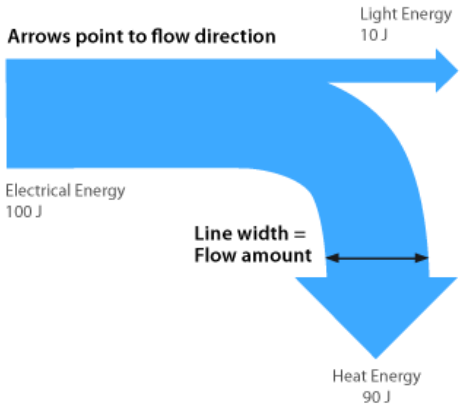
Dot matrix chart: anatomy

- What?
  - 1 categorical attribute
- Why?
  - Part-to-whole
  - Identify patterns
- Remarks
  - Spatial arrangement often used to encode a categorical key



Sankey diagram: anatomy

- What?
  - 1 quantitative attribute
  - 1 categorical key
- Why?
  - Part-to-whole
- Remarks
  - Color (hue) can encode an additional categorical attribute



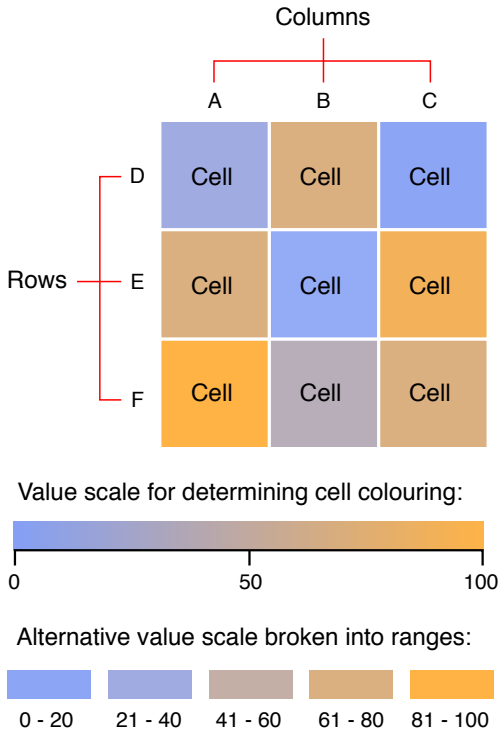
Word cloud: anatomy

- What?
  - 1 categorical attribute (text)
  - 1 quantitative (frequency)
- Why?
  - Distribution of keyword
  - Summarization
- Remarks
  - Poor accuracy
  - Bias due to word length and structure

Idioms for two categorical keys

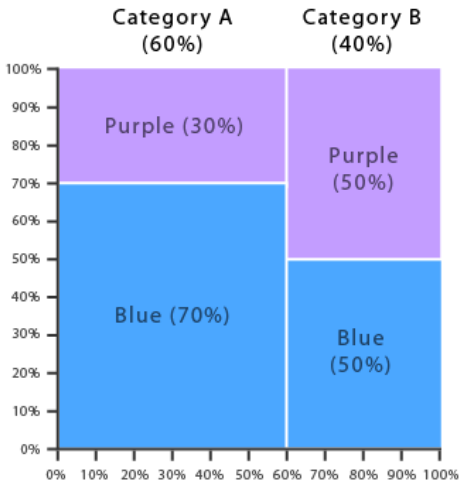
Heatmap: anatomy

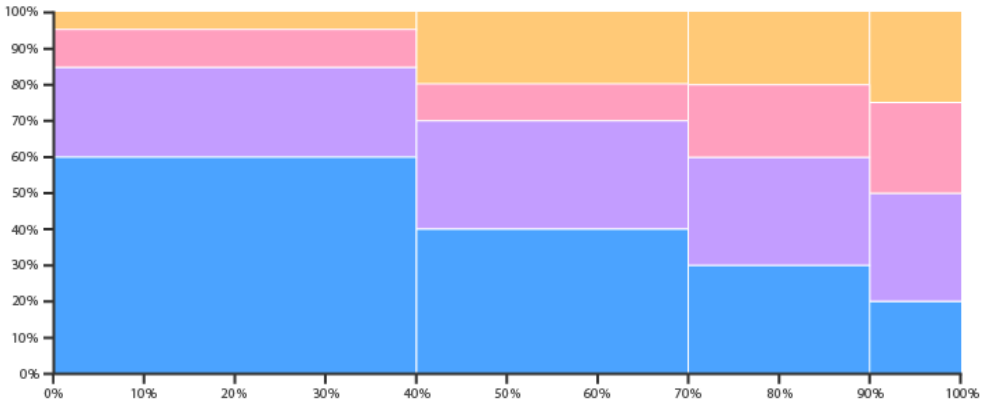
- What?
  - 2 categorical keys
  - 1 quantitative attribute
- Why?
  - Discover patterns, outliers
  - Correlation
- Remarks
  - Scale up to ~1M of items
  - Keys ordering affects the discoverability of patterns



Marimekko chart: anatomy

- What?
  - 2 categorical keys
  - 1 quantitative attribute
- Why?
  - Part-to-whole
- Remarks
  - Value-based ordering of keys might work better



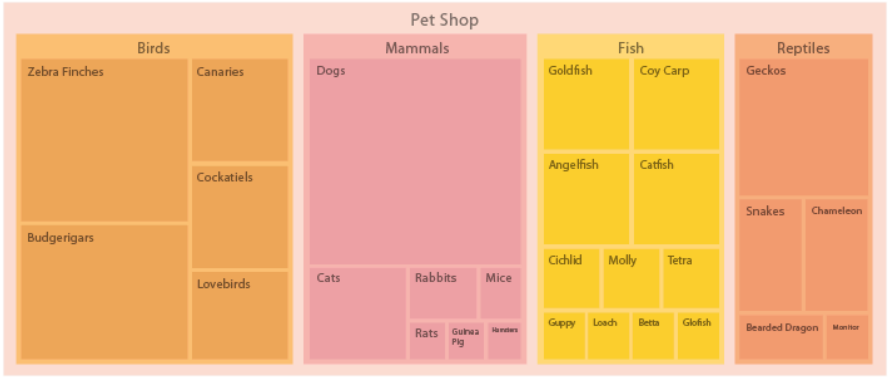


Idioms for many categorical keys

TreeMap: anatomy

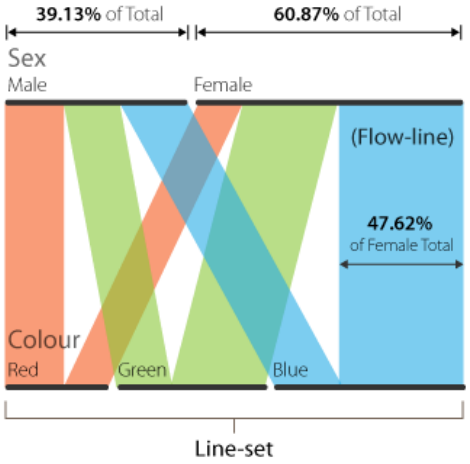
- What?
  - N categorical keys
  - 1 quantitative attribute
- Why?
  - Part-to-whole
  - Compare values
- Remarks
  - Recursion allows to manage many keys
  - Space vs Color encoding
  - Color to encode additional attribute

class	species	num
Birds	Canares	10
Mammals	Dogs	90
Fish	Goldfish	10
…	…	…



Parallel sets: anatomy

- What?
  - N categorical attributes
- Why?
  - Correlation
  - Identify outliers, range and patterns
- Remarks
  - Scale up to hundreds of items and a few attributes
  - Color(hue) can encode additional categorical attribute

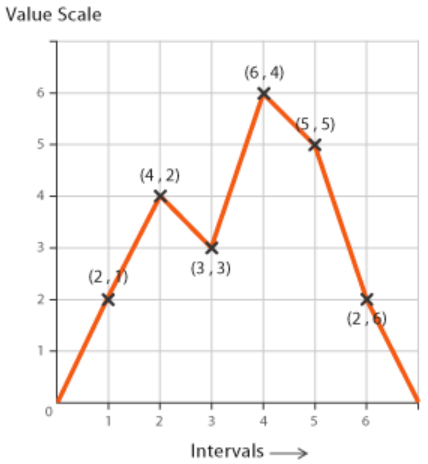


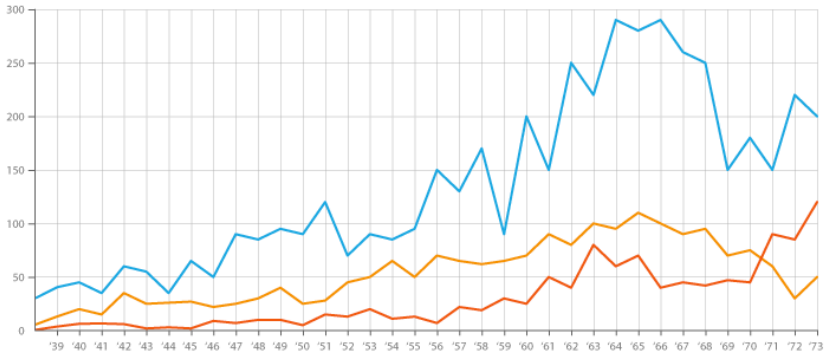
Sex	Colour	Count	% of Sex TOTAL
Male	Red	35	32.41
	Green	33	30.56
	Blue	40	37.04
Female	Red	28	16.67
	Green	60	35.71
	Blue	80	47.62

Idioms for dealing with time

Line graph: anatomy

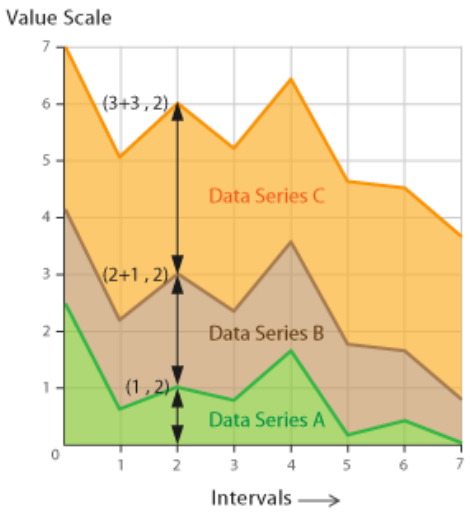
- What?
  - 1 ordered key (time)
  - 1 quantitative attribute
- Why?
  - Identify and compare trends
- Remarks
  - Scale up to 10-20 lines
  - Color can encode an additional categorical attribute

