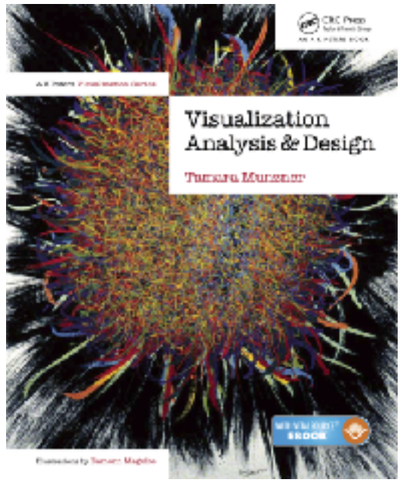
Visualization Analysis & Design



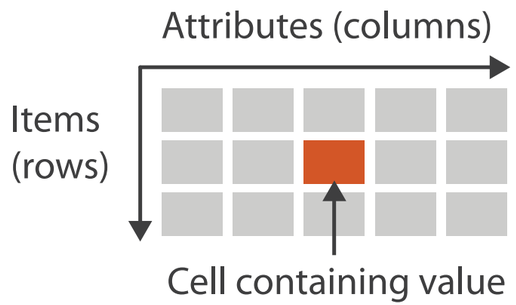
Arrange Tables (Ch 7) I

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

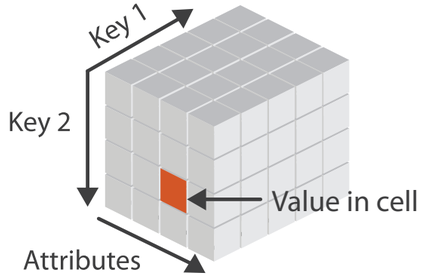
Focus on Tables

Dataset Types

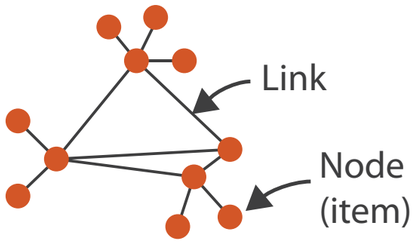
Tables



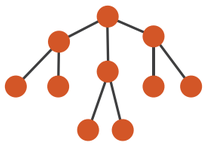
Multidimensional Table



Networks

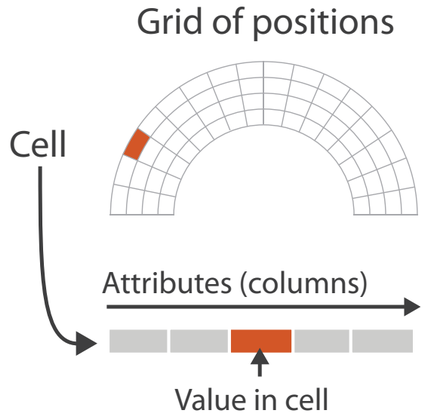


Trees

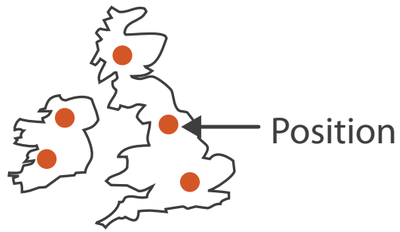


Spatial

Fields (Continuous)



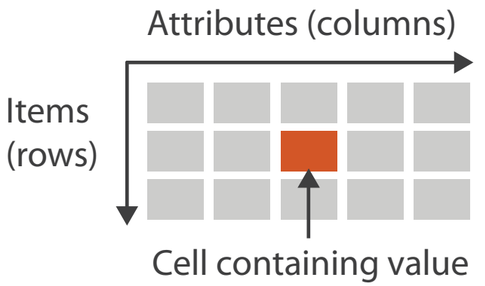
Geometry (Spatial)



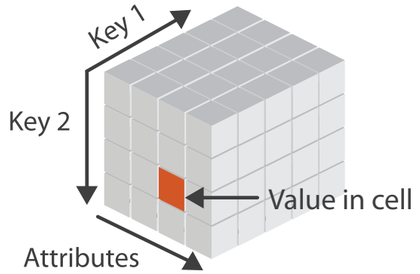
Keys and values

- 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

➔ Tables



➔ *Multidimensional Table*



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 keys used
  - 0, 1, 2, ...

➔ *0 Keys*

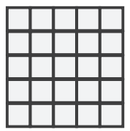
➔ **Express Values**

➔ *1 Key*

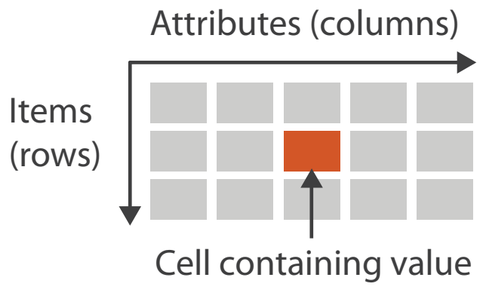
List

➔ *2 Keys*

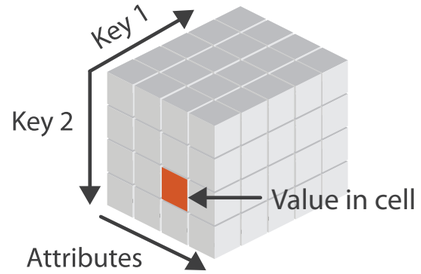
Matrix



➔ Tables

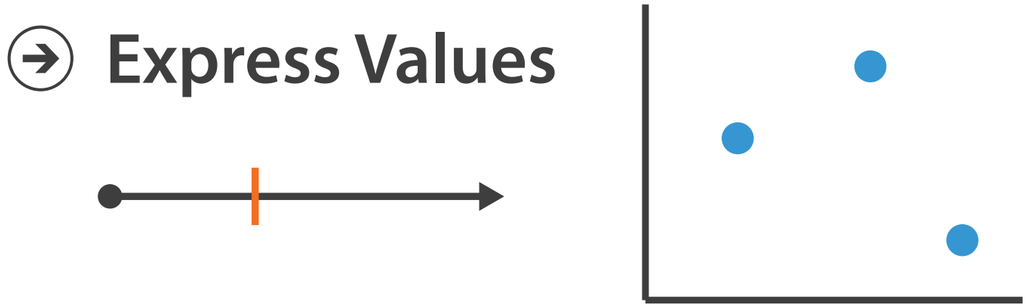


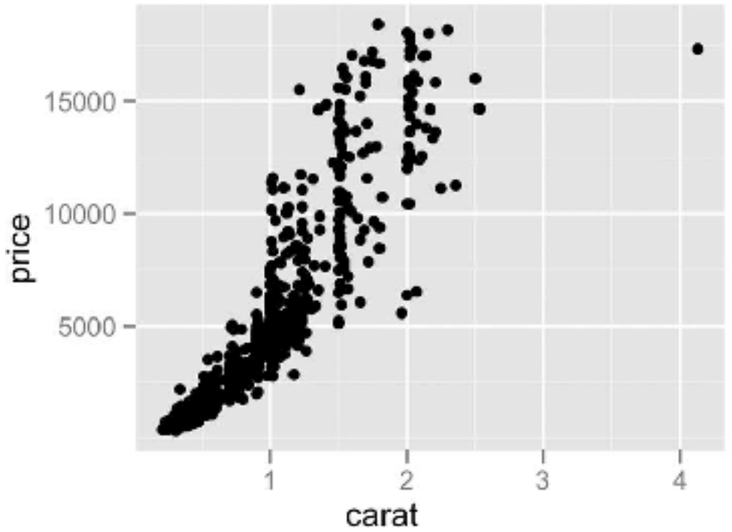
➔ *Multidimensional Table*

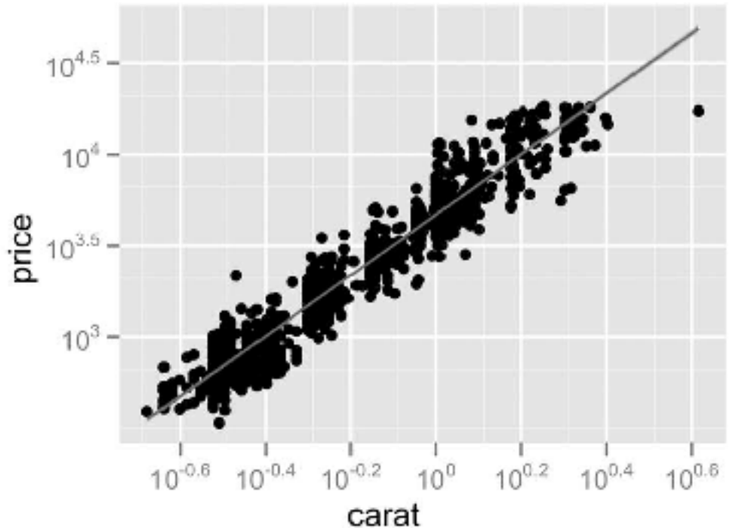


Idiom: **scatterplot**

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



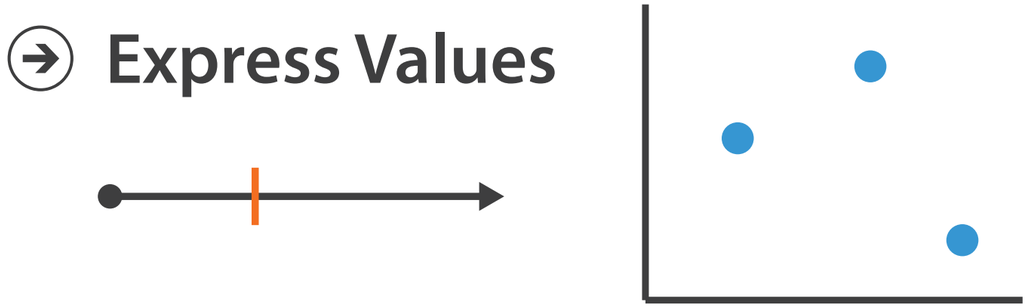


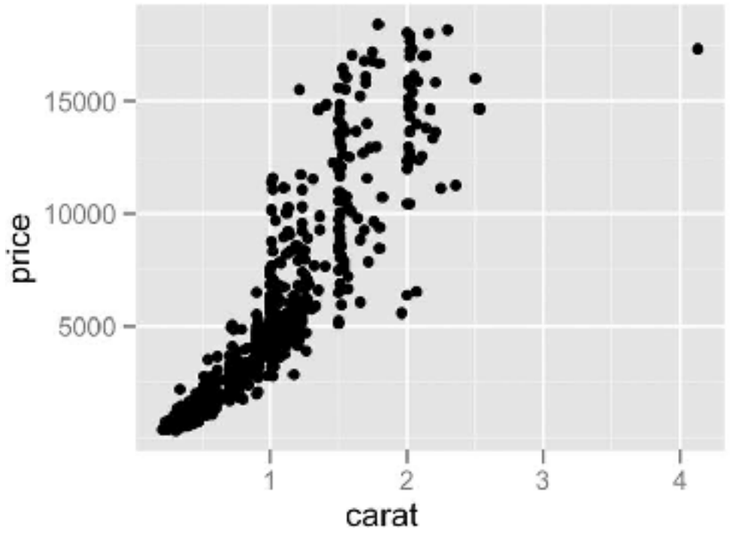


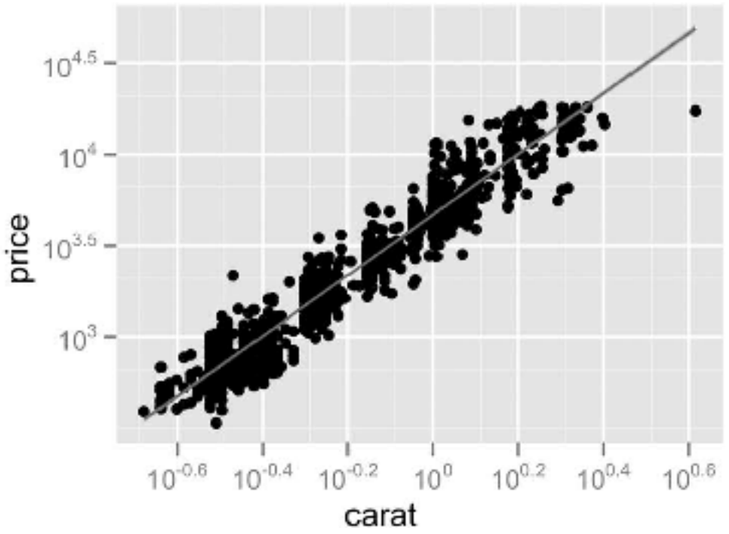
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: **scatterplot**

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

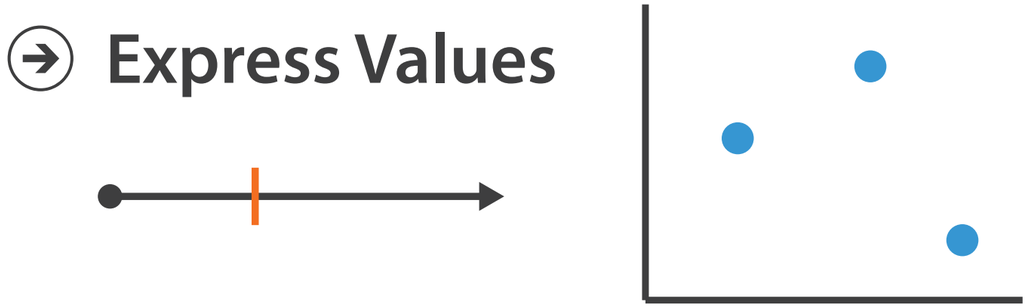




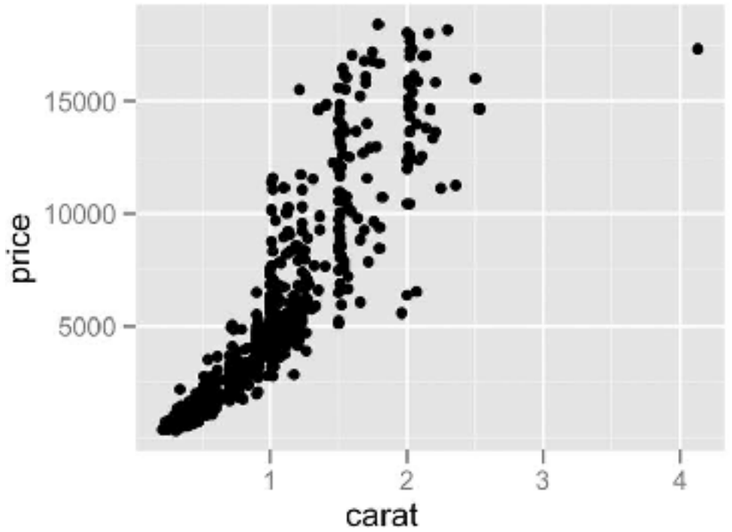


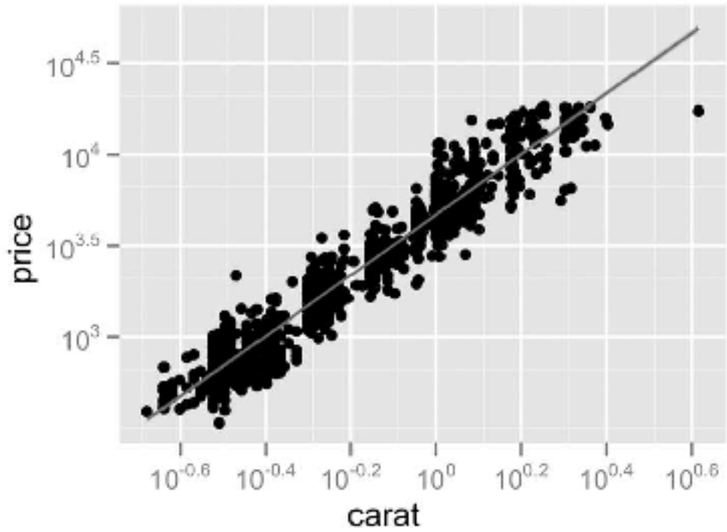
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: **scatterplot**