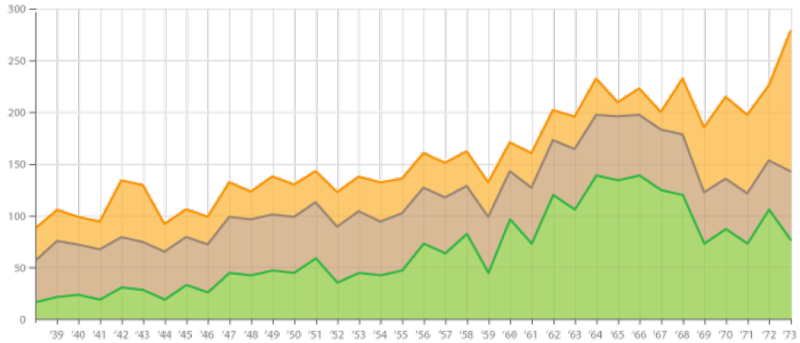




Stacked area graph: anatomy

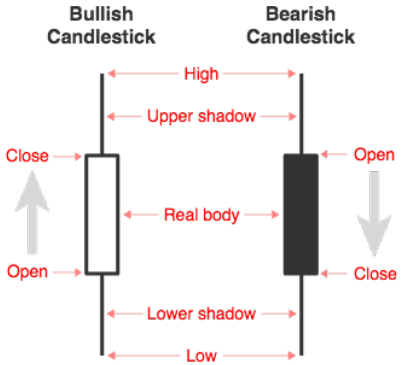
- What?
  - 1 ordered key (time)
  - 1 categorical attribute
- Why?
  - Trend
  - Part-to-whole
  - Compare values
- Remarks
  - Scale up to few values

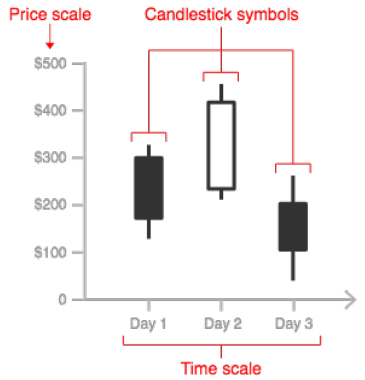




Candlestick chart: anatomy

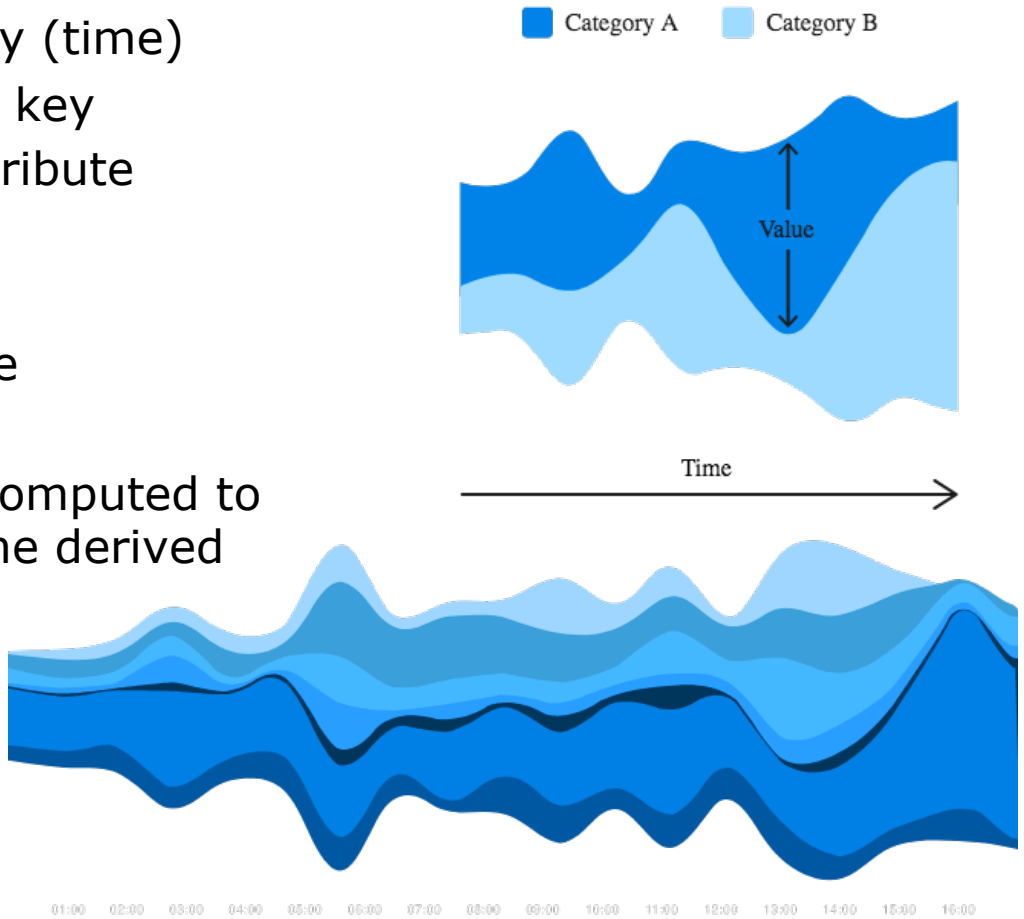
- What?
  - 1 ordered key (time)
  - 4 quantitative attributes
- Why?
  - Identify trends and patterns
- Remarks
  - Red/Green color often used instead of b/w
  - Different glyphs can be used





Stream Graph: anatomy

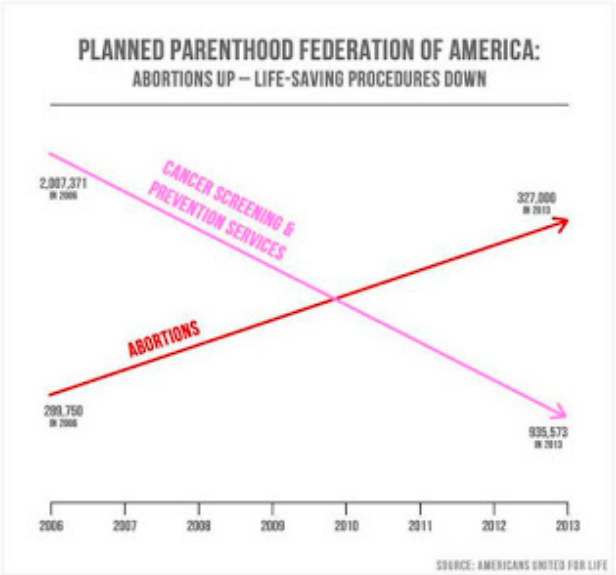
- What?
  - 1 ordered key (time)
  - 1 categorical key
  - 1 derived attribute
- Why?
  - Trends
  - Part-to-whole
- Remarks
  - Ordering is computed to emphasize the derived attribute

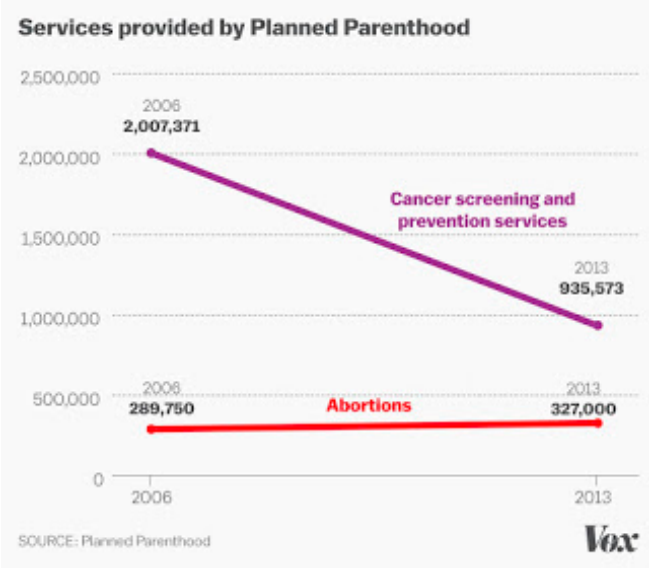


Insights/Guidelines

About chart axes

- Cropping y-axis:
  - Include 0 in bar charts
  - Misleading perception of slopes
- Dual axes controversial acceptable if commensurate!

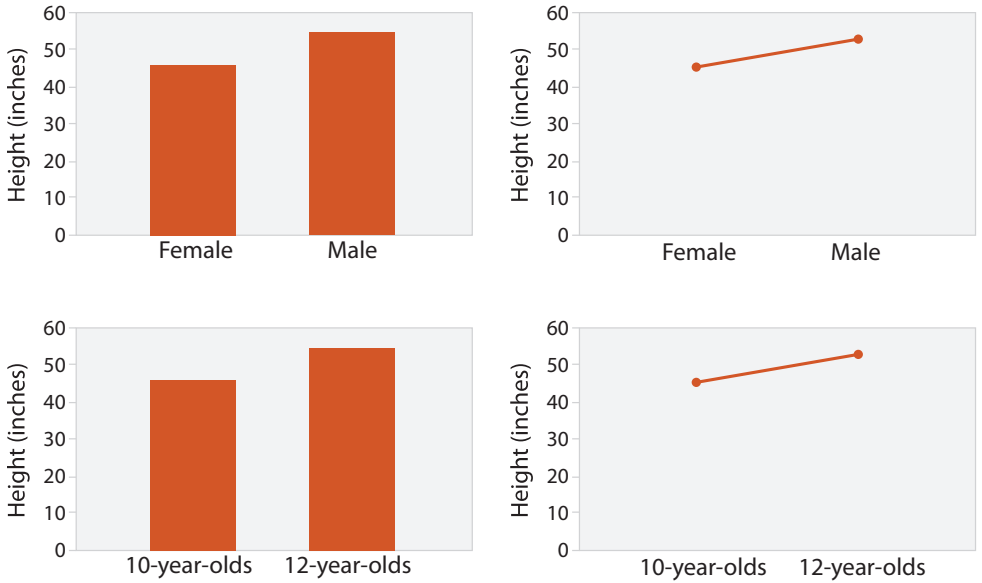




http://www.thefunctionalart.com/2015/10/if-you-see-bullshit-say-bullshit.html

Choosing bar vs line charts

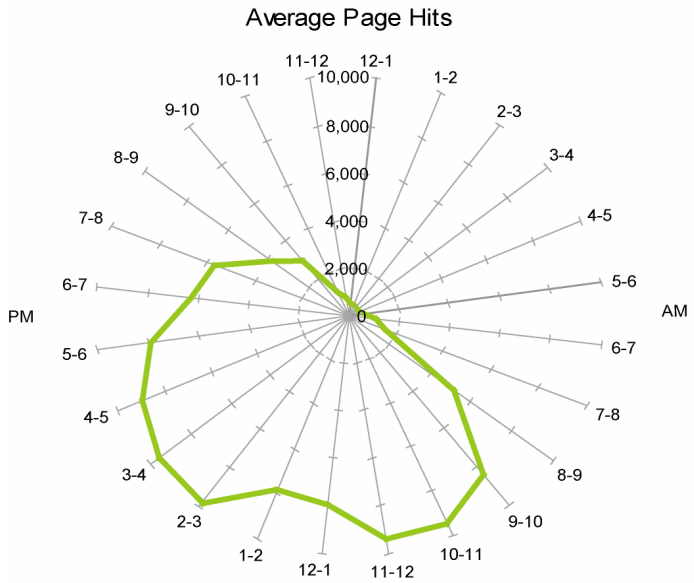
- Based on type of key attribute:
  - bar charts if categorical
  - line charts if ordered
- Implication of trend so strong that it overrides semantics!
  - "The more male a person is, the taller he/she is"



Bars and Lines: A Study of Graphic Communication. Zacks and Tversky(1999)

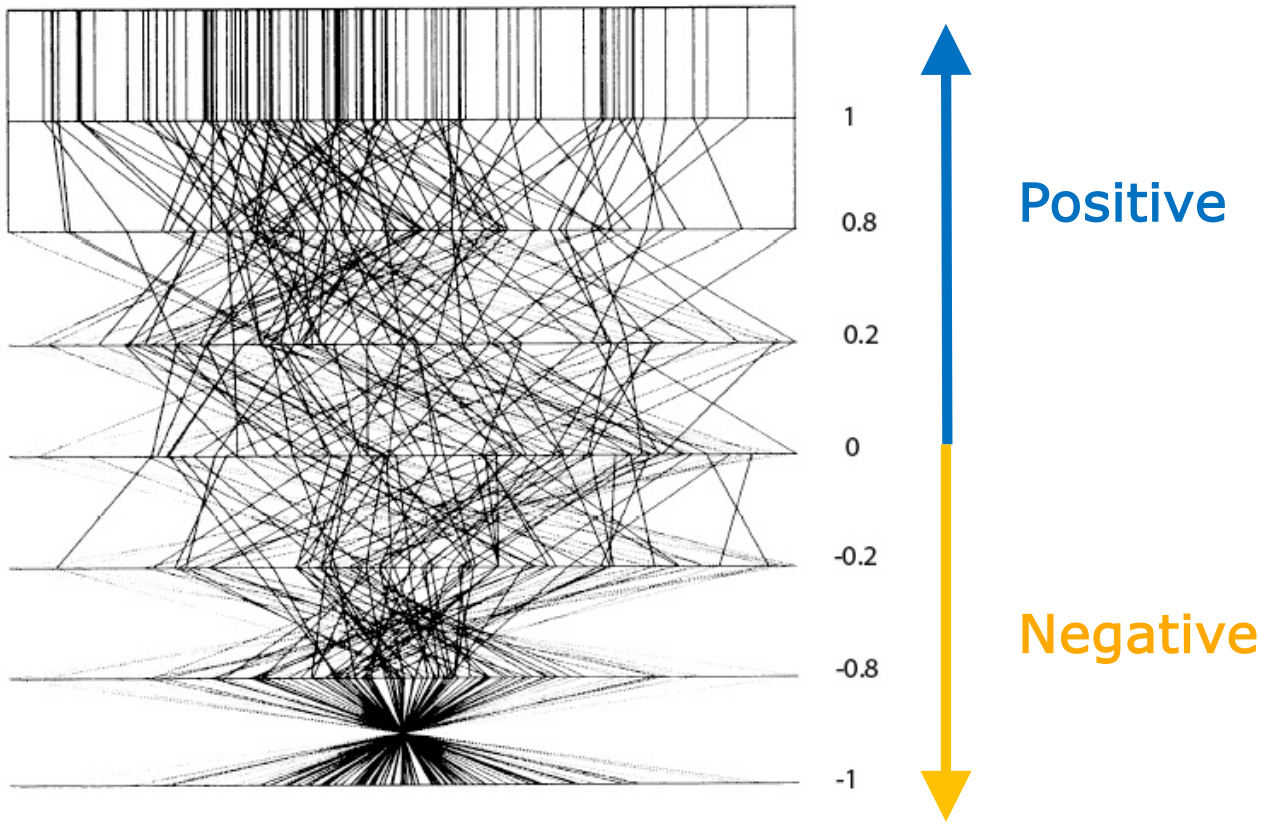
Radial vs linear layout

- Issues with radial layout:
  - accuracy
  - efficient use of the space
- When it makes sense to use it:
  - cyclic data (e.g., months, hours, etc.)
  - data associated to radial layout (e.g., NSWE)



http://www.perceptualedge.com/articles/dmreview/radar_graphs.pdf

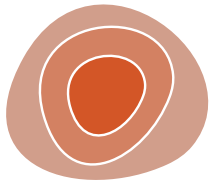
Reading parallel coordinates

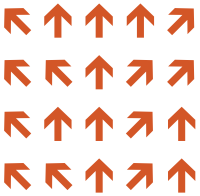


VISUALIZING SPATIAL DATA

Visualizing spatial data

- Geometry
  - Geographic
  - Others
- Scalar fields (one value per cell)
  - Isocontours
  - Direct volume rendering
- Vector and tensor fields (many values per cell)
  - Flow glyphs
  - Geometric (sparse seeds)
  - Textures (dense seeds)
  - Features (globally derived)

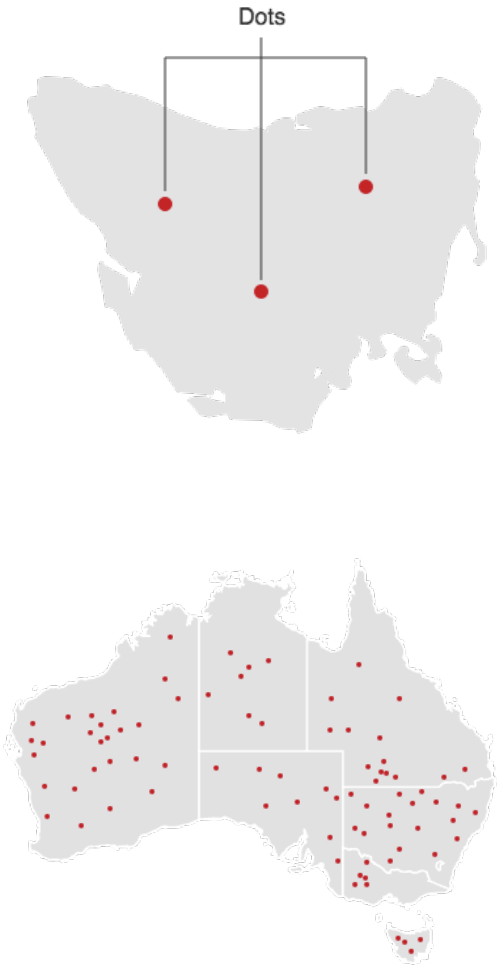




Geometry

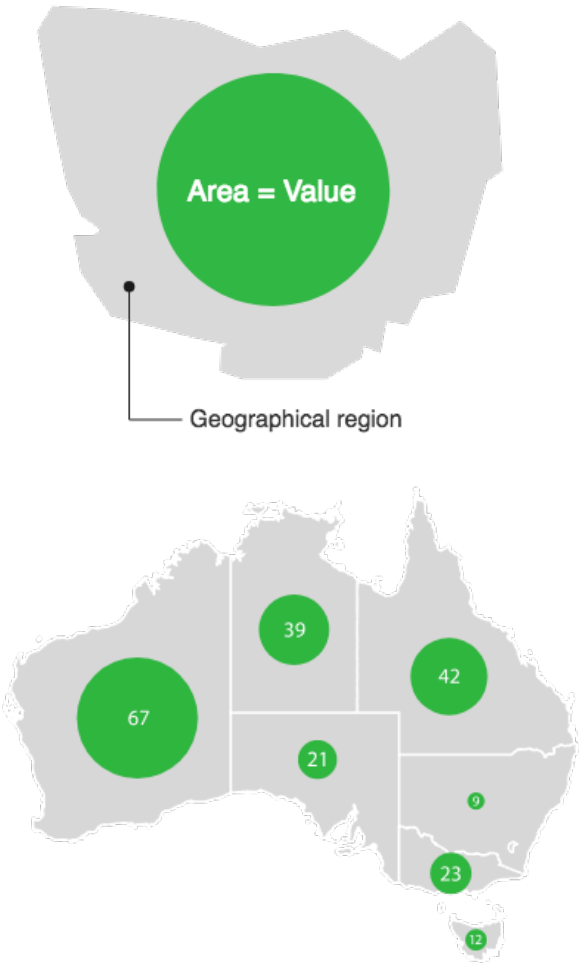
Dot Map: anatomy

- What?
  - Geometry (position)
- Why?
  - Locate data in space
- Remarks
  - Scale up to hundreds of items
  - Color/shape can encode an additional categorical attribute (reduce scalability)



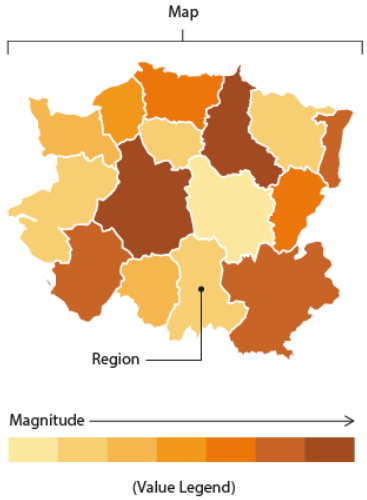
Bubble Map: anatomy

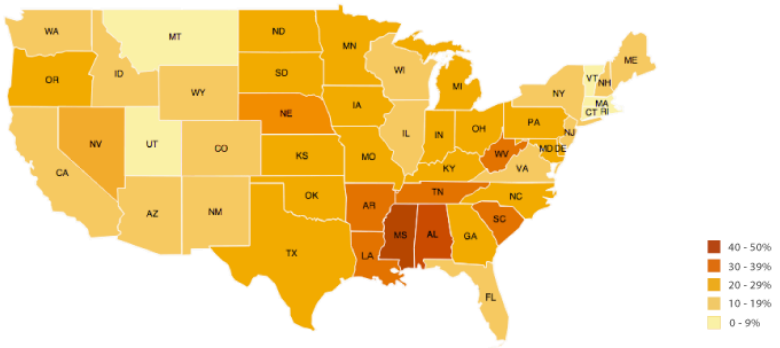
- What?
  - Geometry (position)
  - 1 quantitative attribute
- Why?
  - Locate data in space
  - Lookup and compare
- Remarks
  - Scale up to hundreds of items
  - Color can encode an additional categorical attribute (interaction with size).