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

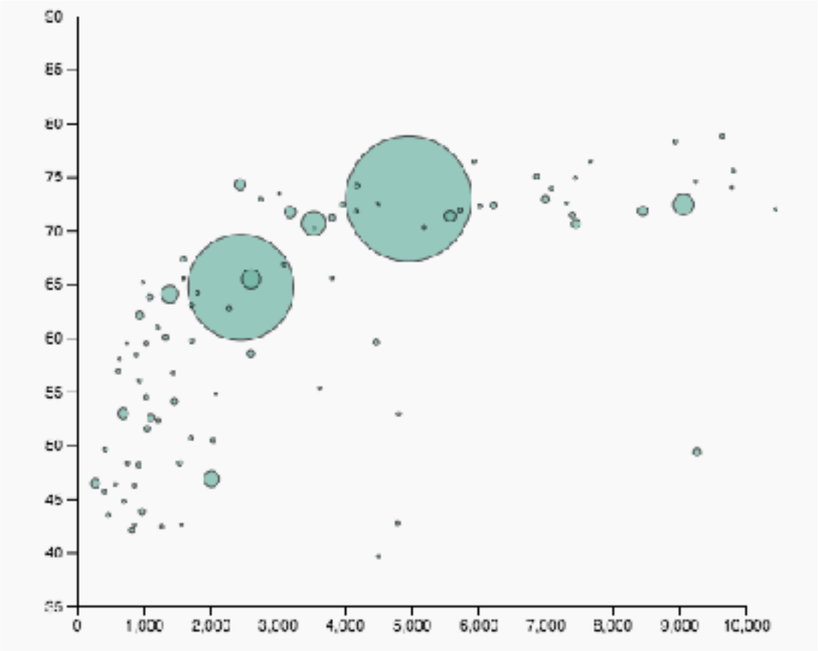


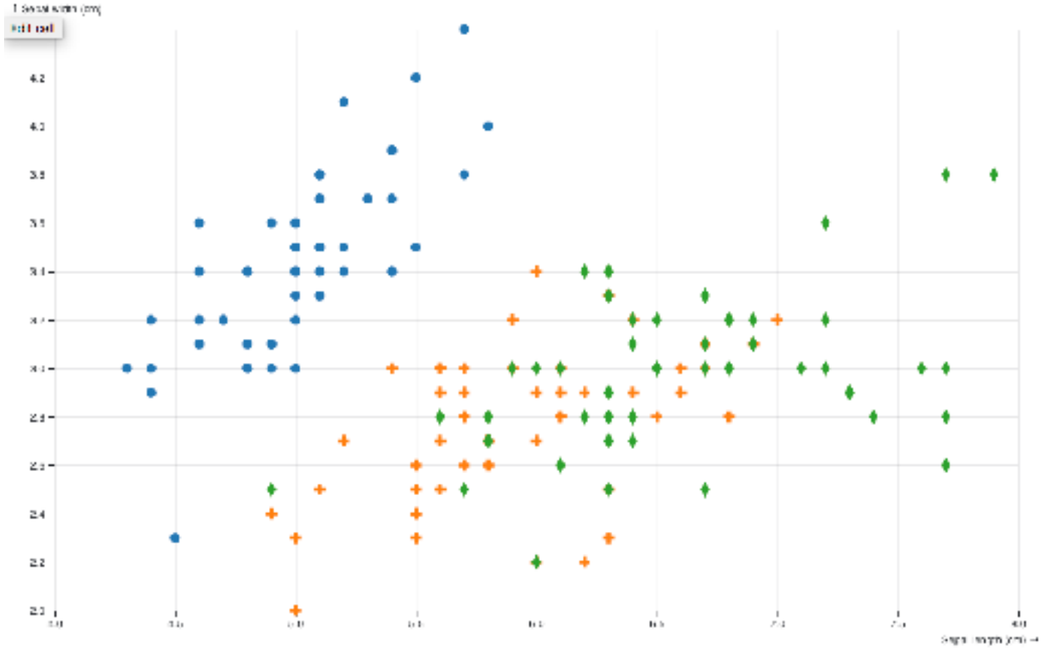


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Scatterplots: Encoding more channels

- additional channels viable since using point marks
  - color
  - size (1 quant attribute, used to control 2D area)
    - note radius would mislead, take square root since area grows quadratically
  - shape





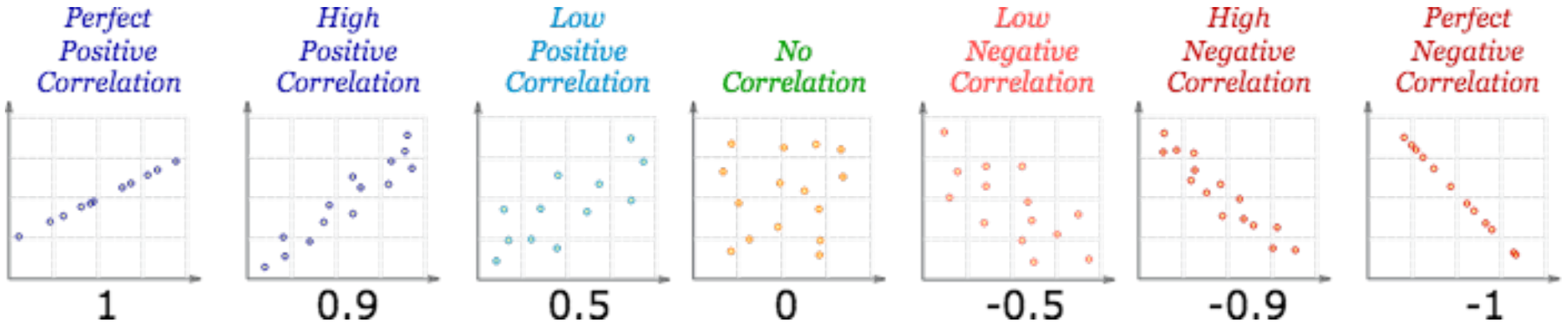
https://www.d3-graph-gallery.com/graph/bubble_basic.html

https://observablehq.com/@d3/scatterplot-with-shapes

Scatterplot tasks

Scatterplot tasks

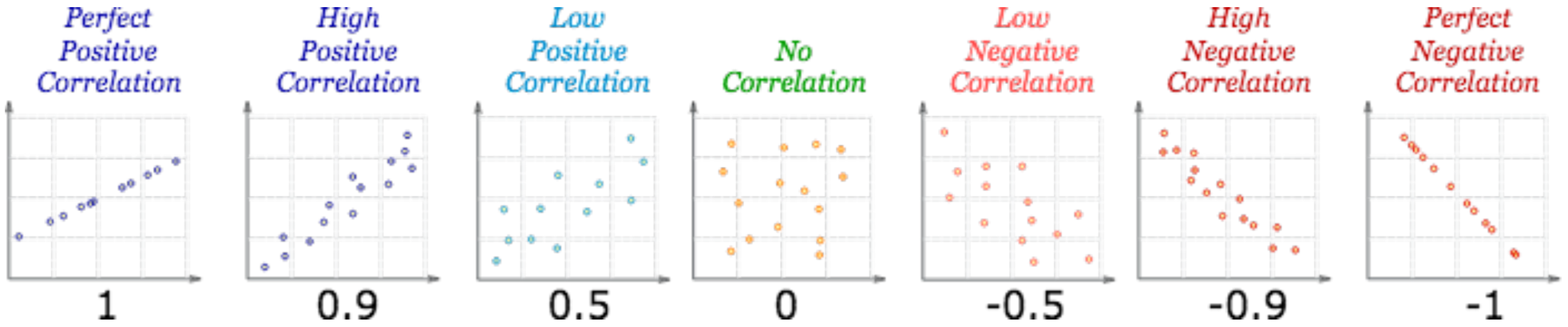
- correlation



https://www.mathsisfun.com/data/scatter-xy-plots.html

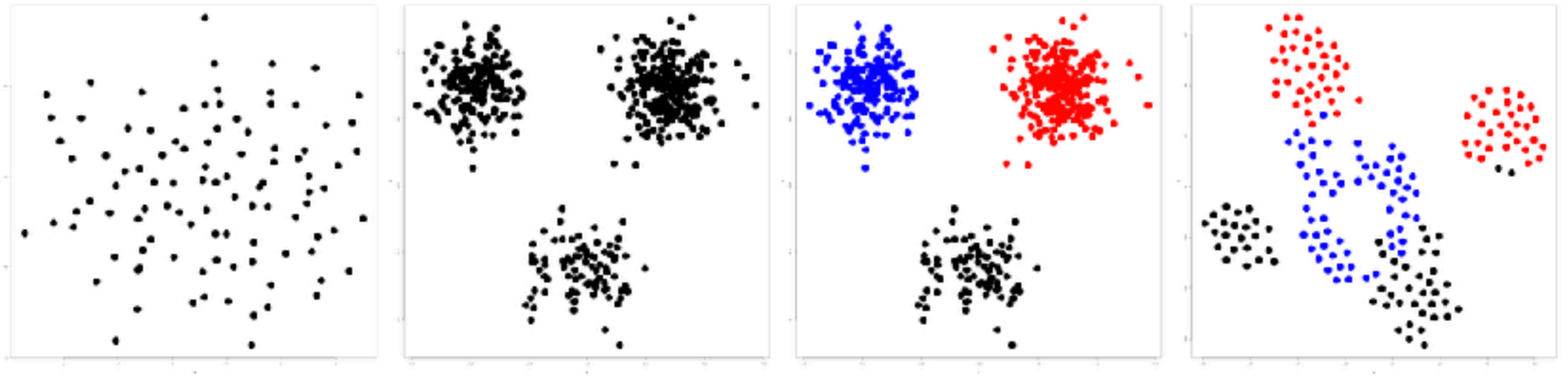
Scatterplot tasks

- correlation



https://www.mathsisfun.com/data/scatter-xy-plots.html

- clusters/groups, and clusters vs classes



https://www.cs.ubc.ca/labs/imager/tr/2014/DRVisTasks/

Some keys

- *0 Keys*

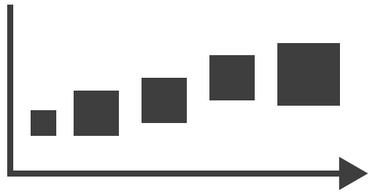
Express Values

- *1 Key*
  List
- *2 Keys*
  Matrix

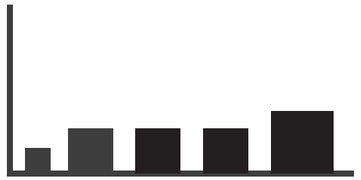
Some keys: Categorical regions

- Separate

- Order



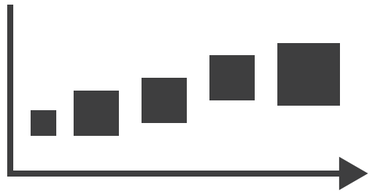
- Align



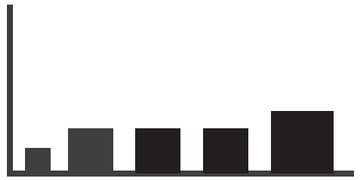
Regions: Separate, order, align

➔ Separate

➔ Order

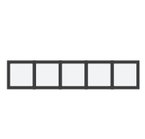


➔ Align

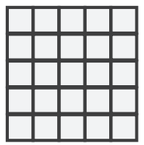


- regions: contiguous bounded areas distinct from each other
  - separate into spatial regions: one mark per region (for now)
- use categorical or ordered attribute to separate into regions
  - no conflict with expressiveness principle for categorical attributes
- use ordered attribute to order and align regions