Choropleth map: anatomy

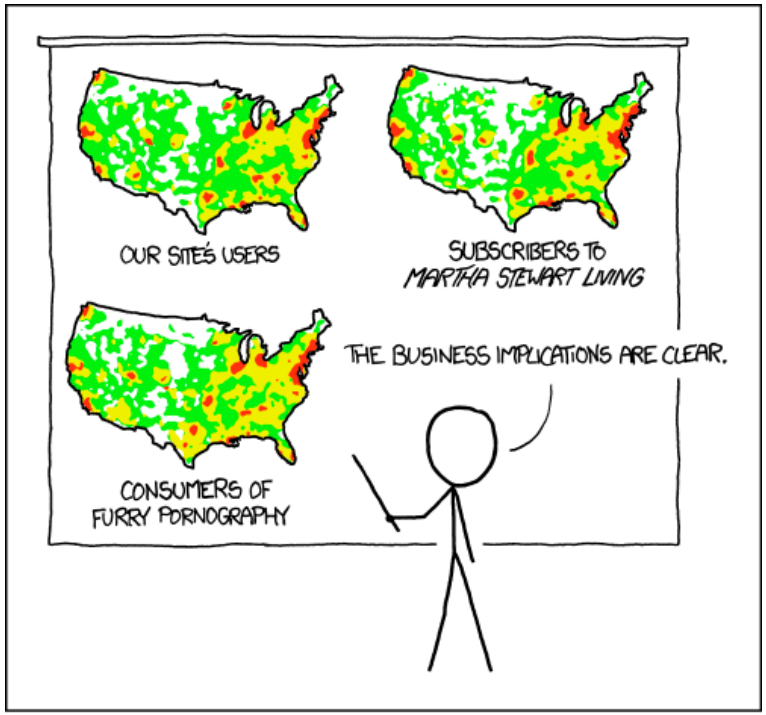
- What?
  - Geometry (position)
  - 1 quantitative attribute
- Why?
  - Locate data in space
  - Lookup and compare
- Remarks
  - Scale up to ~1000 items
  - Hue can encode an additional categorical attribute (better if binary)





Bias of population-related maps

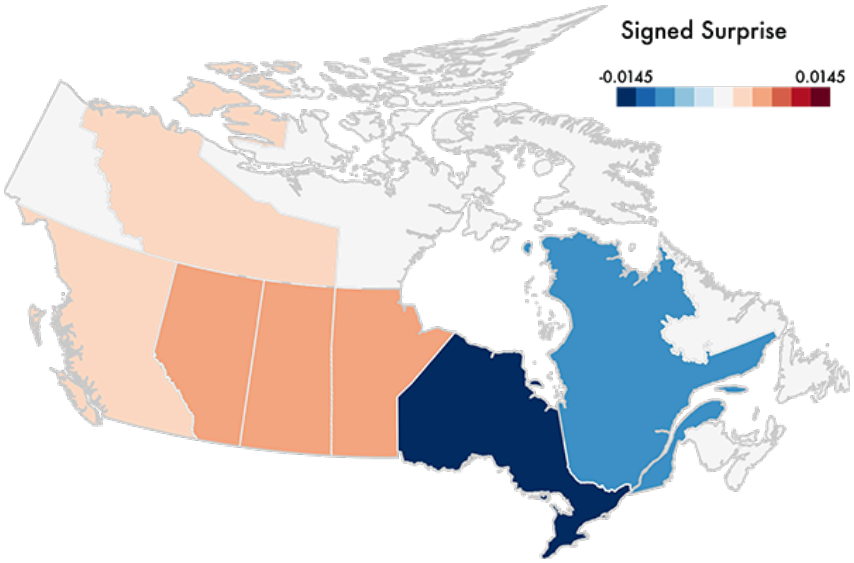
- Using absolute value is dangerous: any map would look like the populatio map!
- How to deal with this?
  - Visualize per capita (relative) values
  - Use statistical models



[https://xkcd.com/1138]

Surprise map: anatomy

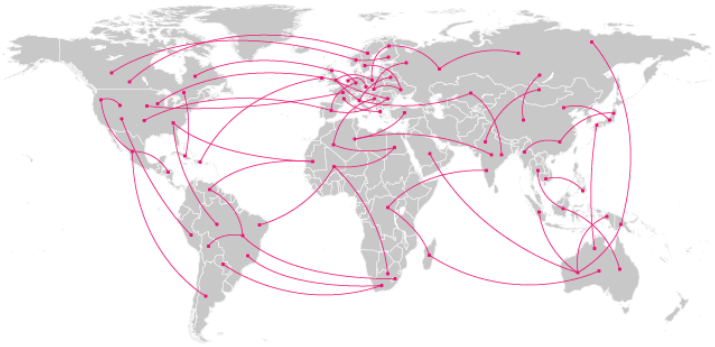
- What?
  - Geometry (position)
  - 1 quantitative attribute
  - 1 derivative attribute
- Why?
  - Locate data in space
  - Lookup and compare
- Remarks
  - The surprise is computed as a function prior and posterior probability of data distribution.
  - Prior probability is generated with a family of standard models.

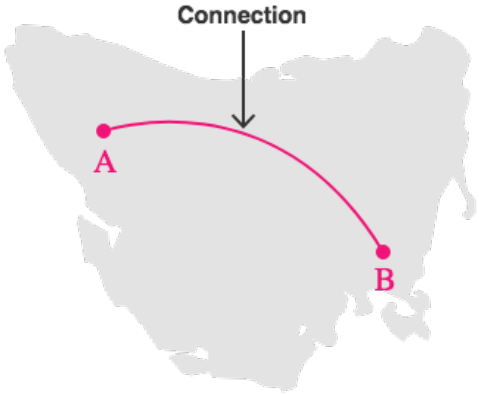


Correll & Heer (2016)

Connection map: anatomy

- What?
  - Network and positions
- Why?
  - Lookup path
  - Identify patterns
- Remarks
  - Size of links can encode an additional ordered attribute (3-4 bins at max)

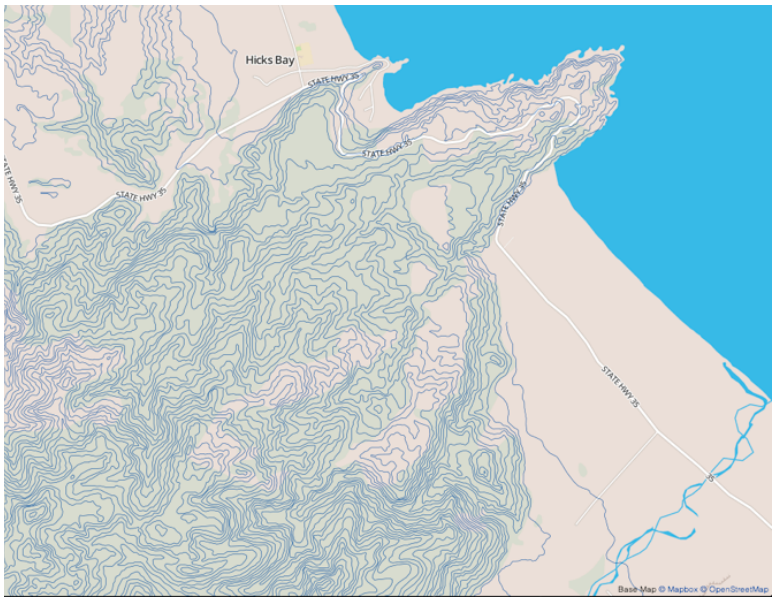




Scalar Fields

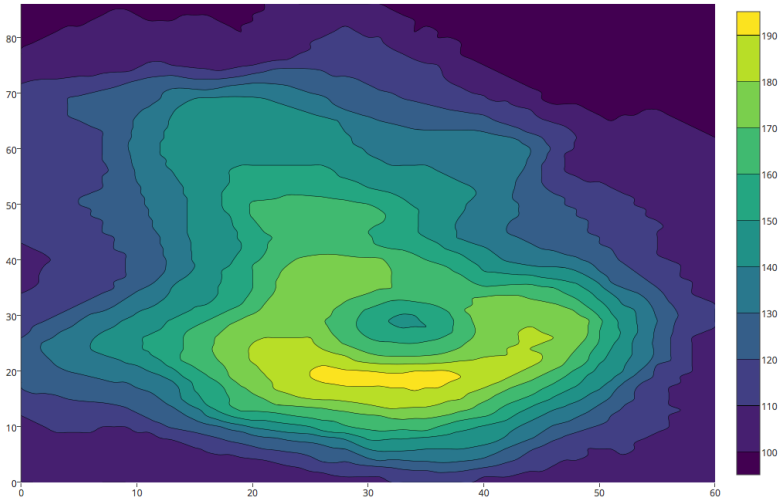
Isocontour map: anatomy

- What?
  - Geographic data
  - 1 quantitative attribute
  - derived positions
- Why?
  - Shape
- Remarks
  - The lines are computed from the values of scalar field
  - Area can be filled and color encoded



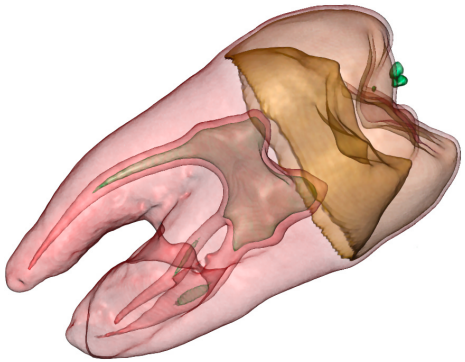
Isocontour plot: anatomy

- What?
  - 2D spatial field
  - 1 quantitative attribute
  - derived geometry
- Why?
  - Shape and patterns
- Remarks
  - The lines are computed from the values of scalar field
  - Area can be empty or filled and color encoded