➔ *1 Key*
List

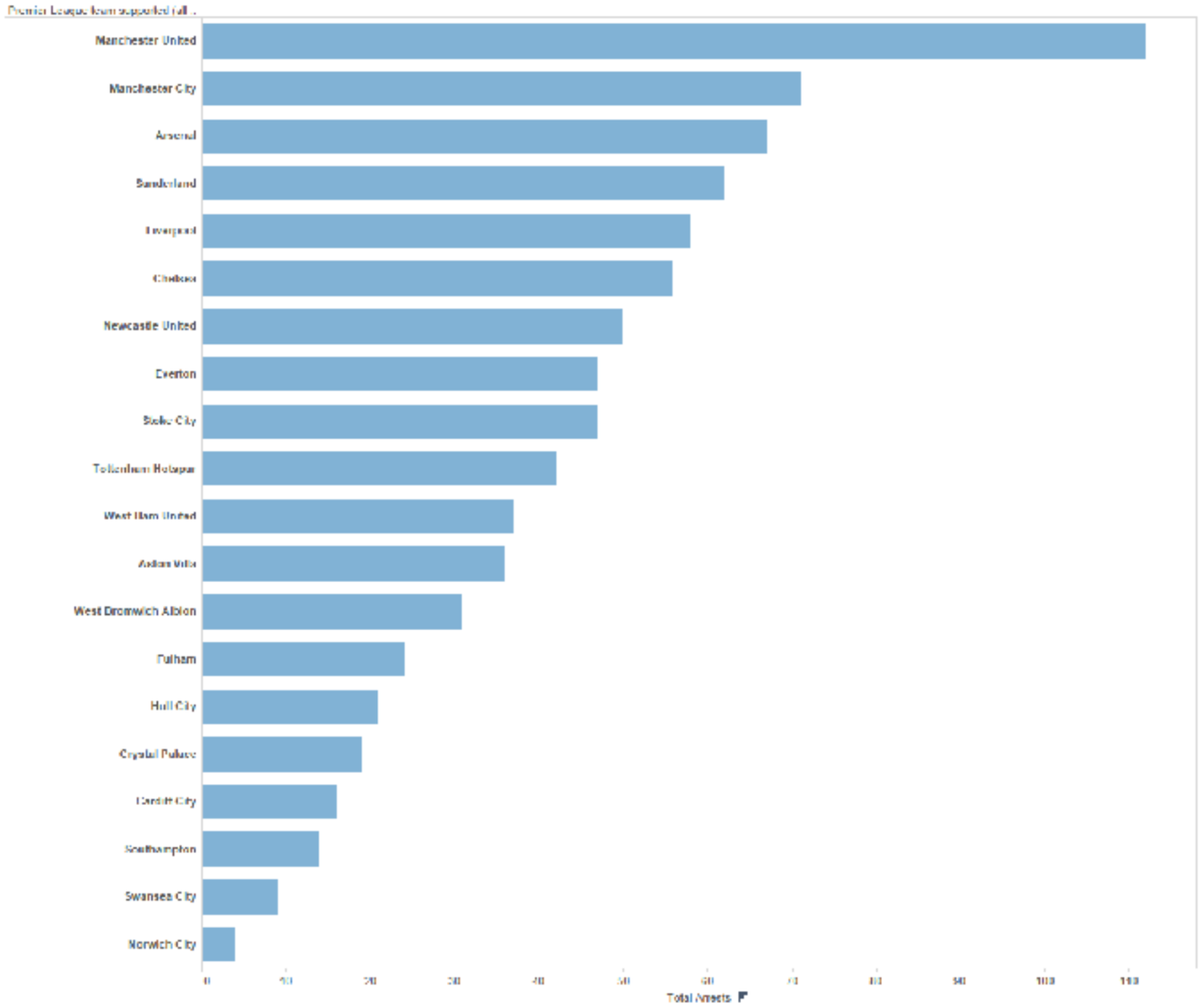


➔ *2 Keys*
Matrix



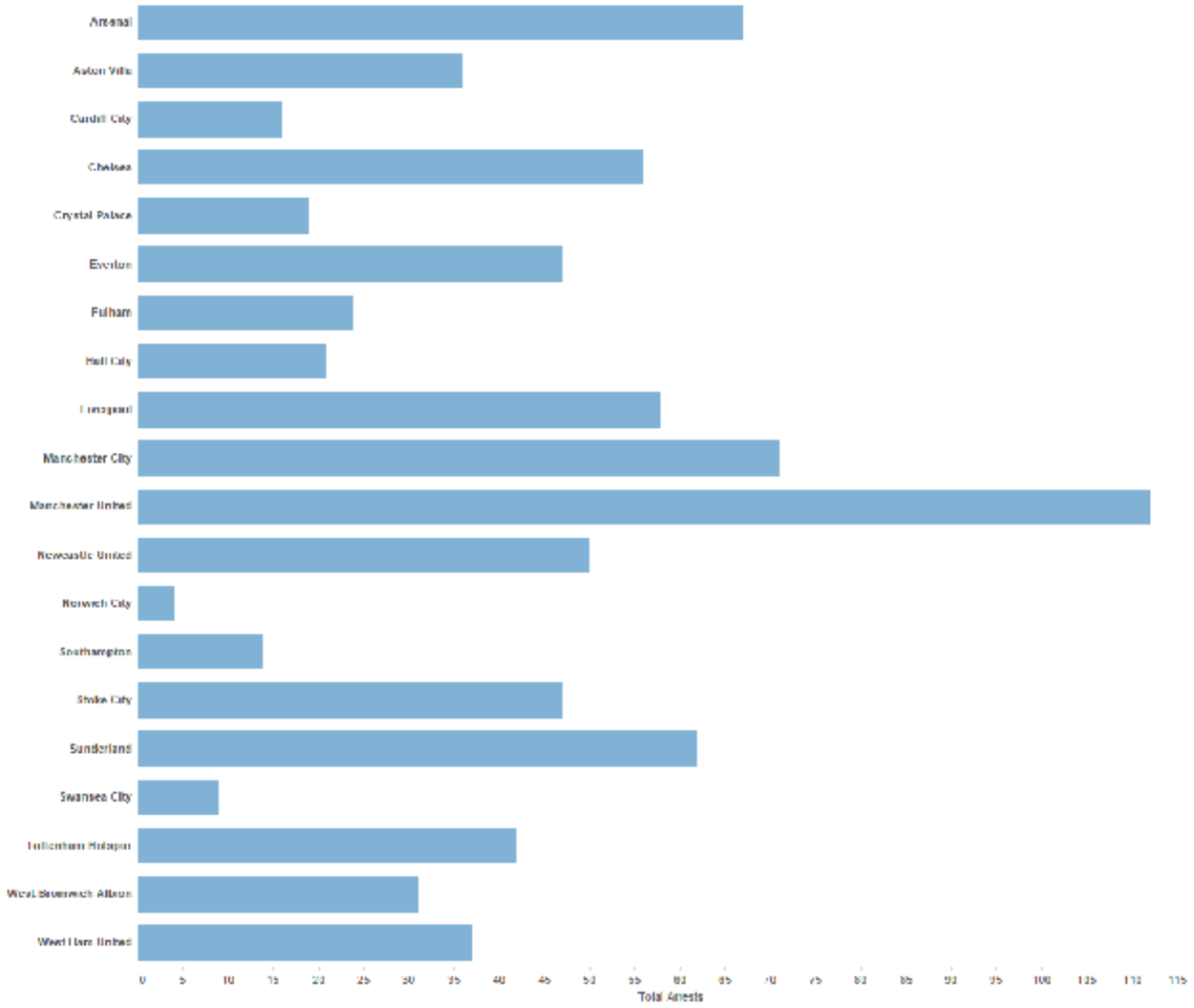
Separated and aligned and ordered

- best case



Separated and aligned but not ordered

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

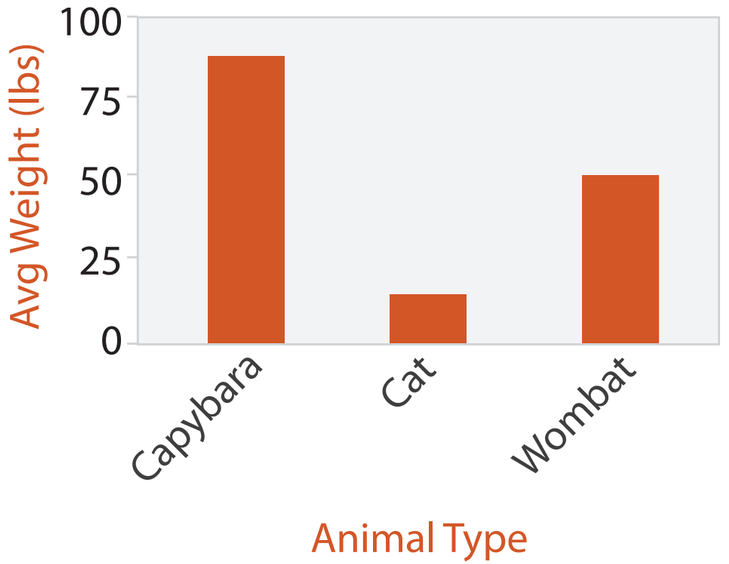


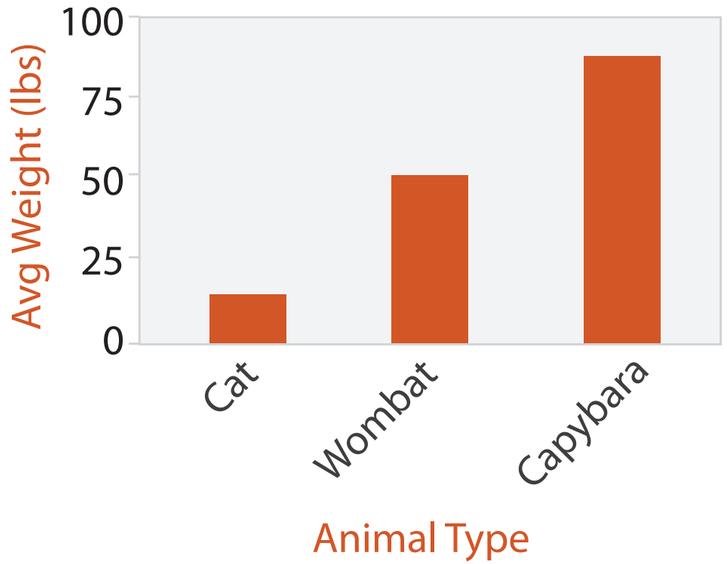
Separated but not aligned or ordered

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

Idiom: **bar chart**

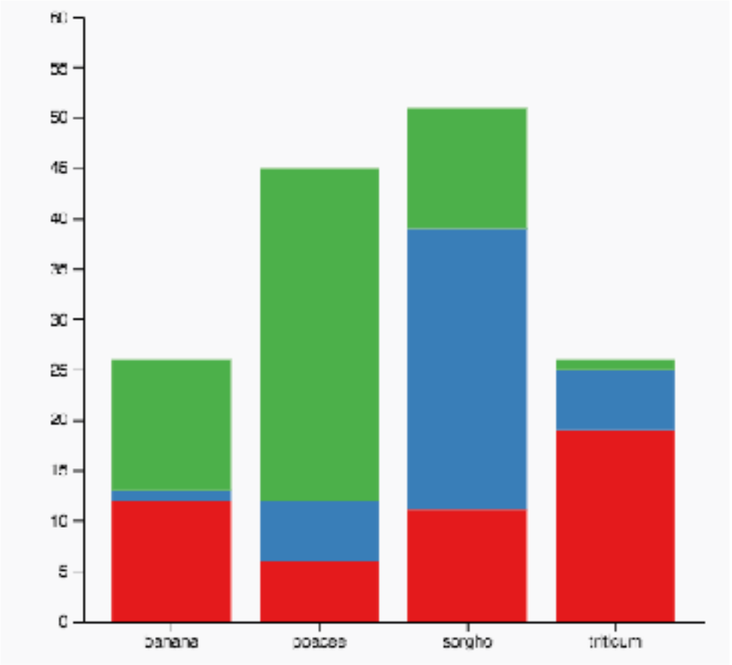
- one key, one value
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
  - channels
    - length to express quant value
    - spatial regions: one per mark
      - separated horizontally, aligned vertically
      - ordered by quant attrib
        - » by label (alphabetical), by length attrib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





Idiom: **stacked bar chart**

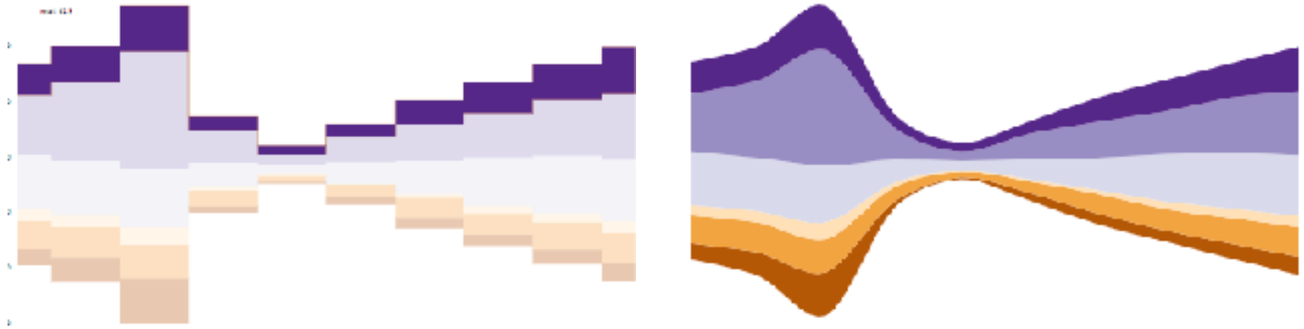
- one more key
  - data
    - 2 categ attrib, 1 quant attrib
  - mark: vertical stack of line marks
    - **glyph**: composite object, internal structure from multiple marks
  - channels
    - length and color hue
    - spatial regions: one per glyph
      - aligned: full glyph, lowest bar component
      - unaligned: other bar components
  - task
    - part-to-whole relationship
  - scalability: asymmetric
    - for *stacked* key attrib, 10-12 levels [segments]
    - for *main* key attrib, dozens to hundreds of levels [bars]



https://www.d3-graph-gallery.com/graph/barplot_stacked_basicWide.html

Idiom: **streamgraph**

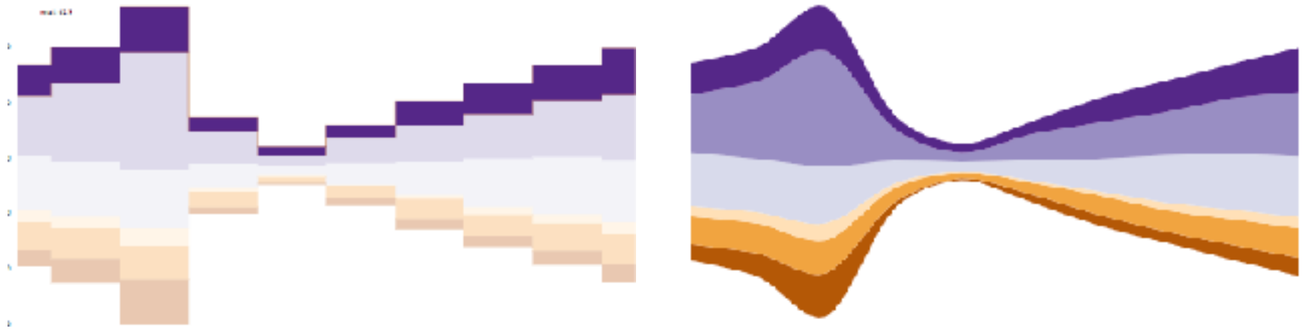
- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
  - data
    - 1 categ key attrib (movies)
    - 1 ordered key attrib (time)
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)



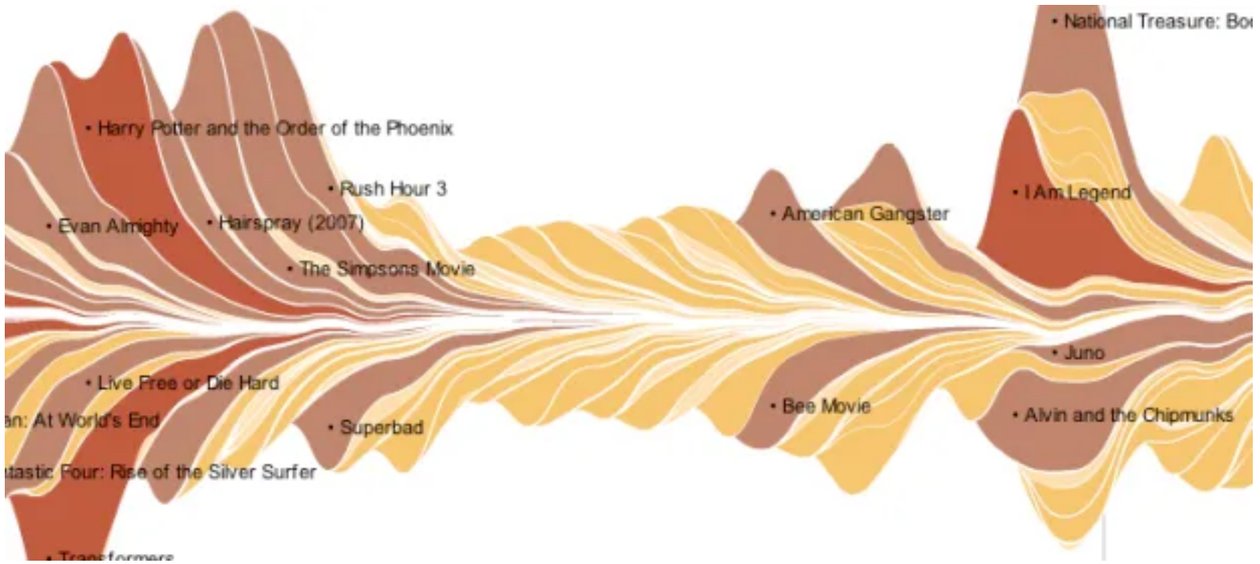
[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]

Idiom: **streamgraph**

- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
  - data
    - 1 categ key attrib (movies)
    - 1 ordered key attrib (time)
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)
  - scalability
    - hundreds of time keys
    - dozens to hundreds of movies keys
      - more than stacked bars: most layers don't extend across whole chart



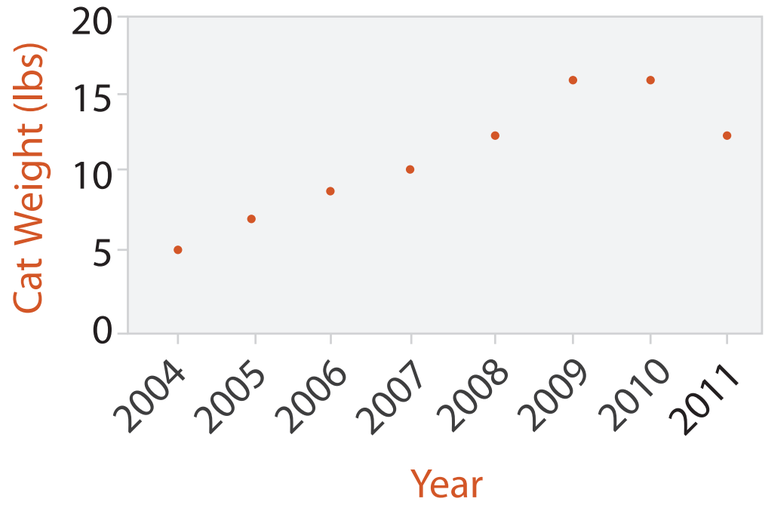
[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]

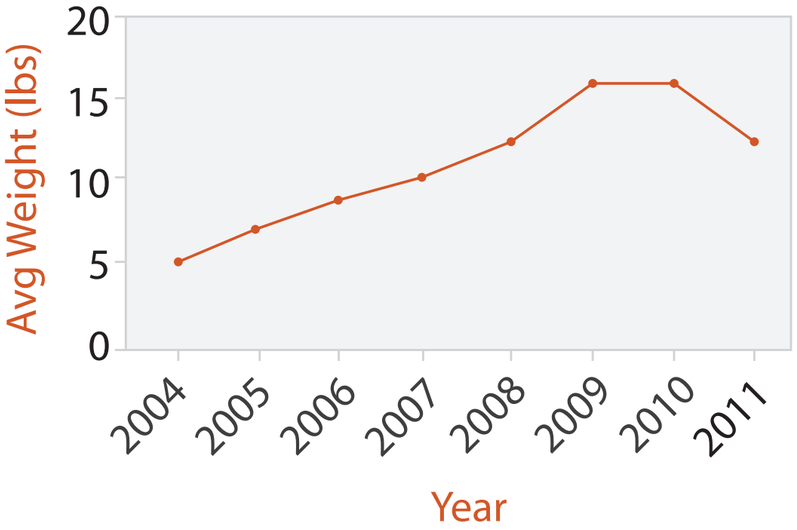


https://flowingdata.com/2008/02/25/ebb-and-flow-of-box-office-receipts-over-past-20-years/

Idiom: **dot / line chart**

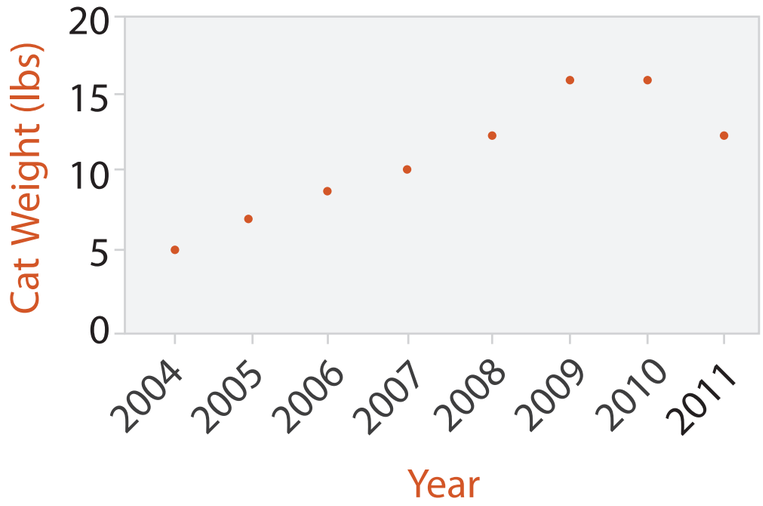
- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions

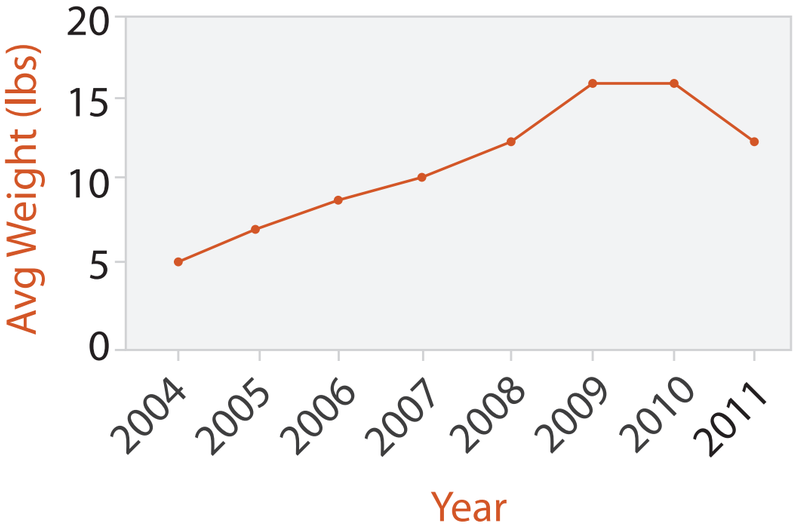




Idiom: **dot / line chart**

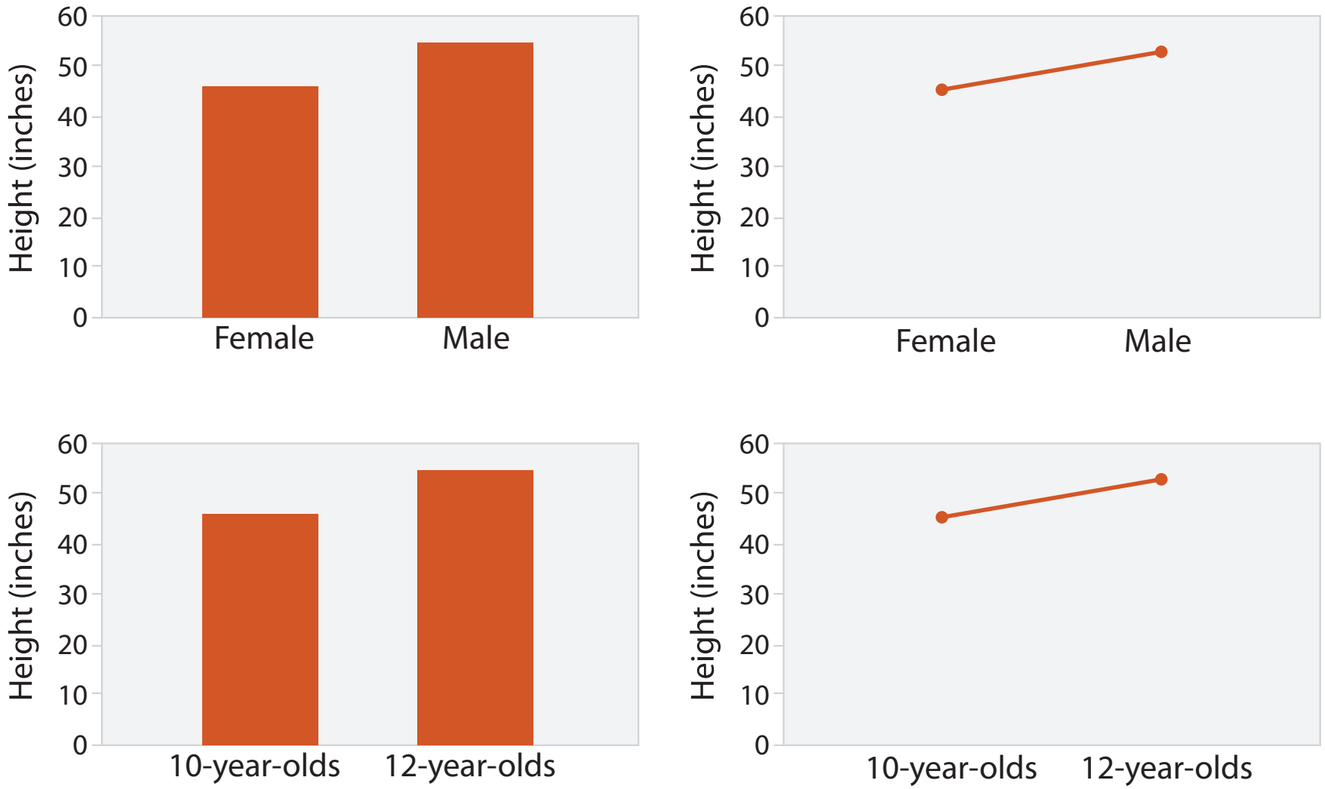
- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions
  - task
    - find trend
      - connection marks emphasize ordering of items along key axis by explicitly showing relationship between one item and the next
  - scalability
    - hundreds of key levels, hundreds of value levels





Choosing bar vs line charts

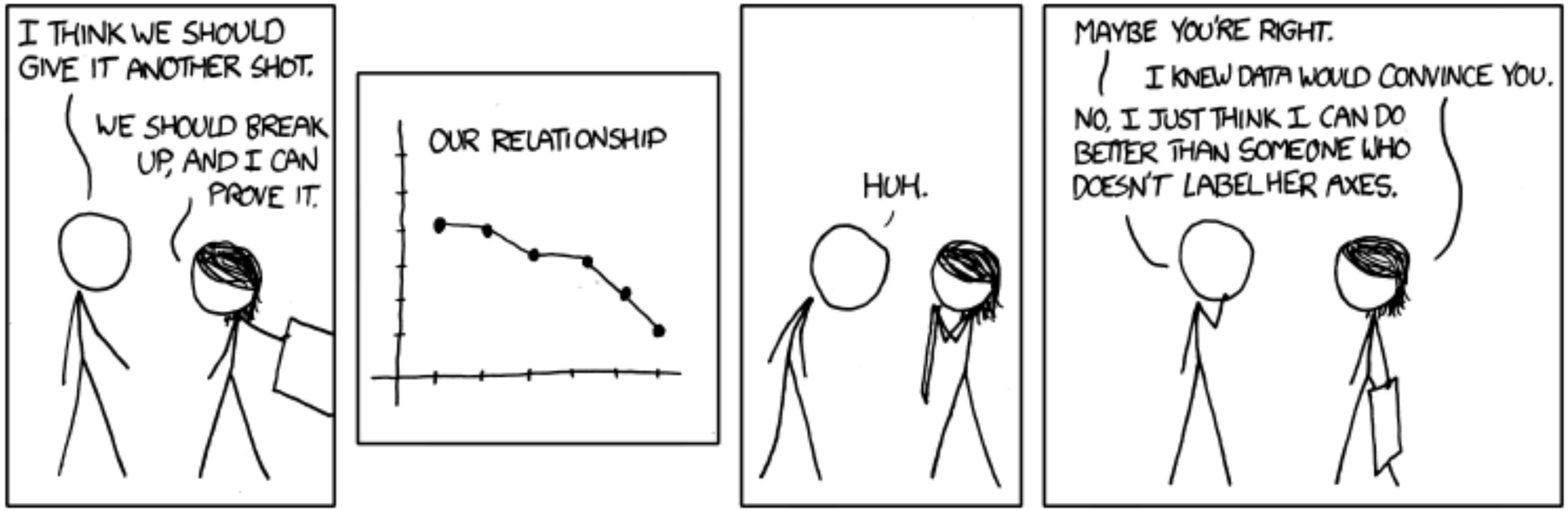
- depends on type of key attrib
  - bar charts if categorical
  - line charts if ordered
- do not use line charts for categorical key attribs
  - violates expressiveness principle
    - implication of trend so strong that it overrides semantics!
      - "The more male a person is, the taller he/she is"



after [Bars and Lines: A Study of Graphic Communication. Zacks and Tversky. Memory and Cognition 27:6 (1999), 1073–1079.]

Chart axes: label them!

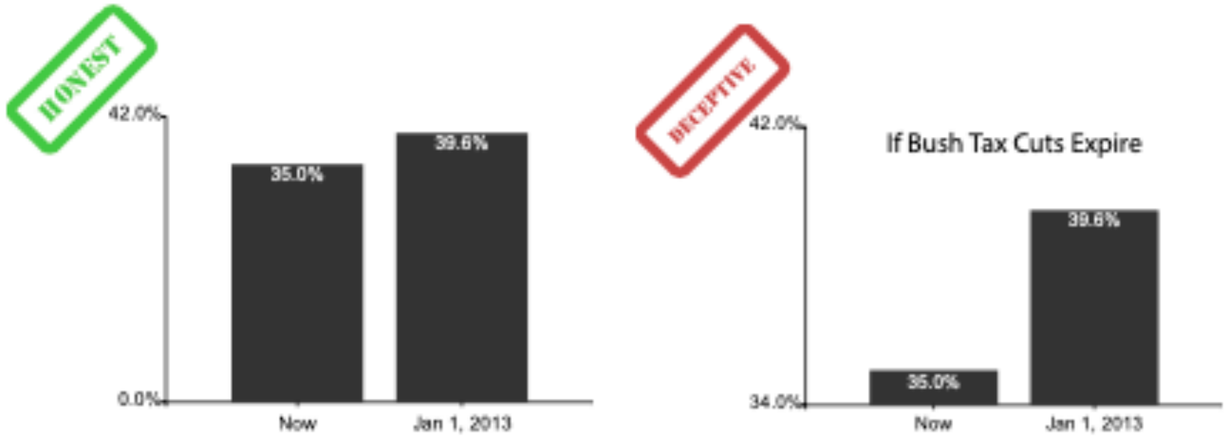
- best practice to label
  - few exceptions: individual small multiple views could share axis label



https://xkcd.com/833/

Chart axes: avoid cropping y axis

- include 0 at bottom left or slope misleads

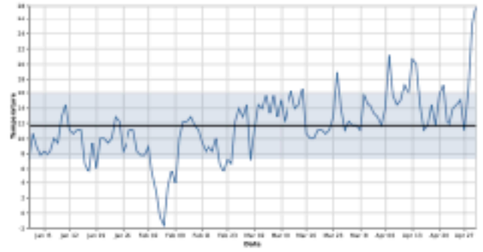


[Truncating the Y-Axis: Threat or Menace?
Correll, Bertini, & Franconeri, CHI 2020.]

Chart axes: avoid cropping y axis

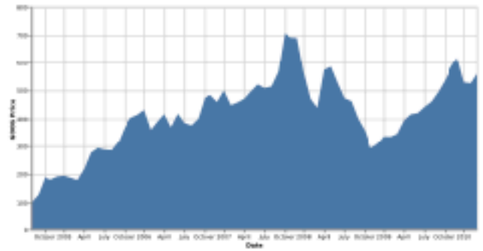
- include 0 at bottom left or slope misleads
  - some exceptions (arbitrary 0, small change matters)

[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]

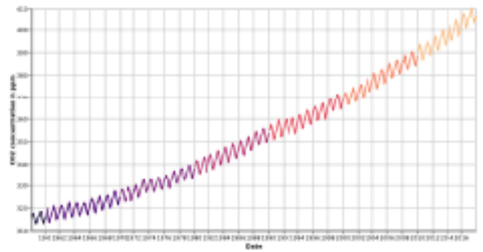


(a) Statistical process charts rely on comparison to an expected value, and so deviations from that value, not from zero, are important

(b) Index charts compare to an indexed value rather than zero.



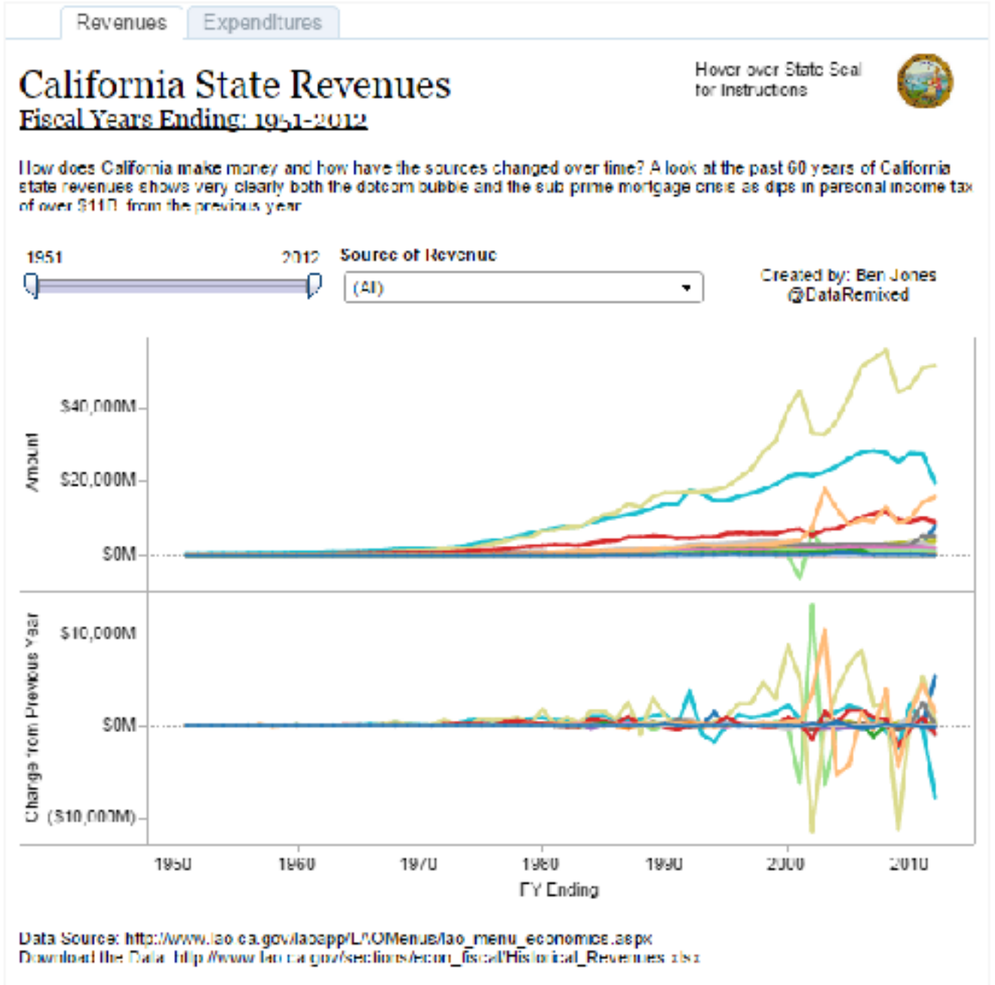
(c) Stock charts must show small differences in stock value, as these can translate to enormous monetary gains or losses.



(d) Climate Anomaly charts rely on both highlighting deviation from a non-zero expected value but also emphasize the potentially disastrous impact of even minute changes in climate.

Idiom: **Indexed line charts**

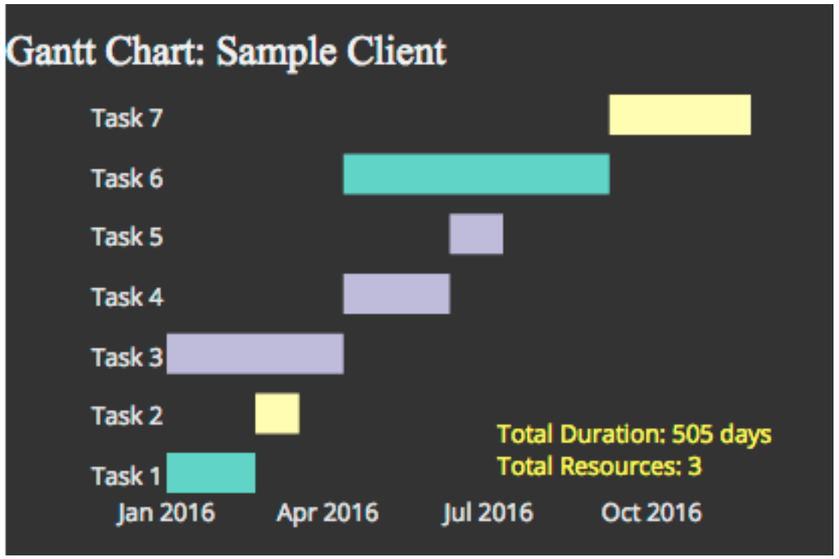
- data: 2 quant attribs
  - 1 key + 1 value
- derived data: new quant value attrib
  - index
  - plot instead of original value
- task: show change over time
  - principle: normalized, not absolute
- scalability
  - same as standard line chart



https://public.tableau.com/profile/ben.jones#!/vizhome/CAStateRevenues/Revenues

Idiom: **Gantt charts**

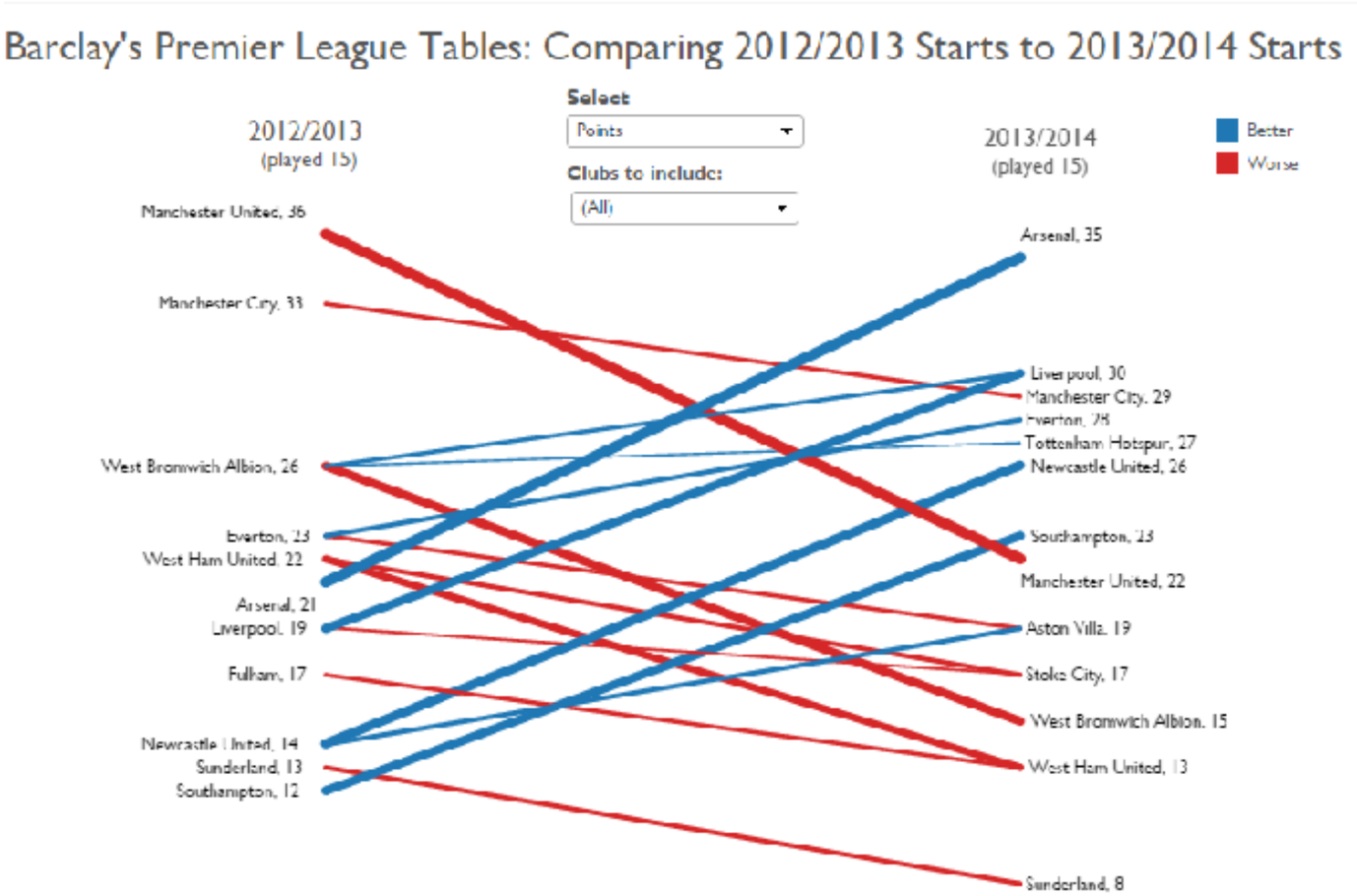
- one key, two (related) values
  - data
    - 1 categ attrib, 2 quant attribs
  - mark: line
    - length: duration
  - channels
    - horiz position: start time (+end from duration)
  - task
    - emphasize temporal overlaps & start/end dependencies between items
  - scalability
    - dozens of key levels [bars]
    - hundreds of value levels [durations]



https://www.r-bloggers.com/gantt-charts-in-r-using-plotly/

Idiom: **Slopegraphs**

- two values
  - data
    - 2 quant value attribs
    - (1 derived attrib: change magnitude)
  - mark: point + line
    - line connecting mark between pts
  - channels
    - 2 vertical pos: express attrib value
    - (linewidth/size, color)
  - task
    - emphasize changes in rank/value
  - scalability
    - hundreds of value levels
    - dozens of items



https://public.tableau.com/profile/ben.jones#!/vizhome/Slopegraphs/Slopegraphs

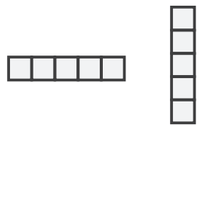
2 Keys

➔ *0 Keys*

➔ **Express Values**

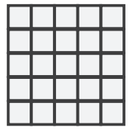
➔ *1 Key*

List



➔ *2 Keys*

Matrix

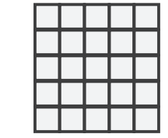


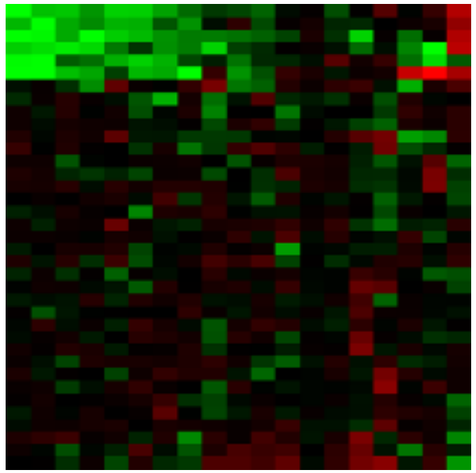
Idiom: **heatmap**

- two keys, one value
  - data
    - 2 categ attribs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: point
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)
  - task
    - find clusters, outliers
  - scalability
    - 1M items, 100s of categ levels, ~10 quant attrib levels