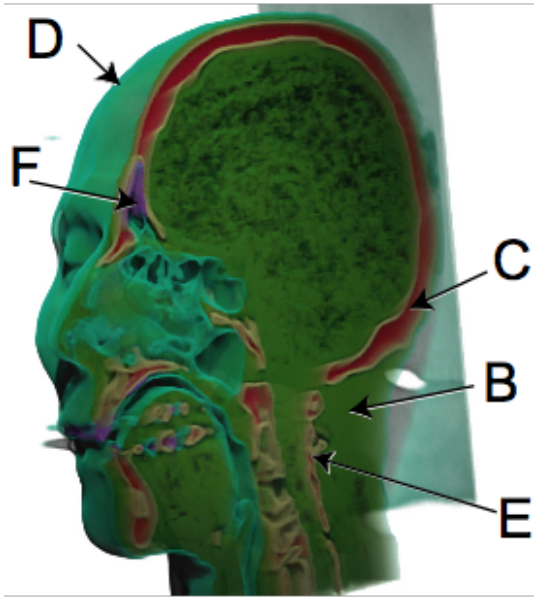
Isosurface plot: anatomy

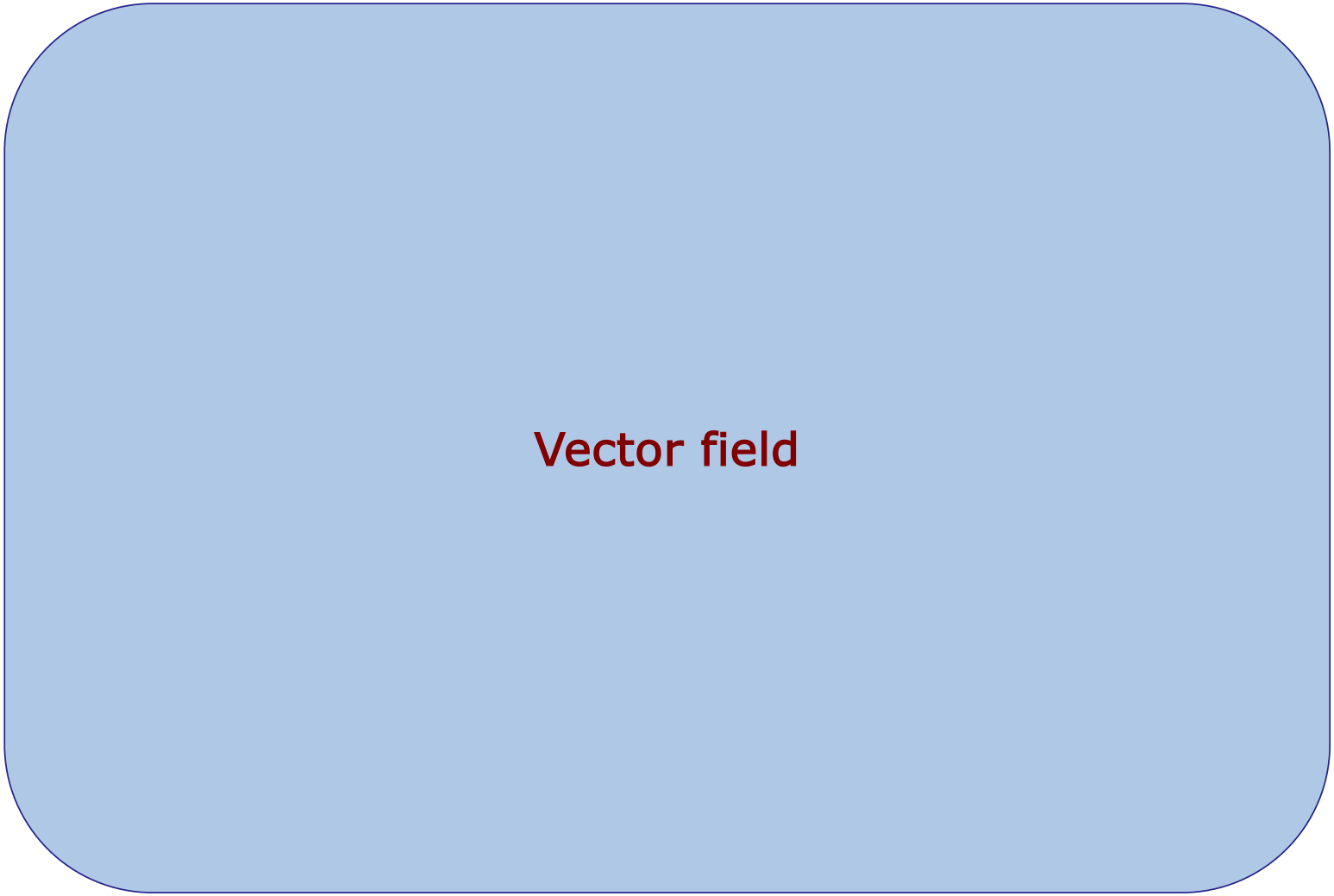
- What?
  - 3D spatial scalar field
  - 1 quantitative attribute
  - derived geometry
- Why?
  - Shape
- Remarks
  - Tree of isosurfaces: positions computed for specific values of the scalar field



Direct volume rendering: anatomy

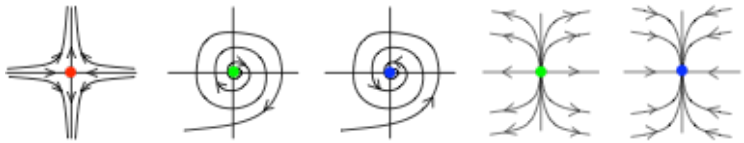
- What?
  - 3D spatial scalar field
  - 1 quantitative attribute
- Why?
  - Shape
- Remarks
  - The values in the field (and the gradient) are mapped directly to color and opacity

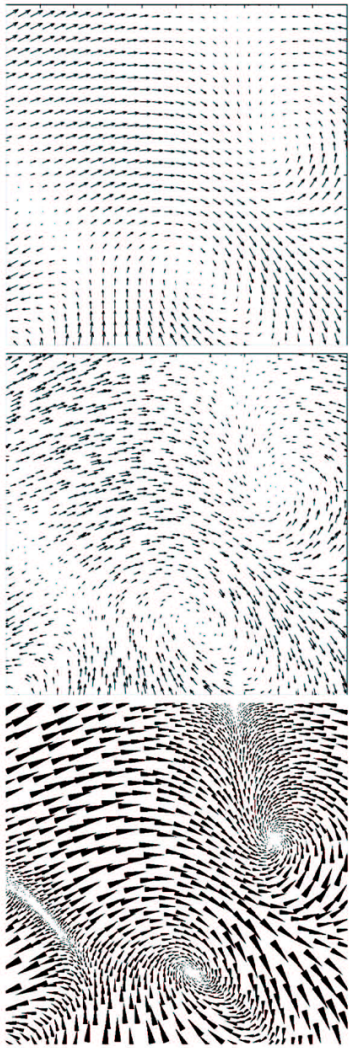



Vector field

Glyph flow: anatomy

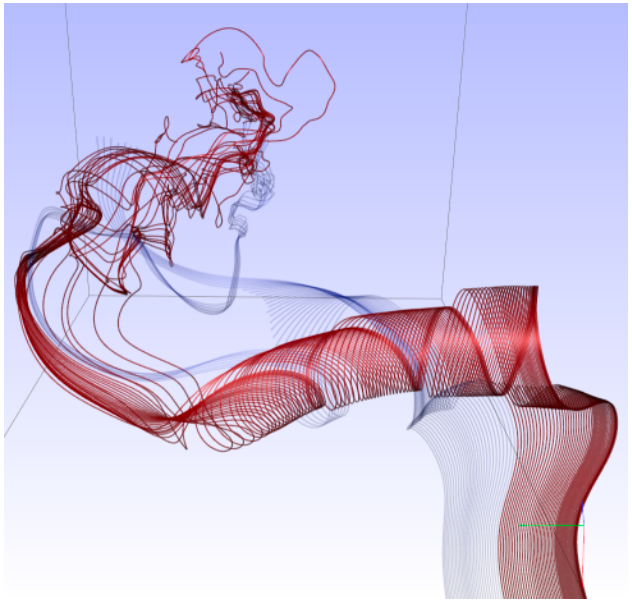
- What?
  - 2D vectorial field
- Why?
  - Shape and patterns
  - Identify critical points
- Remarks
  - Different glyphs can be used to represent vectors
  - Density of grid and jittering





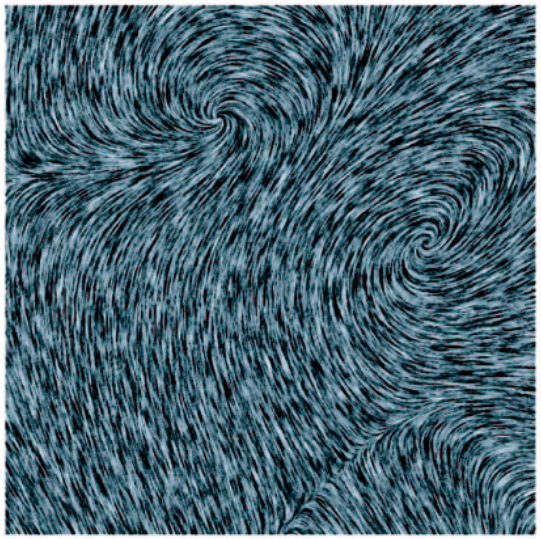
Geometric flow: anatomy

- What?
  - 2D/3D vectorial field
  - derived geometry
- Why?
  - Shape and patterns
  - Identify critical points
- Remarks
  - Seeding strategy affects the outcome
  - Usage of clustering and color coding improves readability