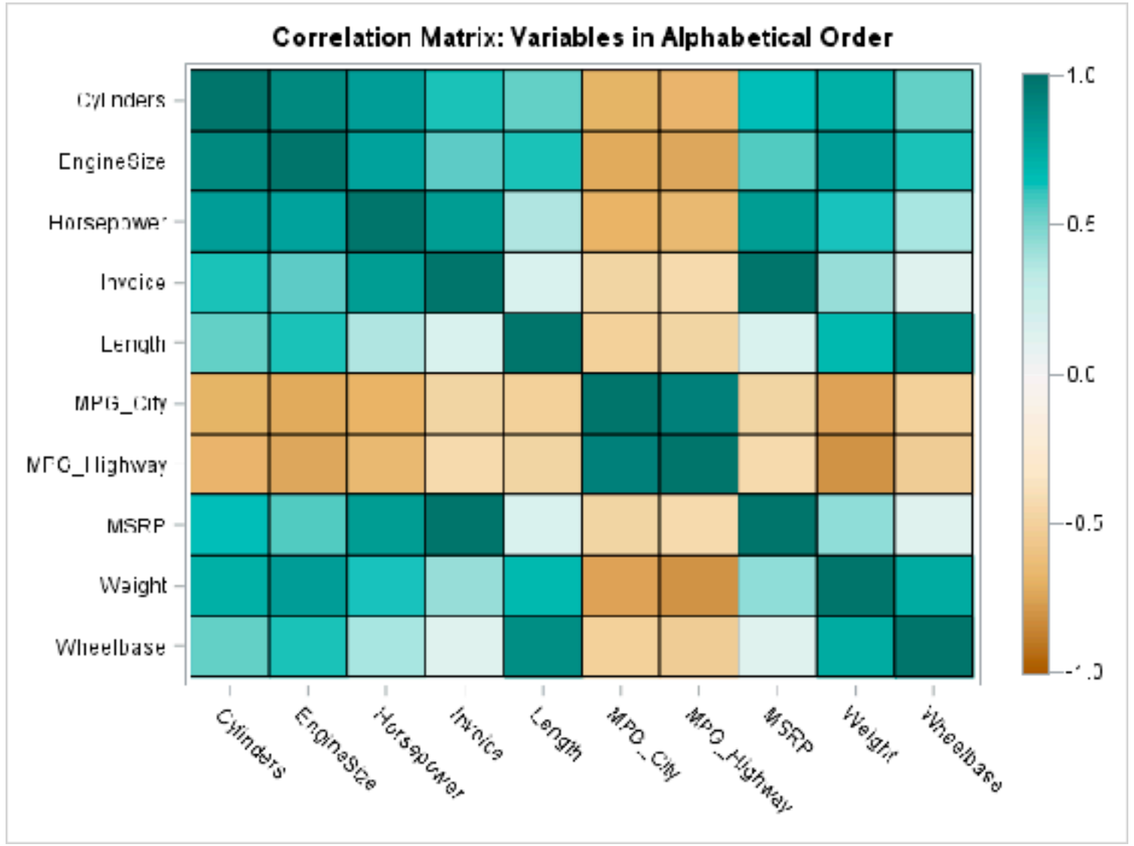
➔ *2 Keys*

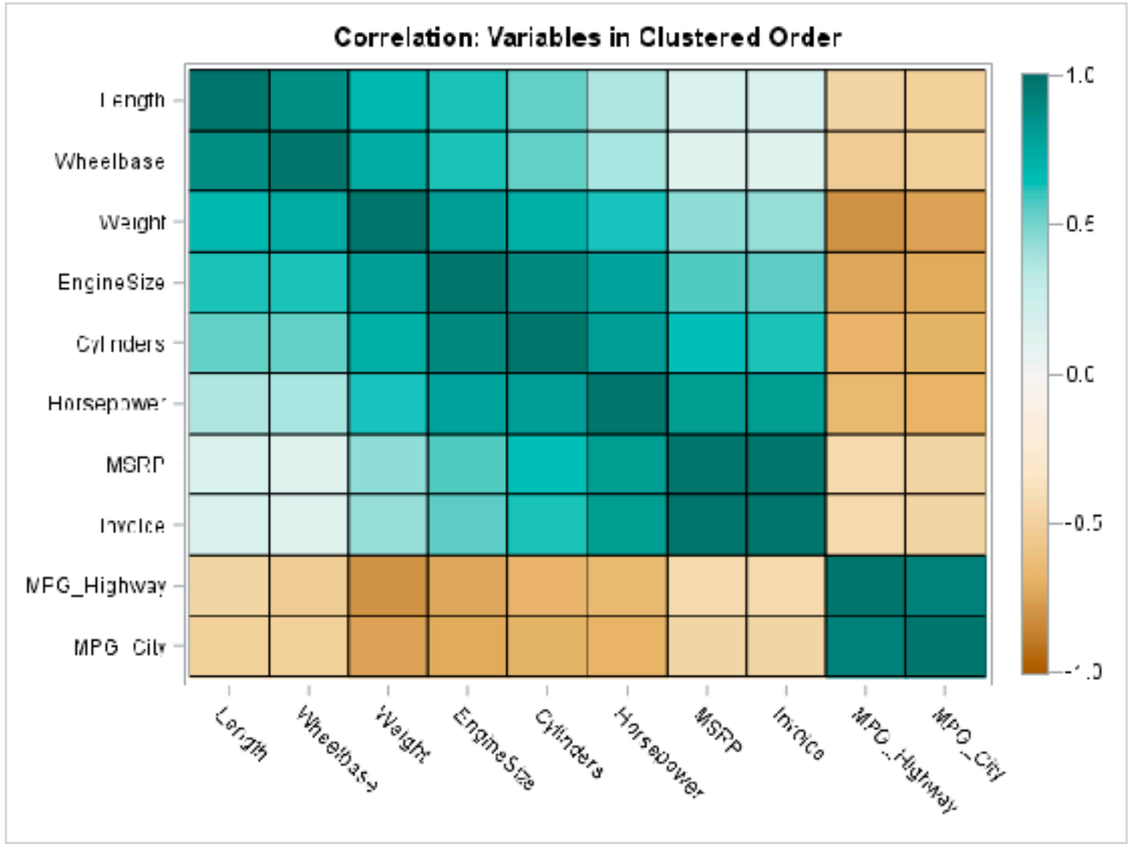
Matrix





Heatmap reordering

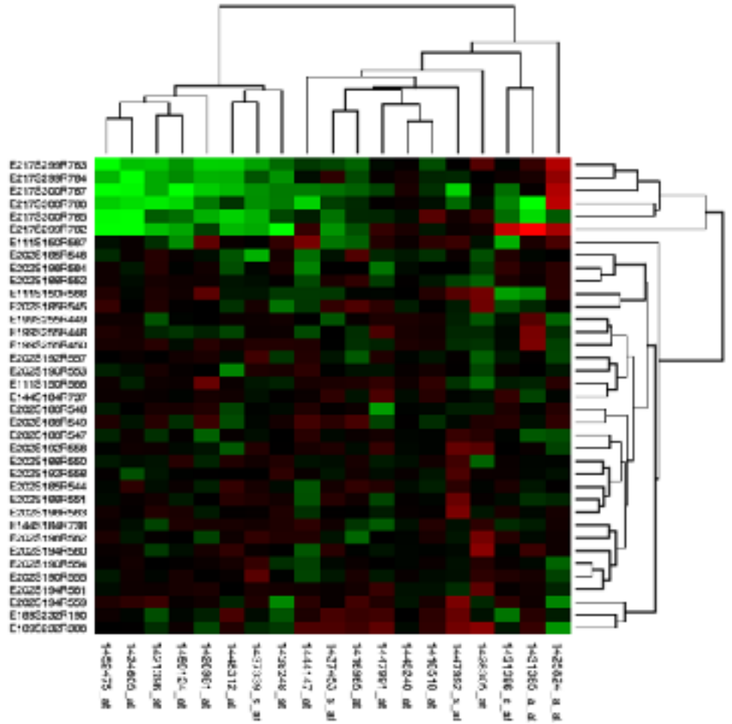




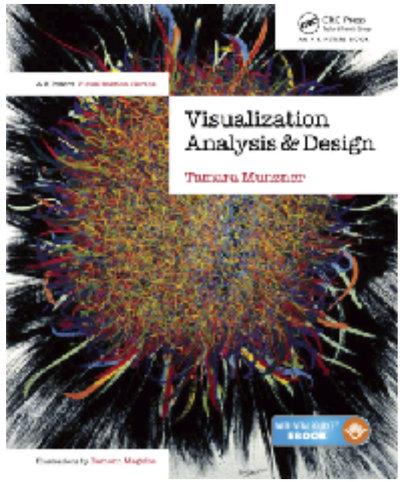
https://blogs.sas.com/content/iml/2018/05/02/reorder-variables-correlation-heat-map.html

Idiom: **cluster heatmap**

- in addition
  - derived data
    - 2 cluster hierarchies
  - dendrogram
    - parent-child relationships in tree with connection line marks
    - leaves aligned so interior branch heights easy to compare
  - heatmap
    - marks (re-)ordered by cluster hierarchy traversal
    - task: assess quality of clusters found by automatic methods



Visualization Analysis & Design

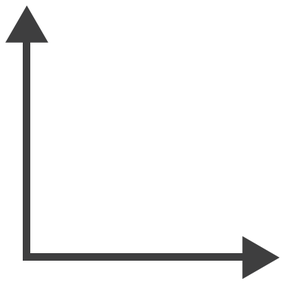


Tables (Ch 7) II

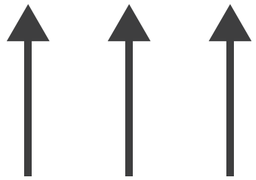
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

Axis Orientation

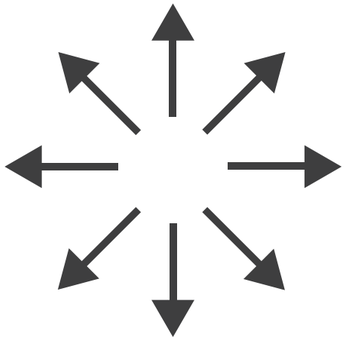
- Rectilinear



- Parallel

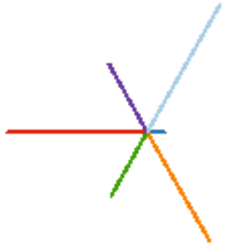


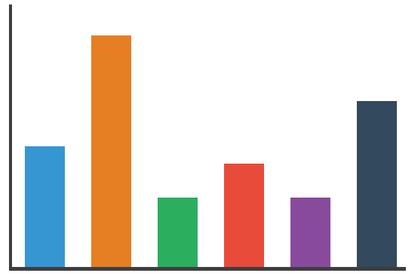
- Radial



Idioms: **radial bar chart, star plot**

- star plot
  - line mark, radial axes meet at central point
- radial bar chart
  - line mark, radial axes meet at central ring
  - channels: length, angle/orientation
- bar chart
  - rectilinear axes, aligned vertically





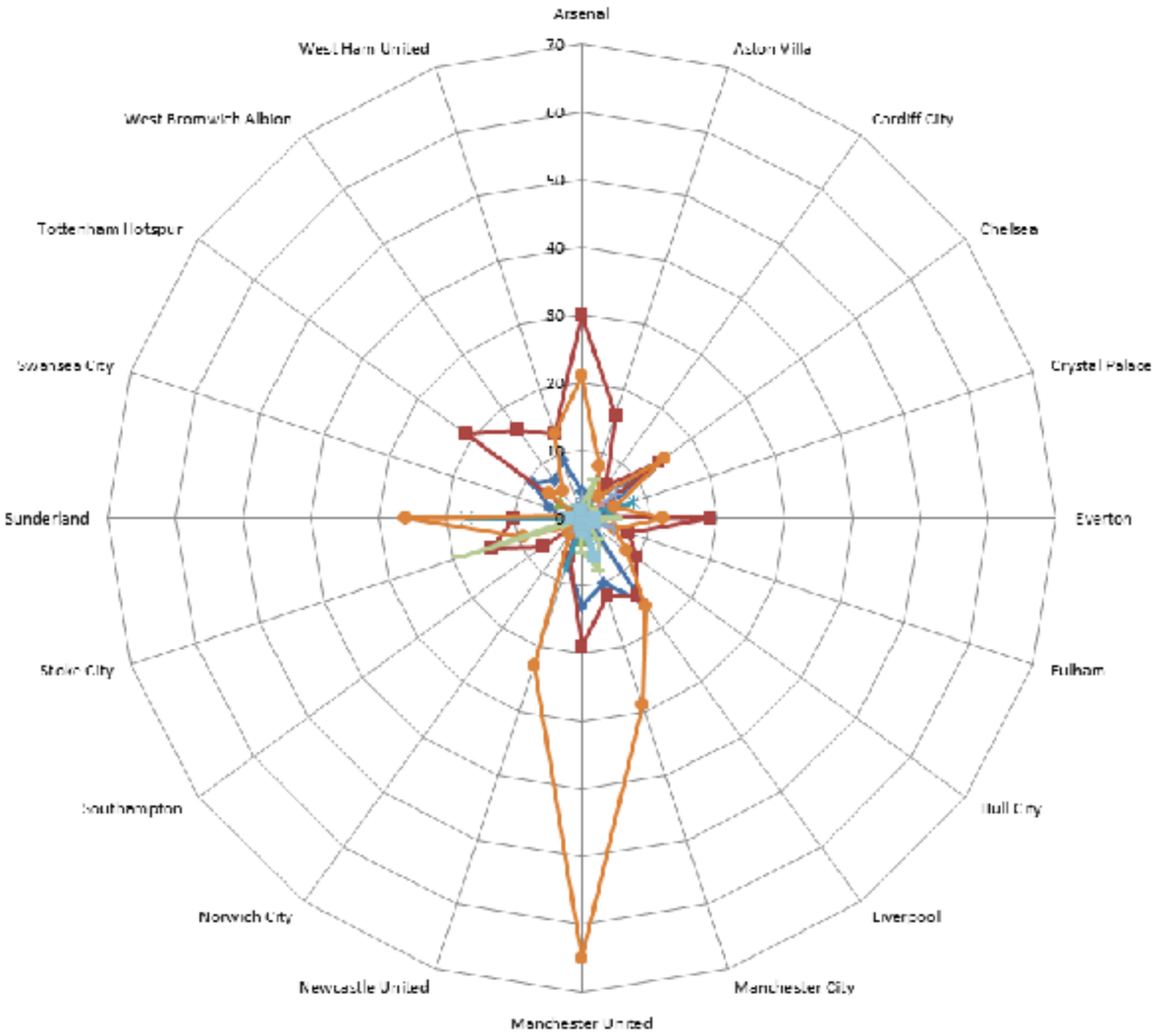
- accuracy
  - length not aligned with radial layouts
    - less accurately perceived than rectilinear aligned

[Vismon: Facilitating Risk Assessment and Decision Making In Fisheries Management. Booshehrian, Möller, Peterman, and Munzner. Technical Report TR 2011-04, Simon Fraser University, School of Computing Science, 2011.]

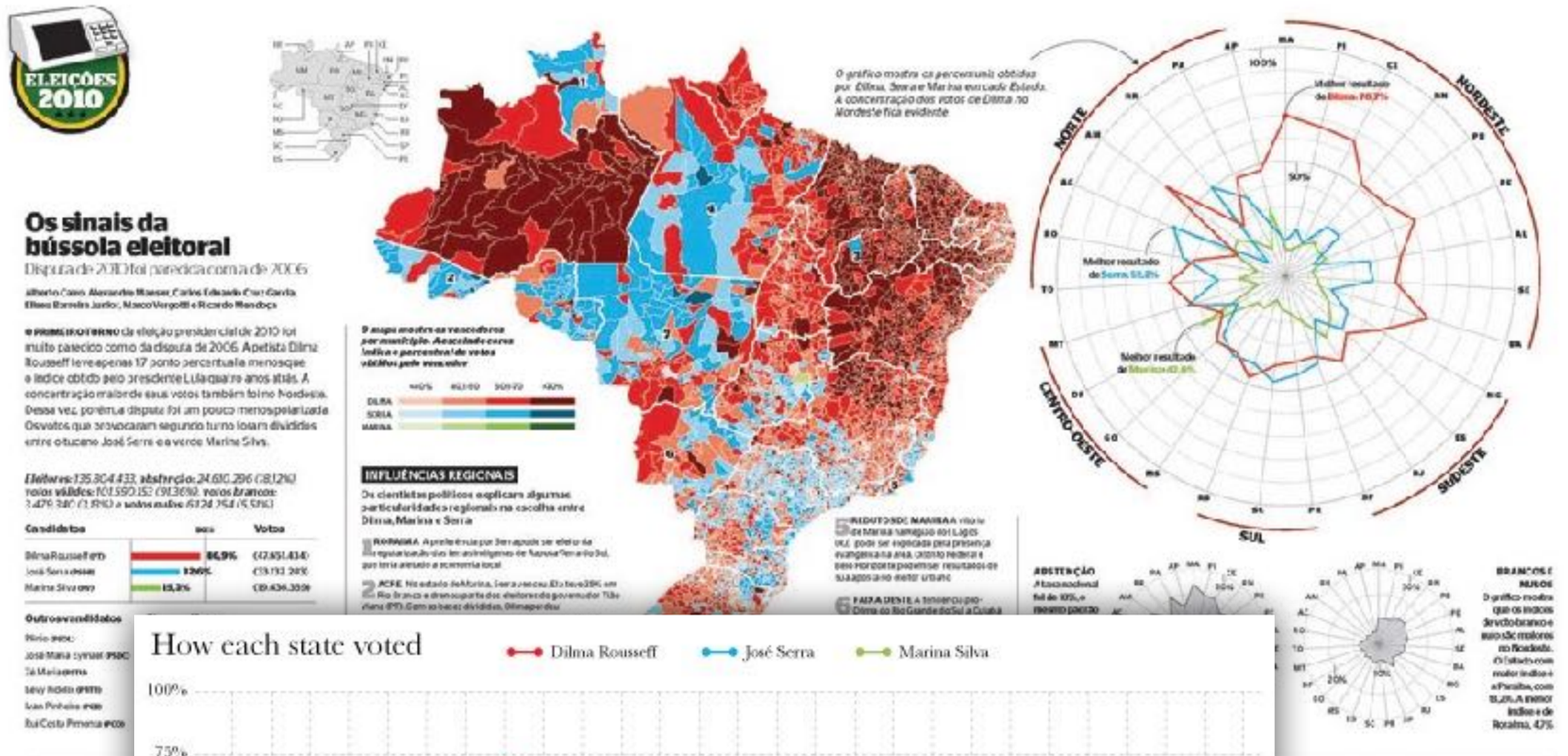
Idiom: **radar plot**

- radial line chart
  - point marks, radial layout
  - connecting line marks

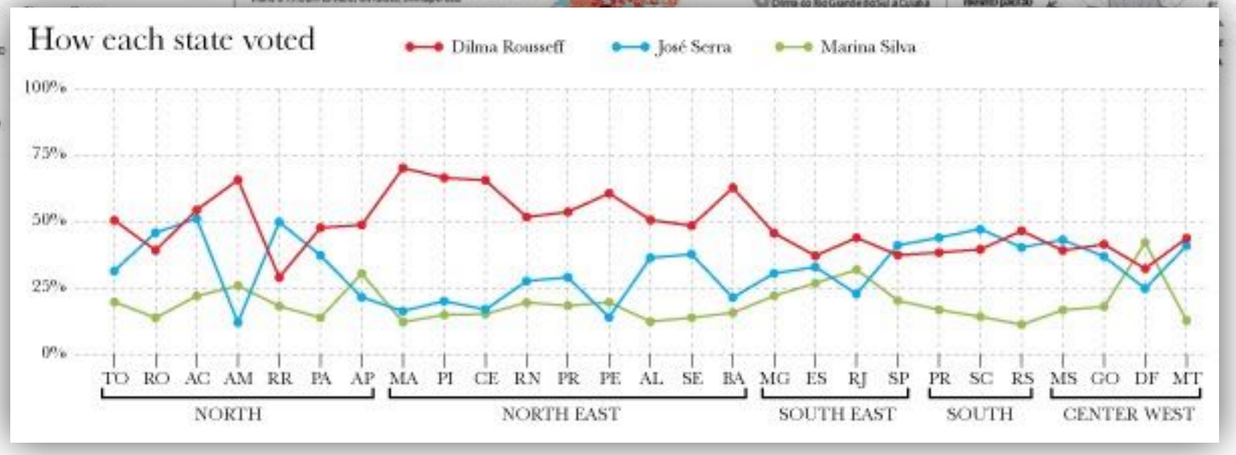
- avoid unless data is cyclic



“Radar graphs: Avoid them (99.9% of the time)”



original
difficult to interpret

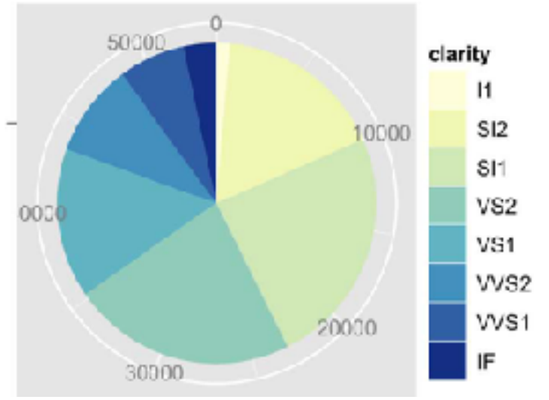


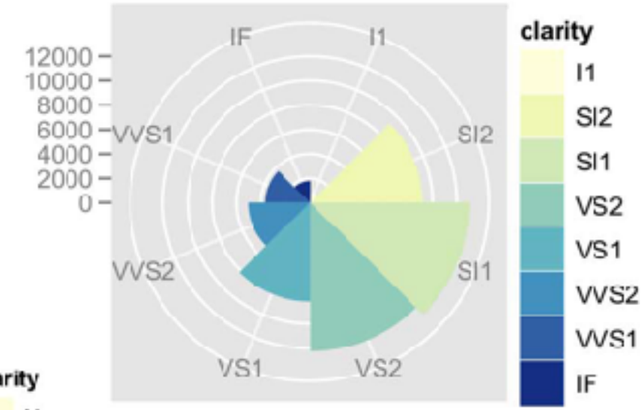
redesign for
rectilinear

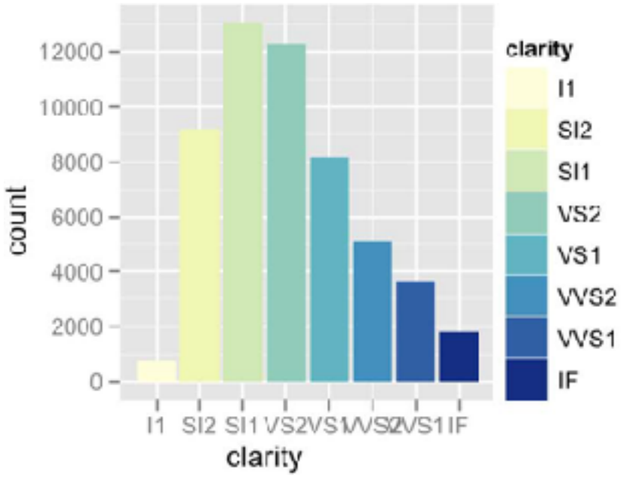
http://www.thefunctionalart.com/2012/11/radar-graphs-avoid-them-999-of-time.html

Idioms: **pie chart, coxcomb chart**

- pie chart
  - **interlocking area** marks with angle channel: **2D area varies**
    - separated & ordered radially, uniform height
  - accuracy: area less accurate than rectilinear aligned line length
  - **task: part-to-whole judgements**
- coxcomb chart
  - line marks with length channel: **1D length varies**
    - separated & ordered radially, uniform width
  - direct analog to radial bar charts
- data
  - 1 categ key attrib, 1 quant value attrib



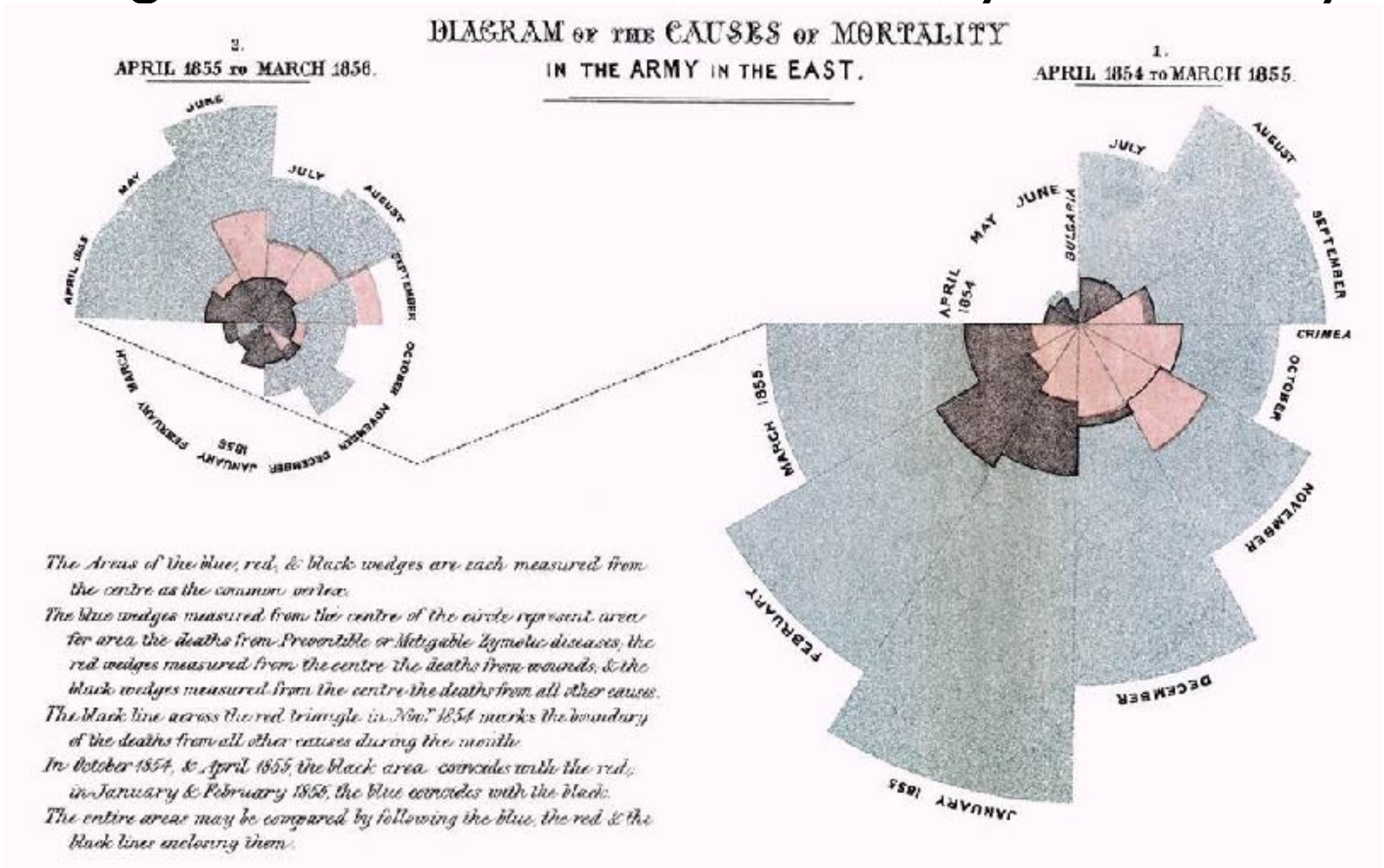




[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Coxcomb / nightingale rose / polar area chart

- invented by Florence Nightingale:
  Diagram of the Causes of Mortality in the Army in the East

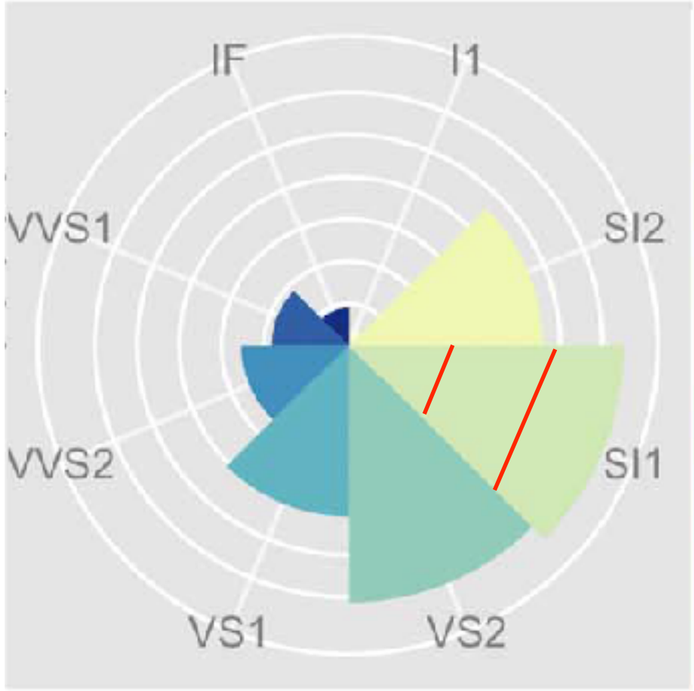


Coxcomb: perception

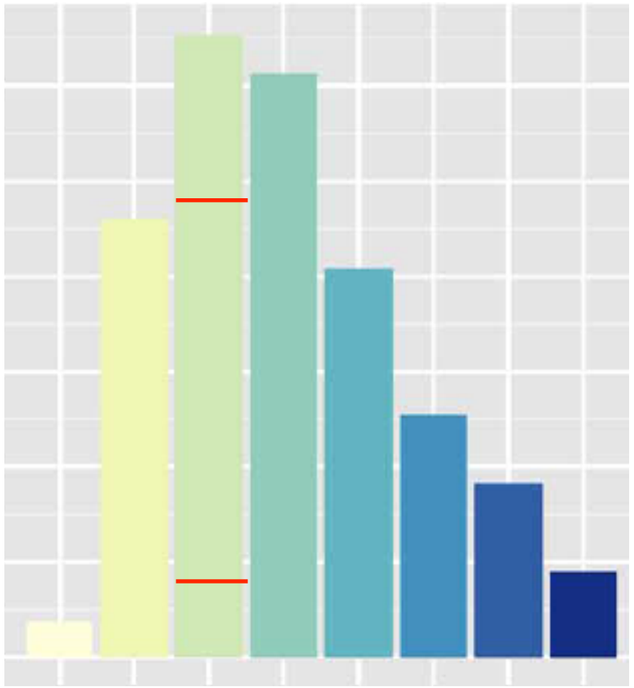
- encode: 1D length
- decode/perceive: 2D area

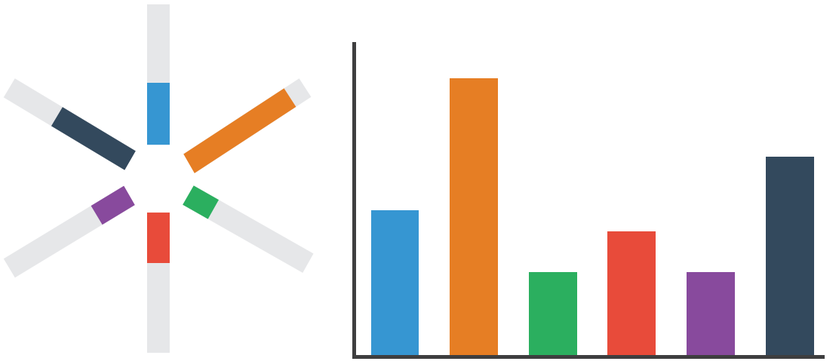
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!

- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases



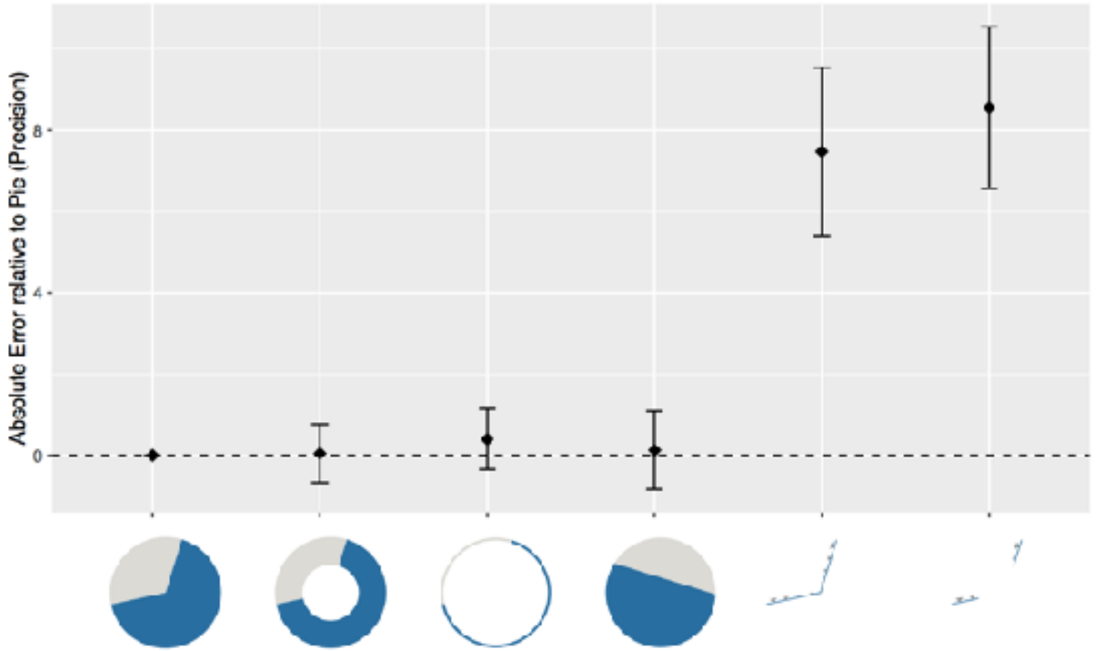
nonuniform width as length increases


uniform width as length increases


radial & rectilinear bars: uniform width as length increases

Pie charts: perception

- some empirical evidence that people respond to arc length
  - decode/perceive: not angles
  - maybe also areas?…
- donut charts no worse than pie charts



[Arcs, Angles, or Areas: Individual Data Encodings in Pie and Donut Charts. Skau and Kosara. Proc. EuroVis 2016.]

https://eagereyes.org/blog/2016/an-illustrated-tour-of-the-pie-chart-study-results