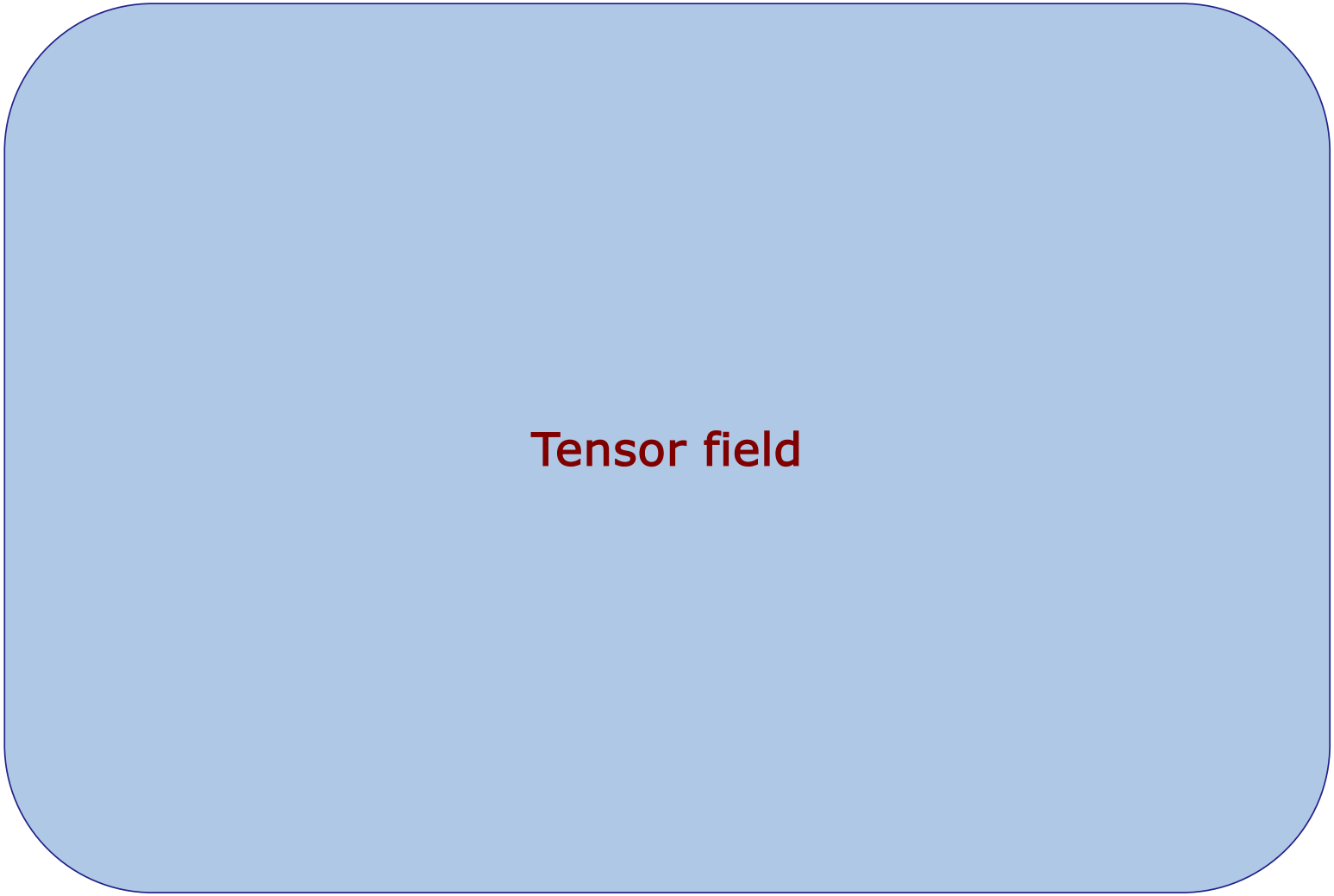
Texture flow: anatomy

- What?
  - 2D vectorial field
- Why?
  - Shape and patterns
  - Identify critical points
- Remarks
  - Similar to glyphs flow, but computes the flow of a continuous distribution of particles



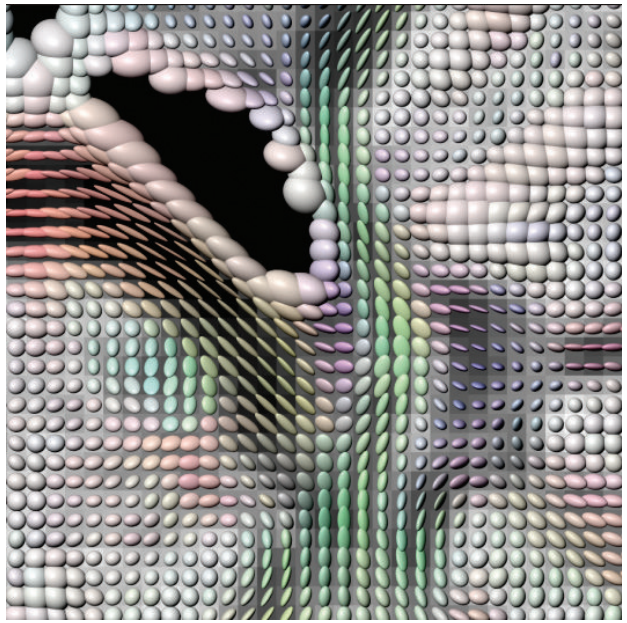
Feature flow: anatomy

- What?
  - 2D vectorial field
- Why?
  - Shape and patterns
  - Identify critical points
- Remarks
  - Similar to glyphs flow, but seeding is based on global computing strategy to identify areas with similar behaviors


Tensor field

Ellipsoid tensor glyphs: anatomy

- What?
  - 2D/3D tensor field
- Why?
  - Shape and patterns
- Remarks
  - Use shape, orientation, color, opacity to represents field tensors



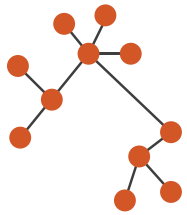
VISUALIZING TREES AND NETWORKS

Major approaches

Node–Link Diagrams

Connection Marks

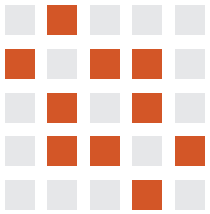
✔ NETWORKS ✔ TREES



Adjacency Matrix

Derived Table

✔ NETWORKS ✔ TREES



Enclosure

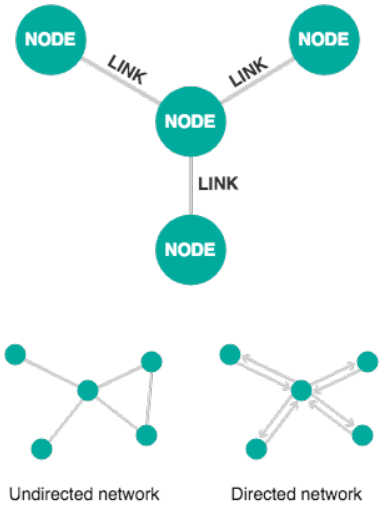
Containment Marks

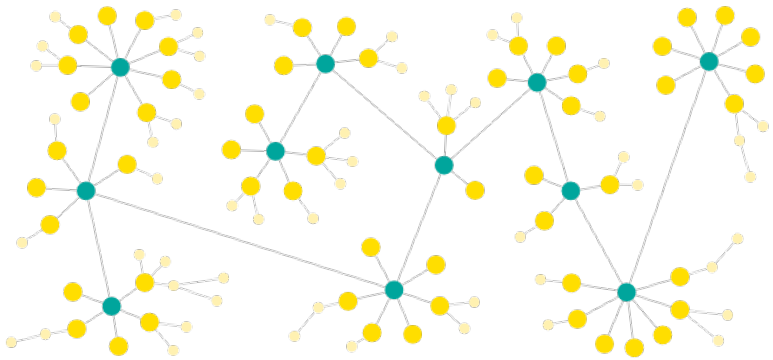
✖ NETWORKS ✔ TREES

Node-Link Diagrams

Node-link diagram: anatomy

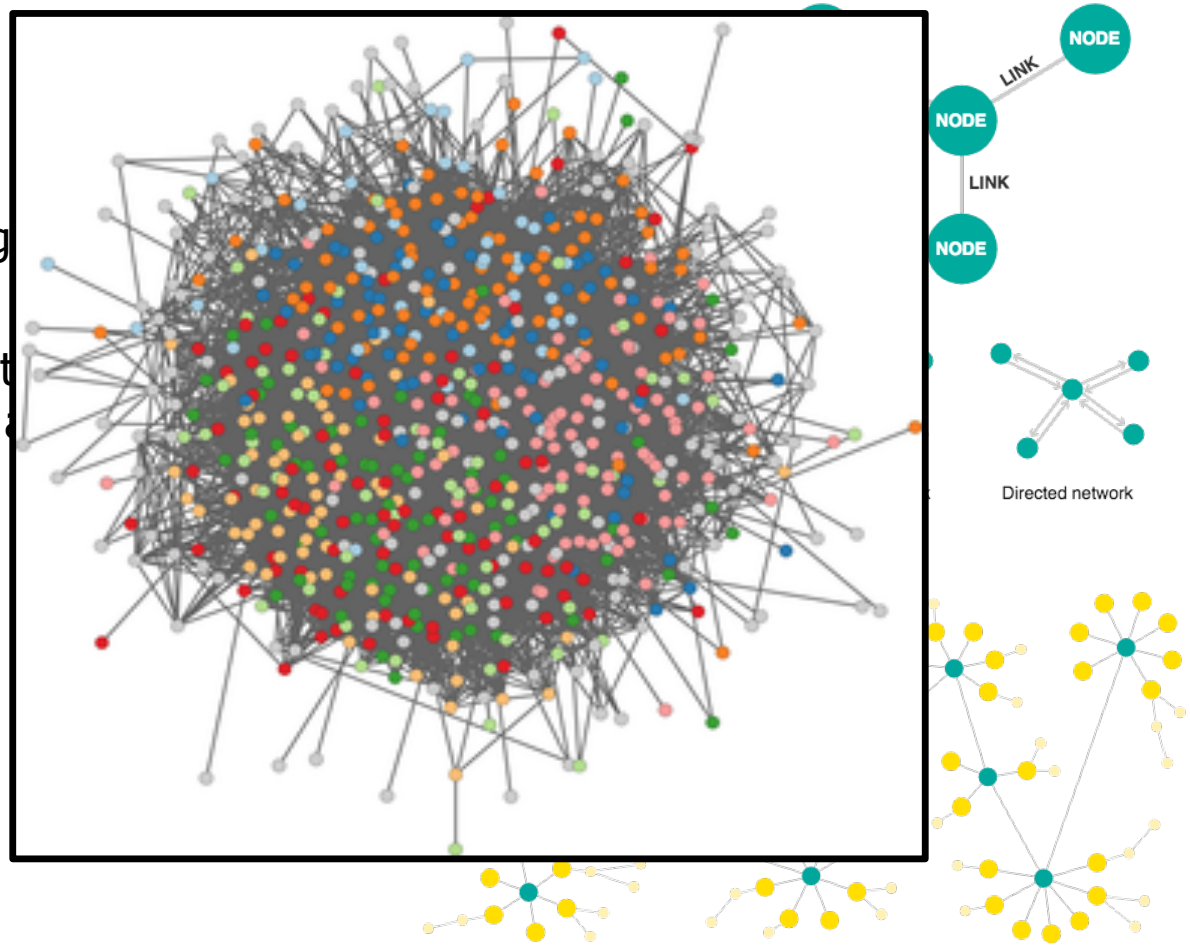
- What?
  - Network
- Why?
  - Explore topology and locate paths
- Remarks
  - Different algorithms to compute layout (sfdp, planar, radial, etc.)
  - **Hairball effect**