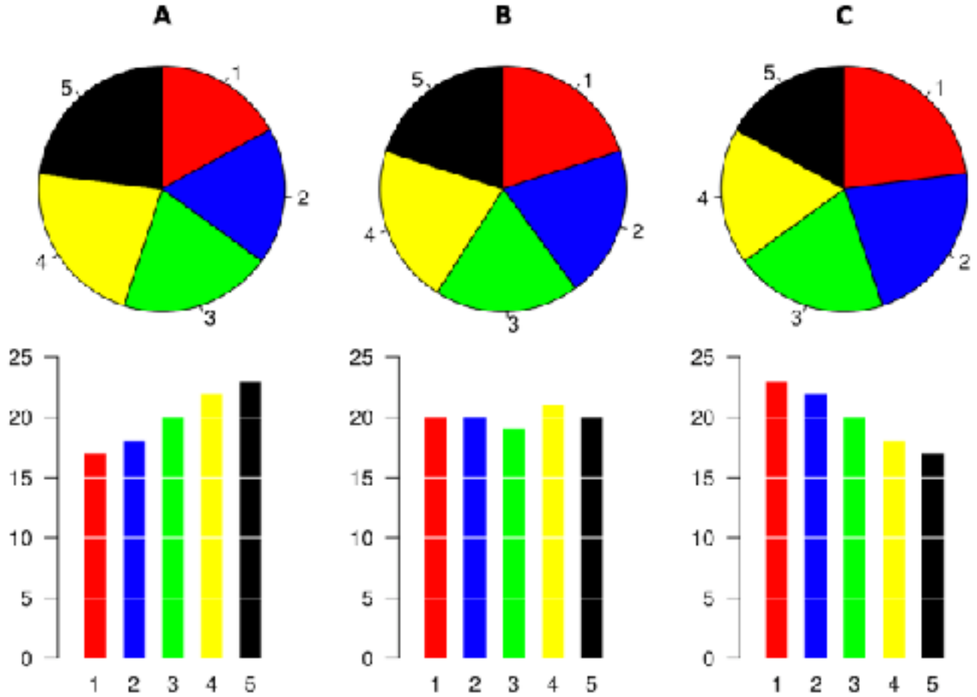
Pie charts: best practices

- not so bad for two (or few) levels, for part-to-whole task

https://eagereyes.org/pie-charts

Pie charts: best practices

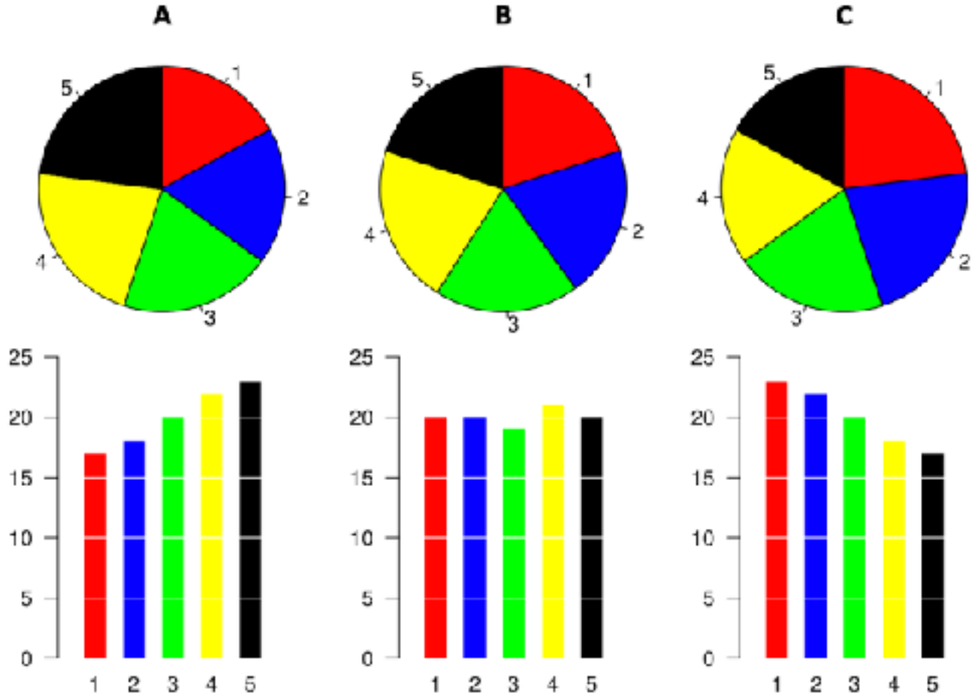
- not so bad for two (or few) levels, for part-to-whole task
- dubious for several levels if details matter

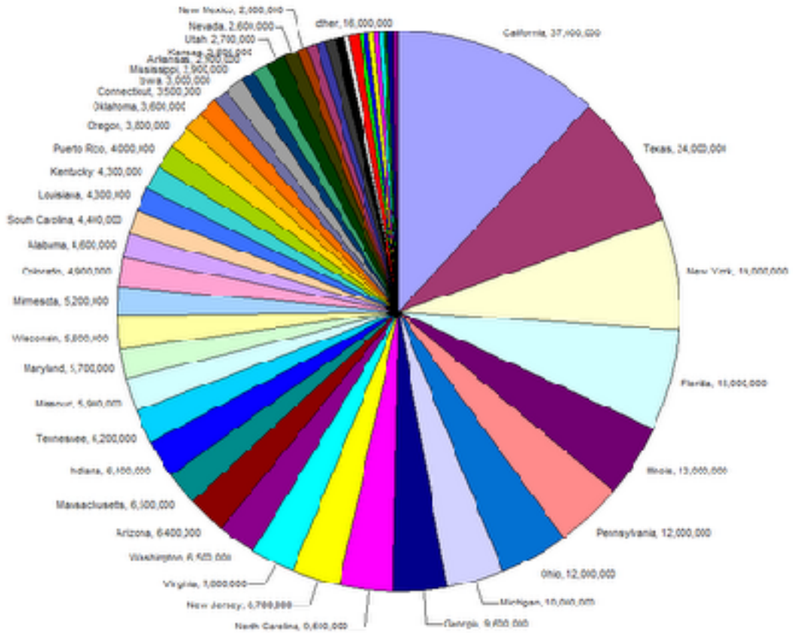


https://eagereyes.org/pie-charts

Pie charts: best practices

- not so bad for two (or few) levels, for part-to-whole task
- dubious for several levels if details matter
- terrible for many levels

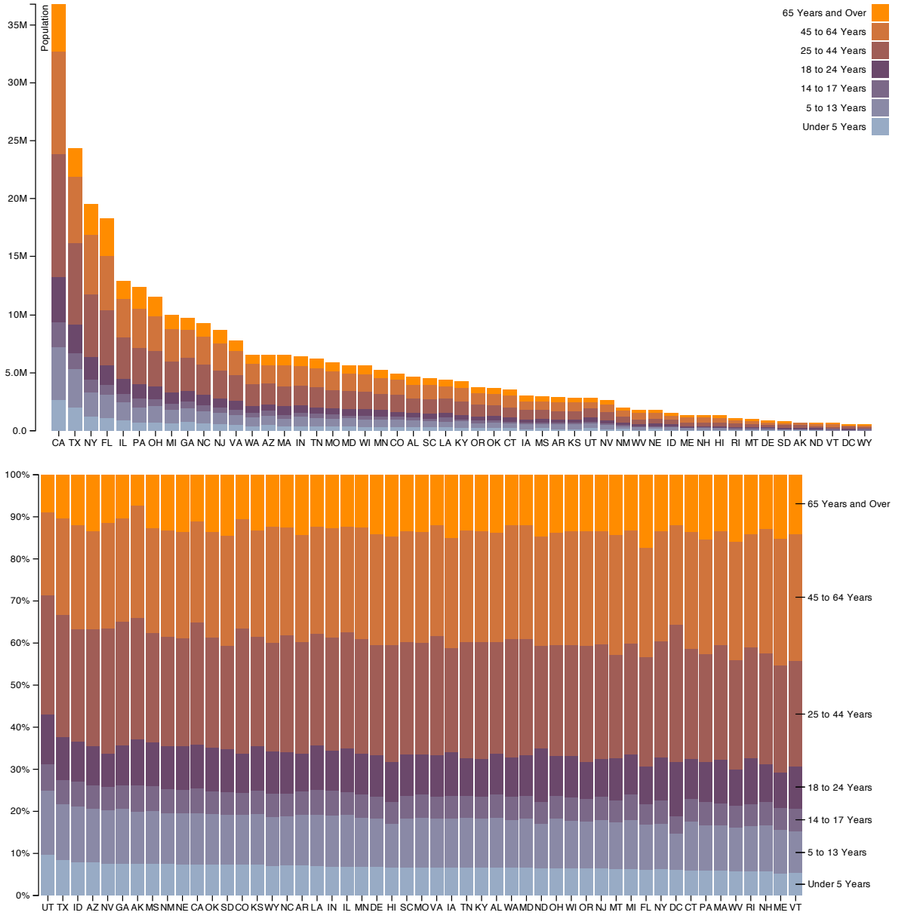


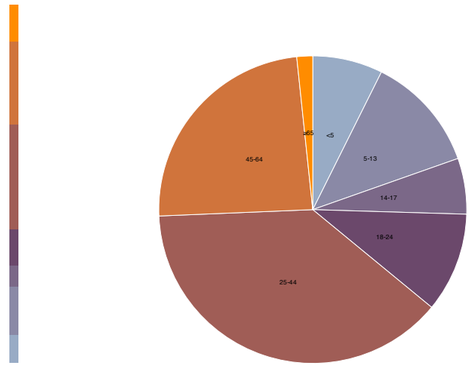


https://eagereyes.org/pie-charts

Idioms: **normalized stacked bar chart**

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





http://bl.ocks.org/mbostock/3886208,

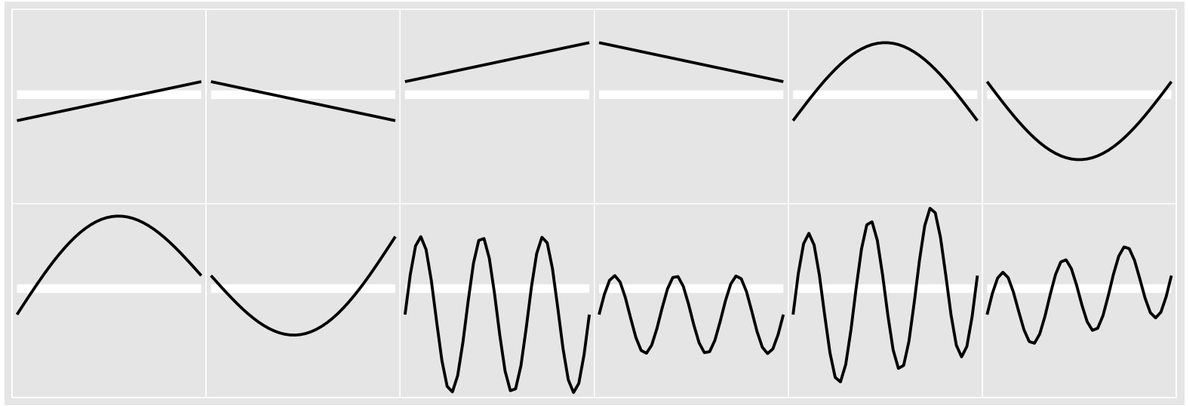
http://bl.ocks.org/mbostock/3887235,

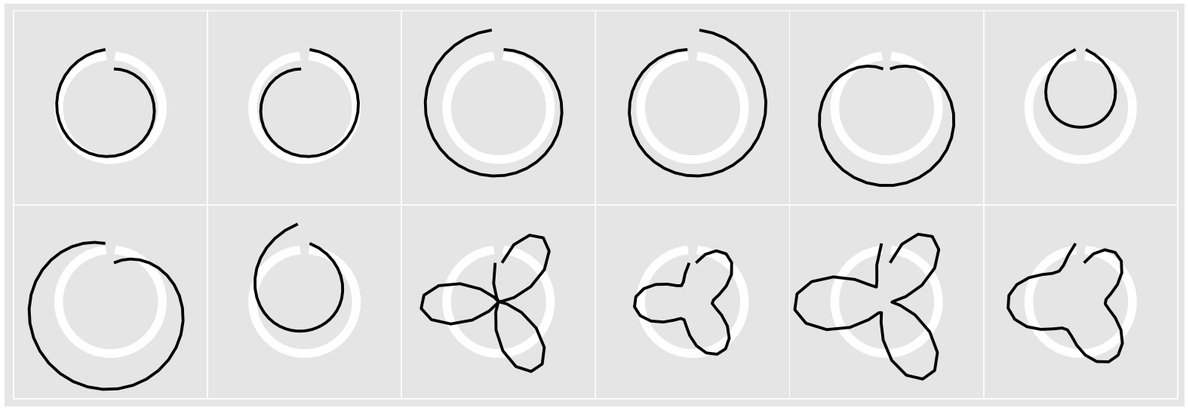
http://bl.ocks.org/mbostock/3886394.

Idiom: **glyphmaps**

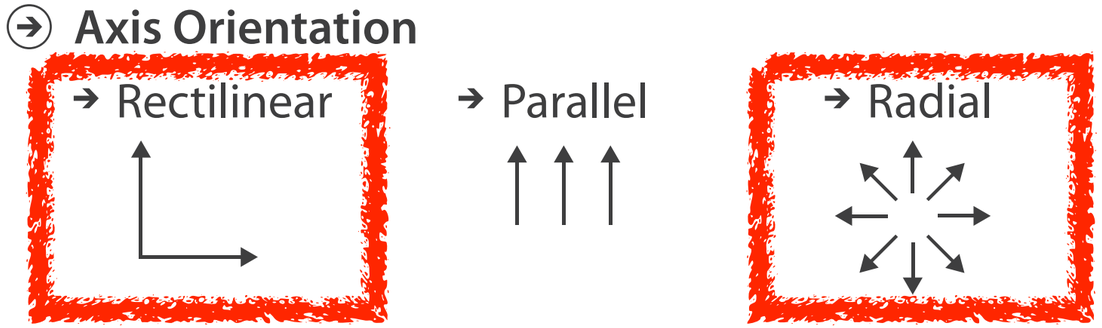
- rectilinear good for linear vs nonlinear trends

- radial good for cyclic patterns
  - evaluating periodicity



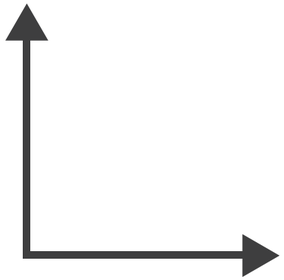


[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmetrics 23:5 (2012), 382–393.]

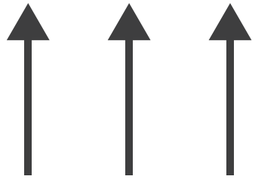


Axis Orientation

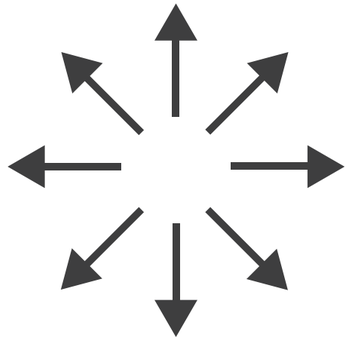
- Rectilinear



- Parallel



- Radial



Idiom: **SPLOM**

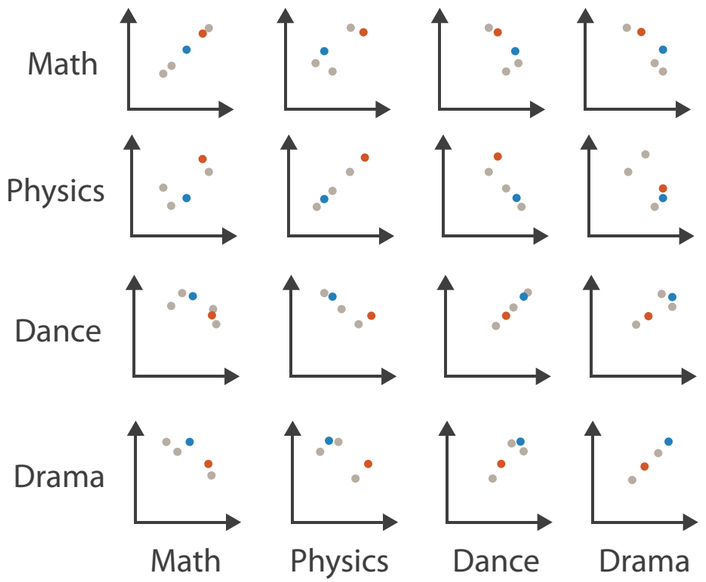
- scatterplot matrix (SPLOM)
  - rectilinear axes, point mark
  - all possible pairs of axes
  - scalability
    - one dozen attribs
    - dozens to hundreds of items

Wilkinson et al., 2005

Idioms: **parallel coordinates**

- scatterplot limitation
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel

Scatterplot Matrix



Table

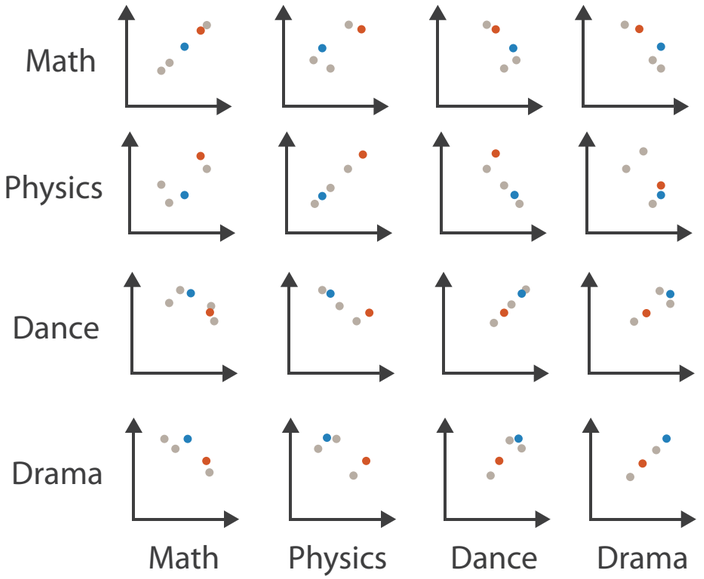
Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

after [Visualization Course Figures. McGuffin, 2014. http://www.michaelmcguffin.com/courses/vis/]

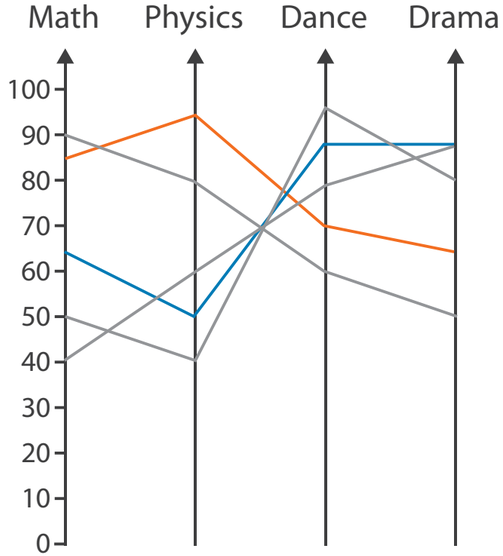
Idioms: **parallel coordinates**

- scatterplot limitation
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel
- alternative: line up axes in parallel to show many attributes with position
  - item encoded with a line with n segments
  - n is the number of attributes shown
- parallel coordinates
  - parallel axes, jagged line for item
  - rectilinear axes, item as point
    - axis ordering is major challenge
  - scalability
    - dozens of attribs
    - hundreds of items

Scatterplot Matrix



Parallel Coordinates



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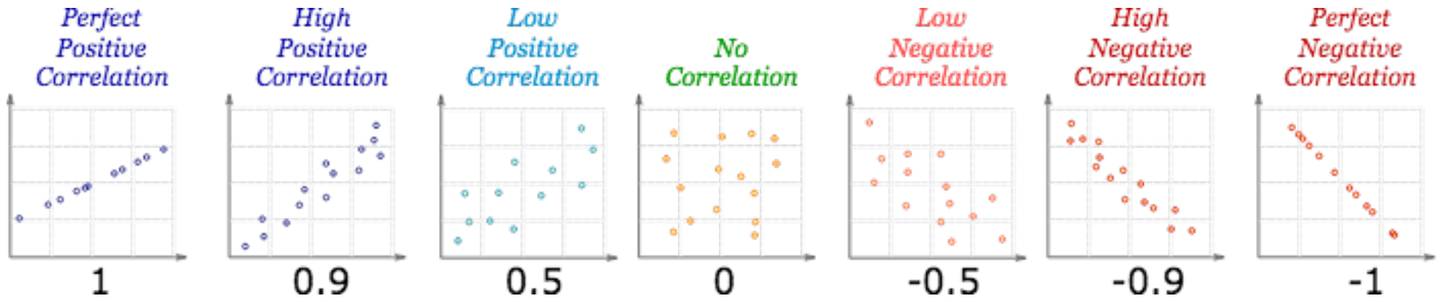
after [Visualization Course Figures. McGuffin, 2014. http://www.michaelmcguffin.com/courses/vis/]

Task: Correlation

- scatterplot matrix
  - positive correlation
    - diagonal low-to-high
  - negative correlation
    - diagonal high-to-low
  - uncorrelated: spread out
- parallel coordinates
  - positive correlation
    - parallel line segments
  - negative correlation
    - all segments cross at halfway point
  - uncorrelated
    - scattered crossings



https://www.mathsisfun.com/data/scatter-xy-plots.html

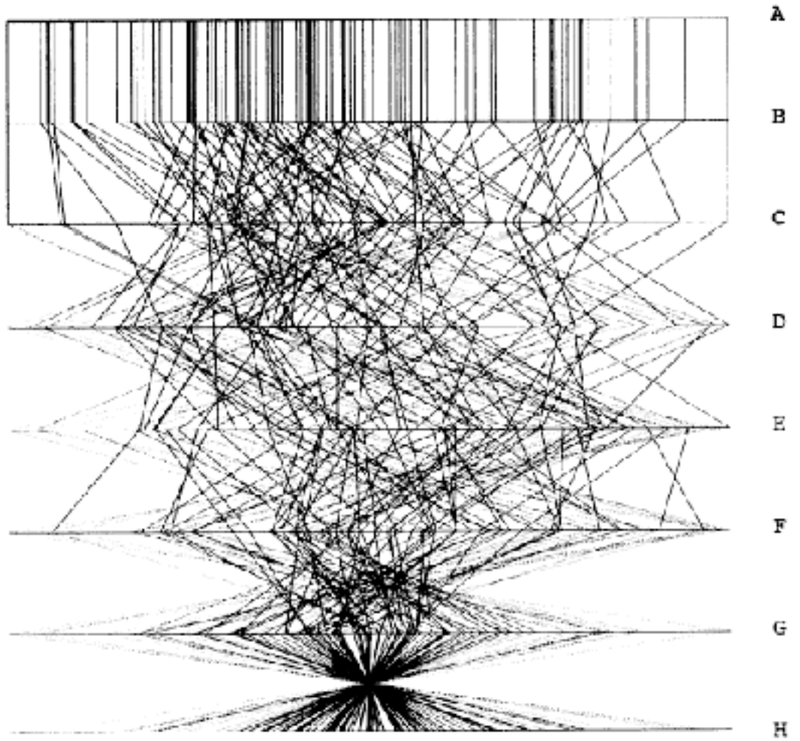
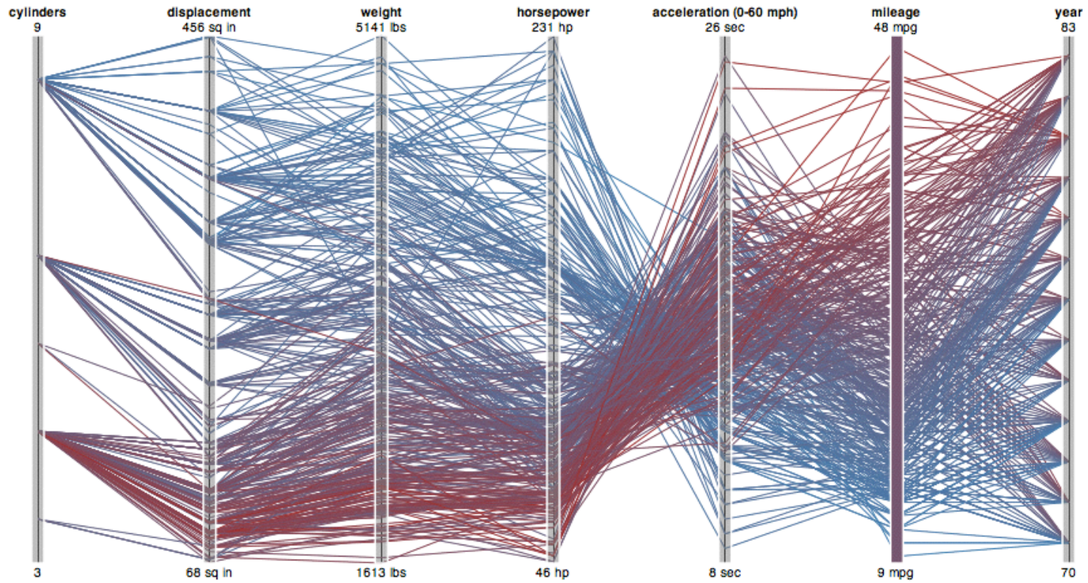


Figure 3. Parallel Coordinate Plot of Six-Dimensional Data Illustrating Correlations of $\rho = 1, .8, .2, 0, -.2, -.8,$ and -1.

[Hyperdimensional Data Analysis Using Parallel Coordinates. Wegman. Journ. American Statistical Association 85:411 (1990), 664–675.]

Parallel coordinates, limitations

- visible patterns only between neighboring axis pairs
- how to pick axis order?
  - usual solution: reorderable axes, interactive exploration
  - same weakness as many other techniques
    - downside of interaction: human-powered search
  - some algorithms proposed, none fully solve

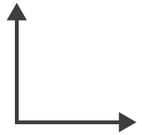


Orientation limitations

- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible

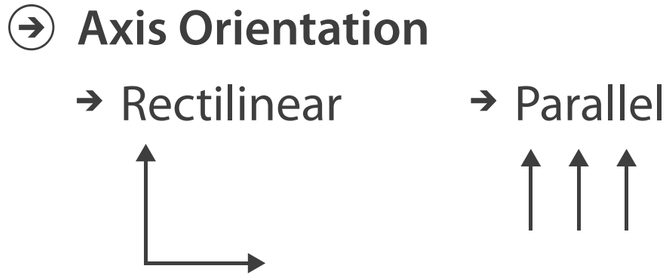
Axis Orientation

→ Rectilinear



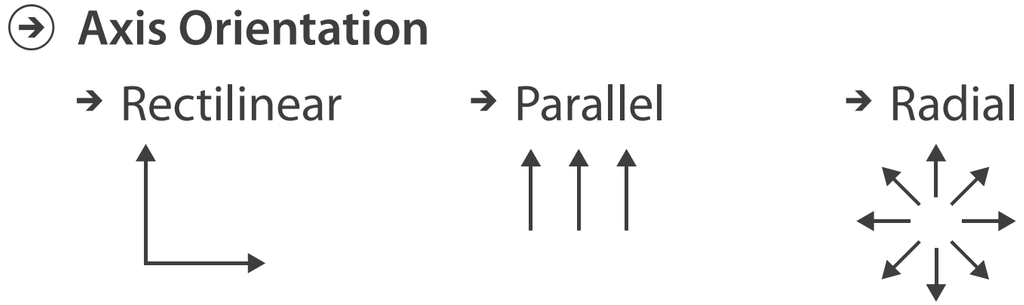
Orientation limitations

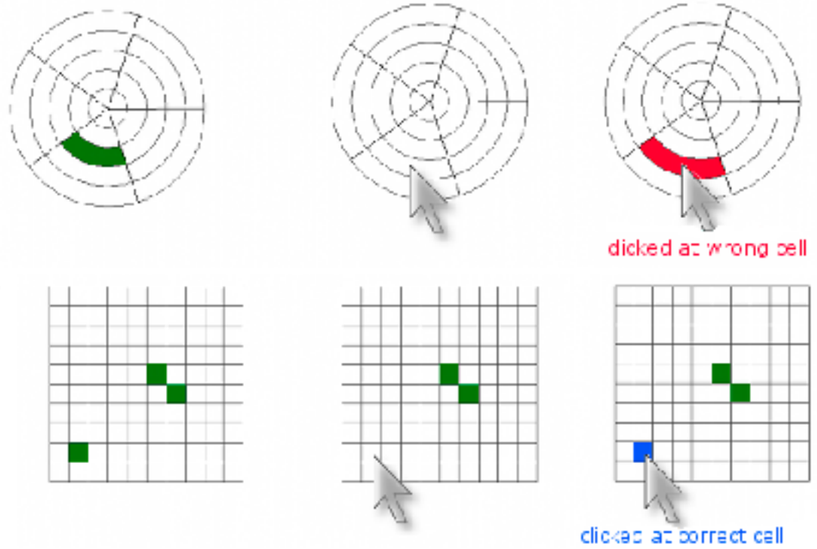
- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
- parallel: unfamiliarity, training time



Orientation limitations

- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
- parallel: unfamiliarity, training time
- radial: perceptual limits
  - polar coordinate asymmetry
    - angles lower precision than length
    - nonuniform sector width/size depending on radial distance
  - frequently problematic
    - but sometimes can be deliberately exploited!
      - for 2 attribs of very unequal importance



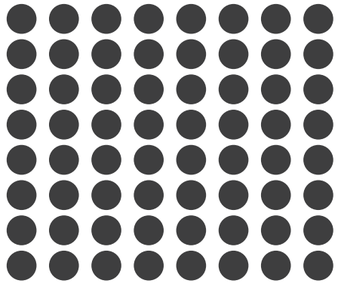


[Uncovering Strengths and Weaknesses of Radial Visualizations - an Empirical Approach. Diehl, Beck and Burch. IEEE TVCG (Proc. InfoVis) 16(6):935–942, 2010.]

Layout density

Layout Density

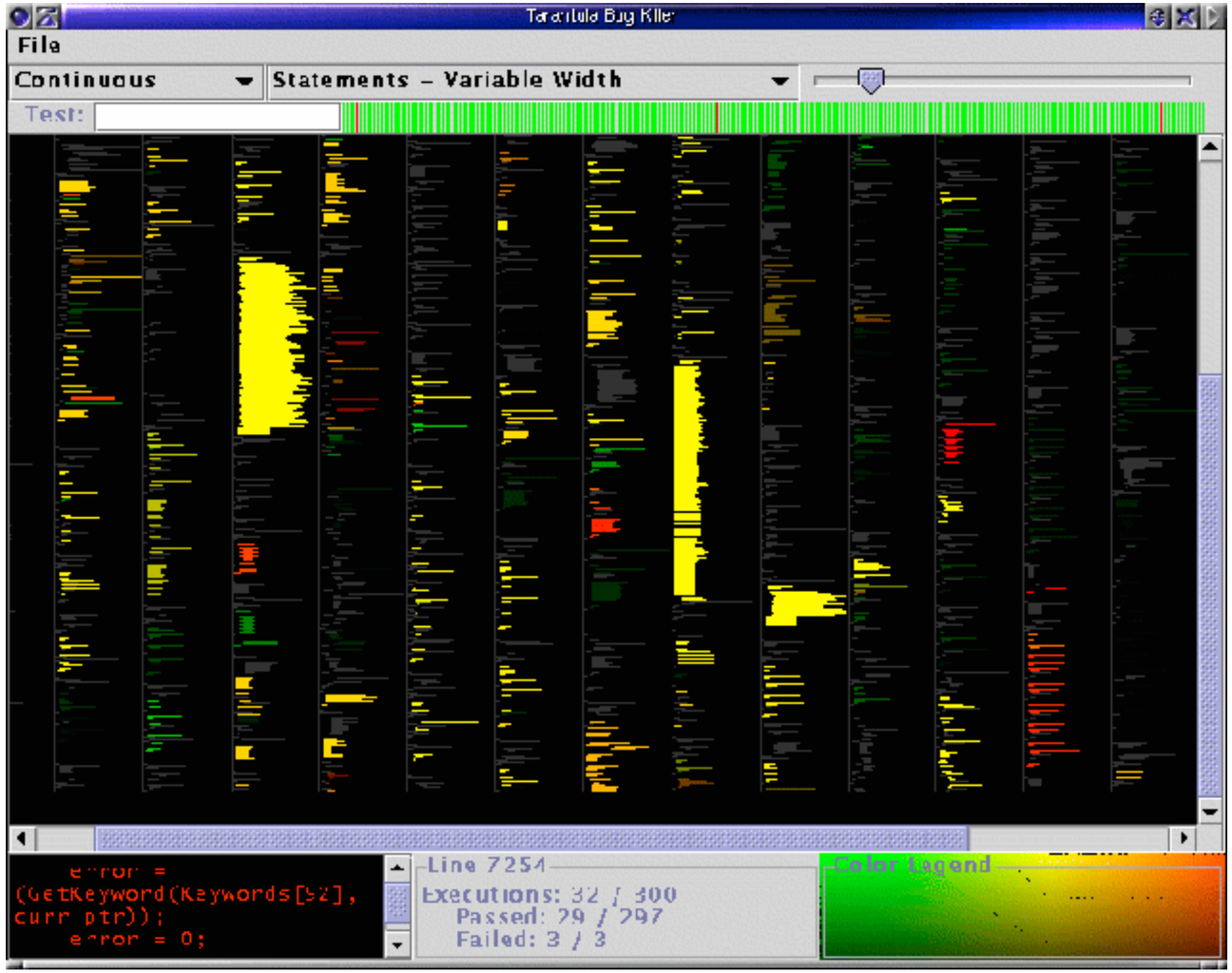
- Dense



- Space-Filling

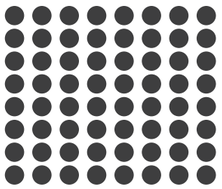
Idiom: Dense software overviews

- data: text
  - text + 1 quant attrib per line
- derived data:
  - one pixel high line
  - length according to original
- color line by attrib
- scalability
  - 10K+ lines



➔ **Layout Density**

➔ Dense



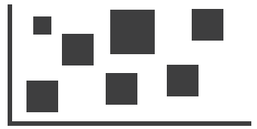
[Visualization of test information to assist fault localization. Jones, Harrold, Stasko. Proc. ICSE 2002, p 467-477.]

Arrange tables

Express Values

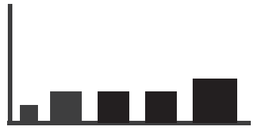
Separate, Order, Align Regions

Separate



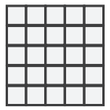
Order

Align



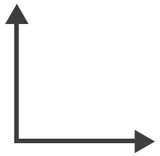
1 Key
List

2 Keys
Matrix



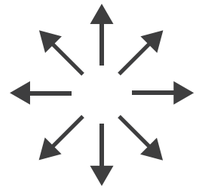
Axis Orientation

Rectilinear



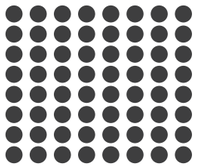
Parallel

Radial



Layout Density

Dense



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

What?

Why?

How?

How?

Encode

Arrange

- Express
- Separate
- Order
- Align
- Use

Map

from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
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Direction, Rate, Frequency, ...

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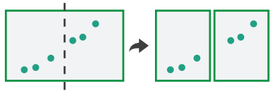

Superimpose

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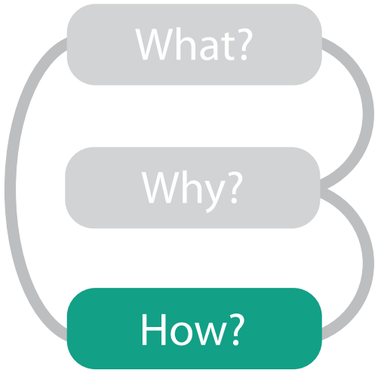
Embed