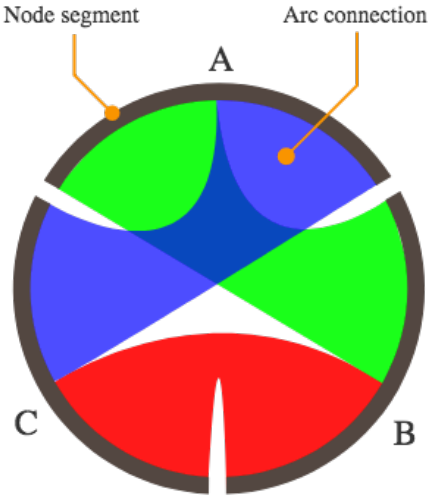
Node-link diagram: anatomy

- What?
  - Network
- Why?
  - Explore topolog
- Remarks
  - Different algorit
    layout (sfdp, pl
  - **Hairball effect**



Chord diagram: anatomy

- What?
  - Network (adjacency matrix)
- Why?
  - Explore connections
  - Identify patterns
- Remarks
  - Size is used to encode quantitative attribute of links
  - Color encodes an additional categorical attribute (or grouping)



	A	B	C
A		10	10
B	10		10
C	10	10	

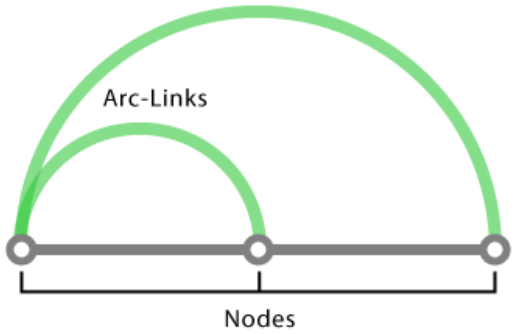
A $\xrightarrow{10}$ B

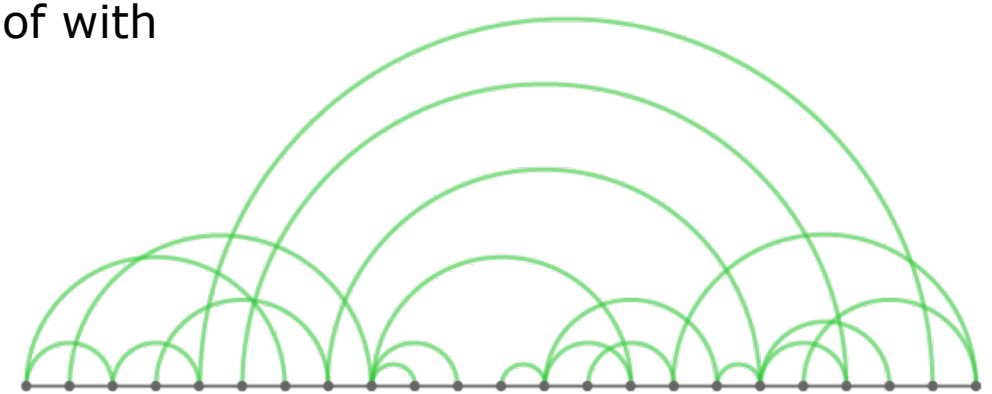
B $\xrightarrow{10}$ C

C $\xrightarrow{10}$ A

Arc diagram: anatomy

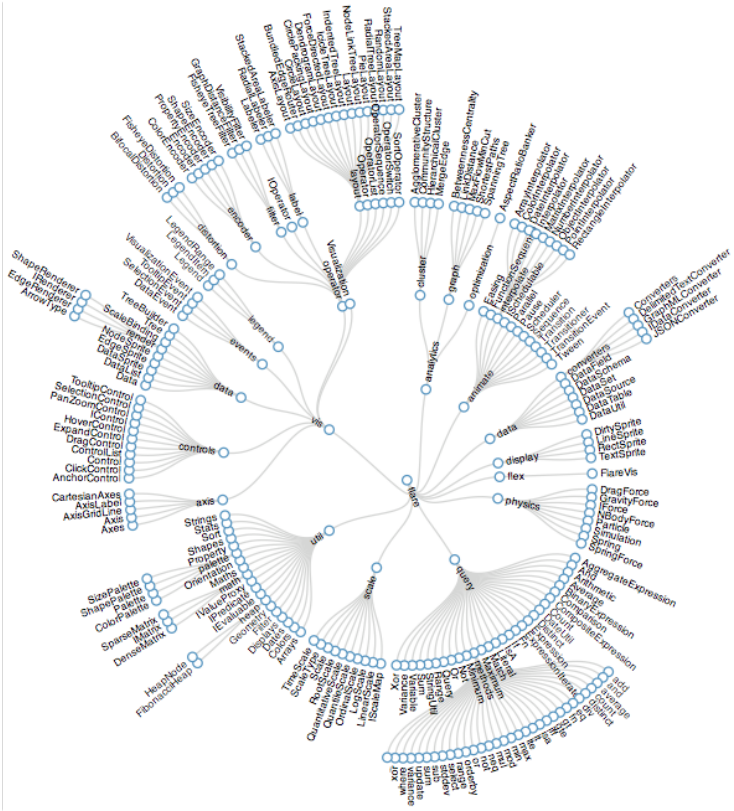
- What?
  - Network (links)
- Why?
  - Locate links and paths
  - Identify patterns
- Remarks
  - Don’t show the topology
  - Encode additional attribute of with link size (ordered) or color (categorical)





Node-link diagram: anatomy

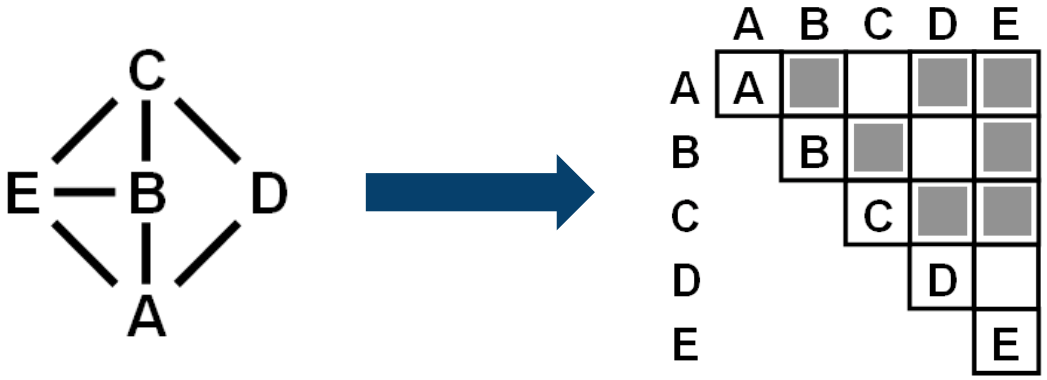
- What?
  - Tree
- Why?
  - Explore topology and locate paths
- Remarks
  - Scale up to 1-10K nodes



Adjacency Matrix

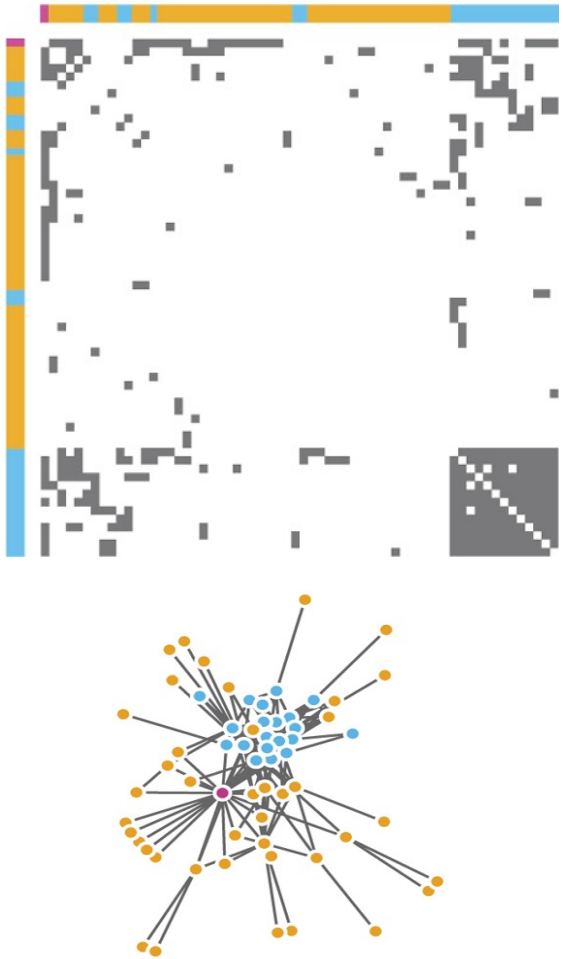
Representing networks with matrix

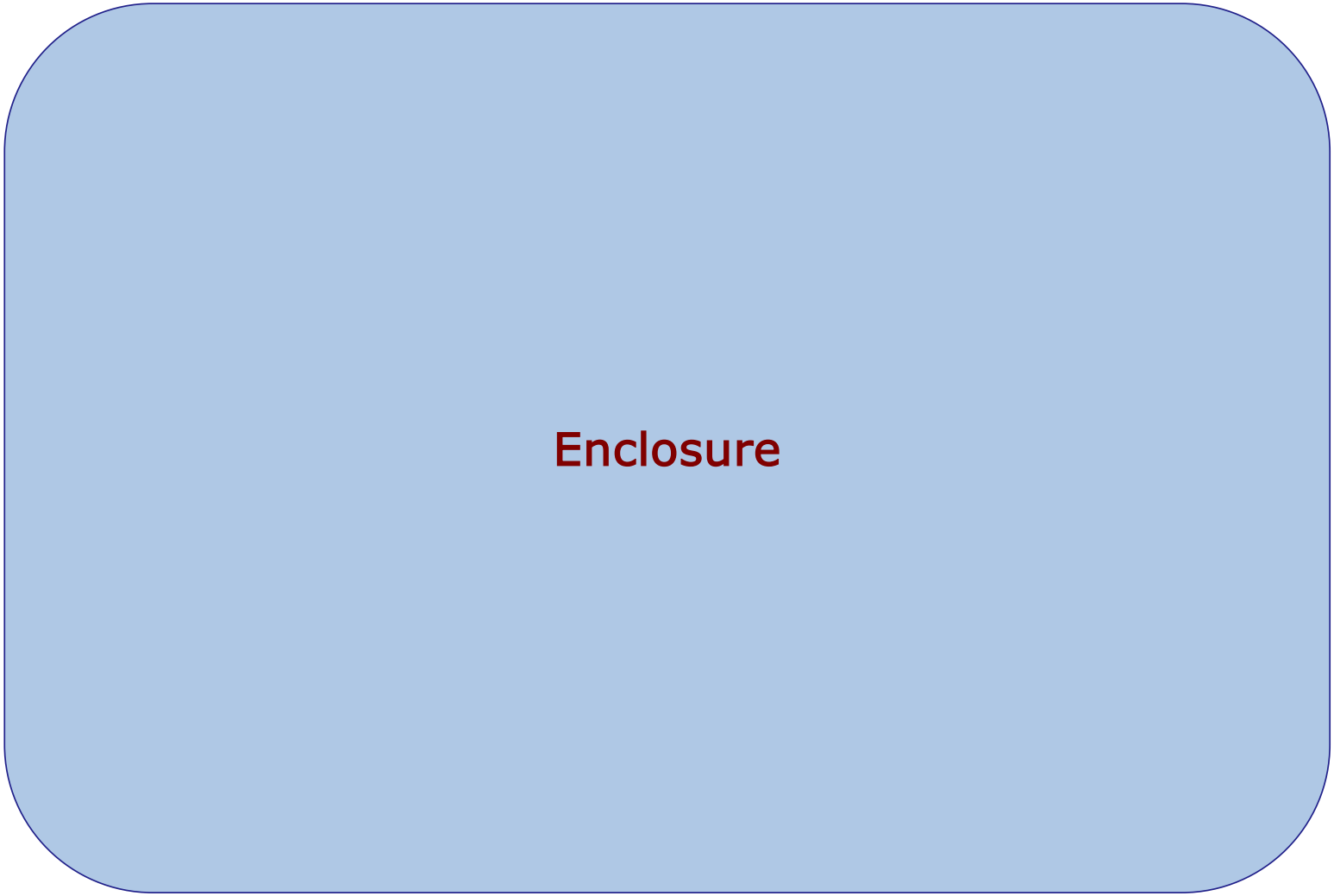
- Adjacency matrix are built from a network:
  - size NxN, with N is the number of nodes
  - M[i,j]≠0 if node i and j are connected
  - M[i,j] might also encode a quantitative attribute of the link



Adjacency matrix: anatomy

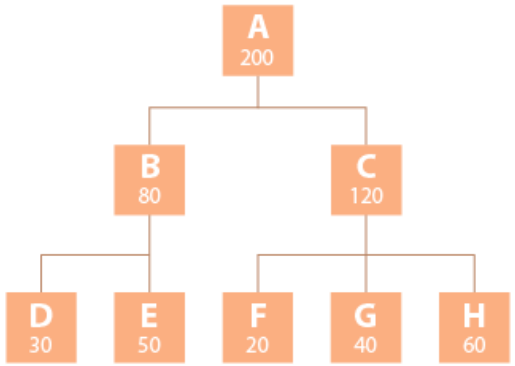
- What?
  - Network
  - Derived Table (2 categorical, 1 quantitative)
- Why?
  - Discover cluster and connectivity patterns
- Remarks
  - Scale up to 1000 nodes and 1M links
  - Color can encode a quantitative attribute of links (e.g., weight)

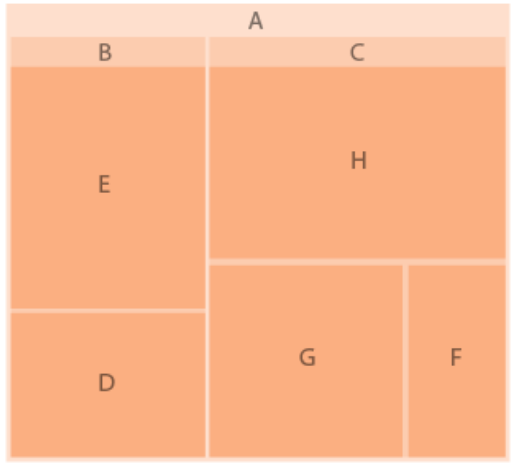



Enclosure

TreeMap: anatomy

- What?
  - Tree
- Why?
  - Part-to-whole
  - Identify hierarchy
- Remarks
  - Recursion allows to manage many levels
  - Color to encode an additional attribute

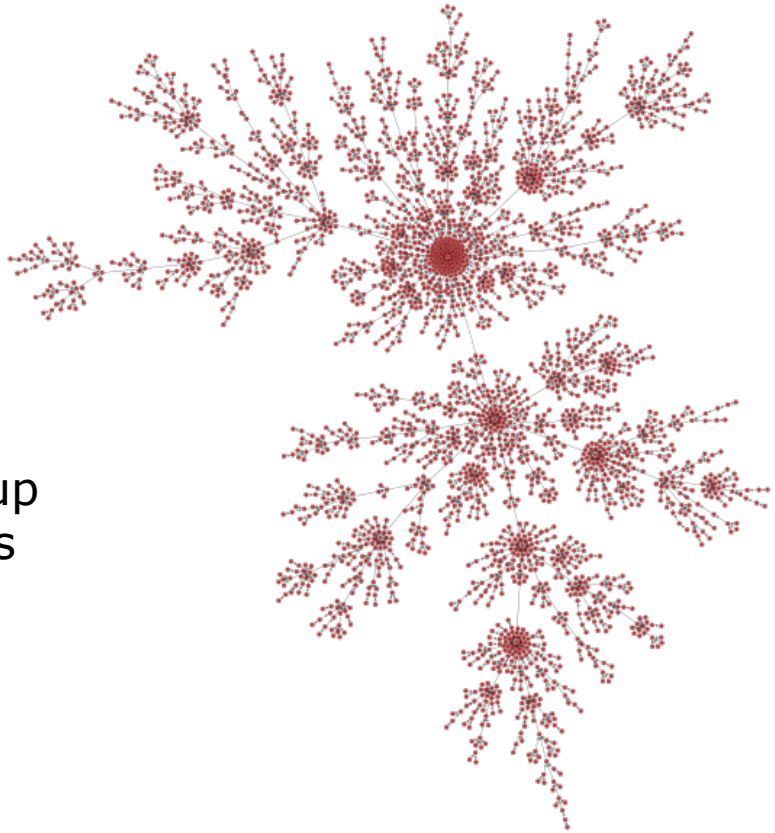





Insights

Force-Directed Placement

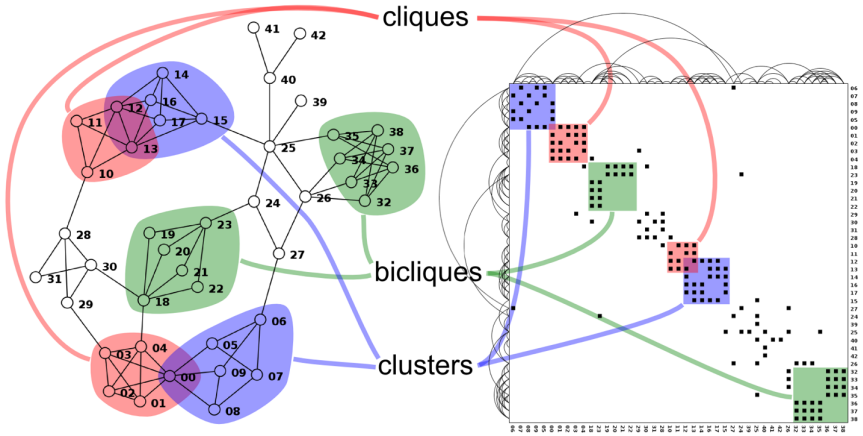
- A popular algorithm to build network layout based on a simulation of physical forces:
  - Node repel each others
  - Links act as springs
  - Scales up to 50-100 nodes and links < 4*nodes
- A multilevel version (sfdp) try to preserve local structures and scales up to 1K-10K nodes and links < 4*nodes



Adj matrix vs node-link diagrams

- Benefit of adj matrix:
  - predictability, scalability, supports reordering
  - some topologies can be identified with training

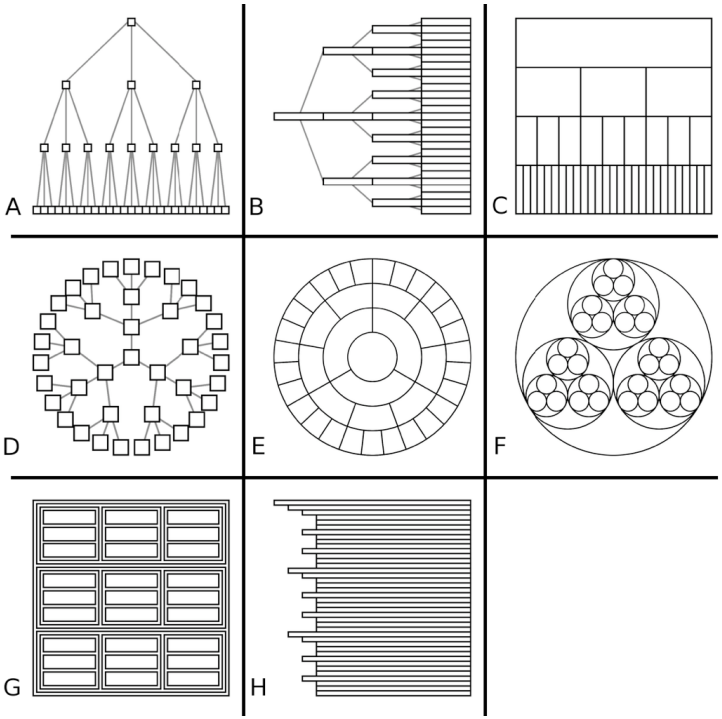
- Benefit of node-link diagram:
  - topology understanding, path tracing
  - intuitive, no training needed



- Guidelines
  - node-link best for small networks
  - matrix best for large networks (if topology is not the focus)

Layouts for trees

- Data to visualize:
  - link relationships
  - tree depth
  - sibling order
- Design choices
  - rectilinear or radial layout
  - connection or containment



[See McGuffin and Robert (2010)]