Marks Revisited: Beyond Bertin

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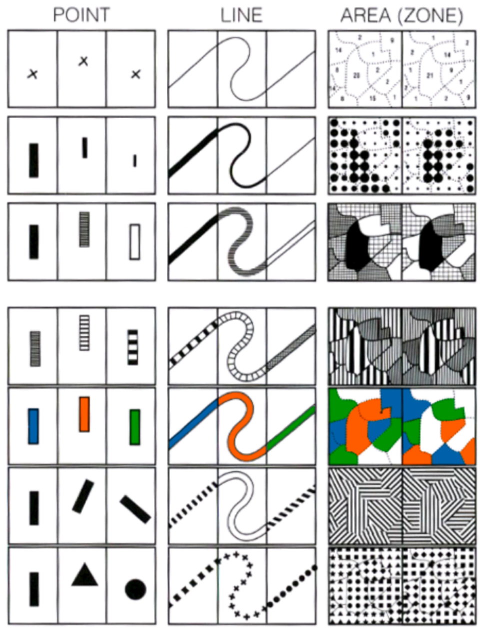
Co-conspirators

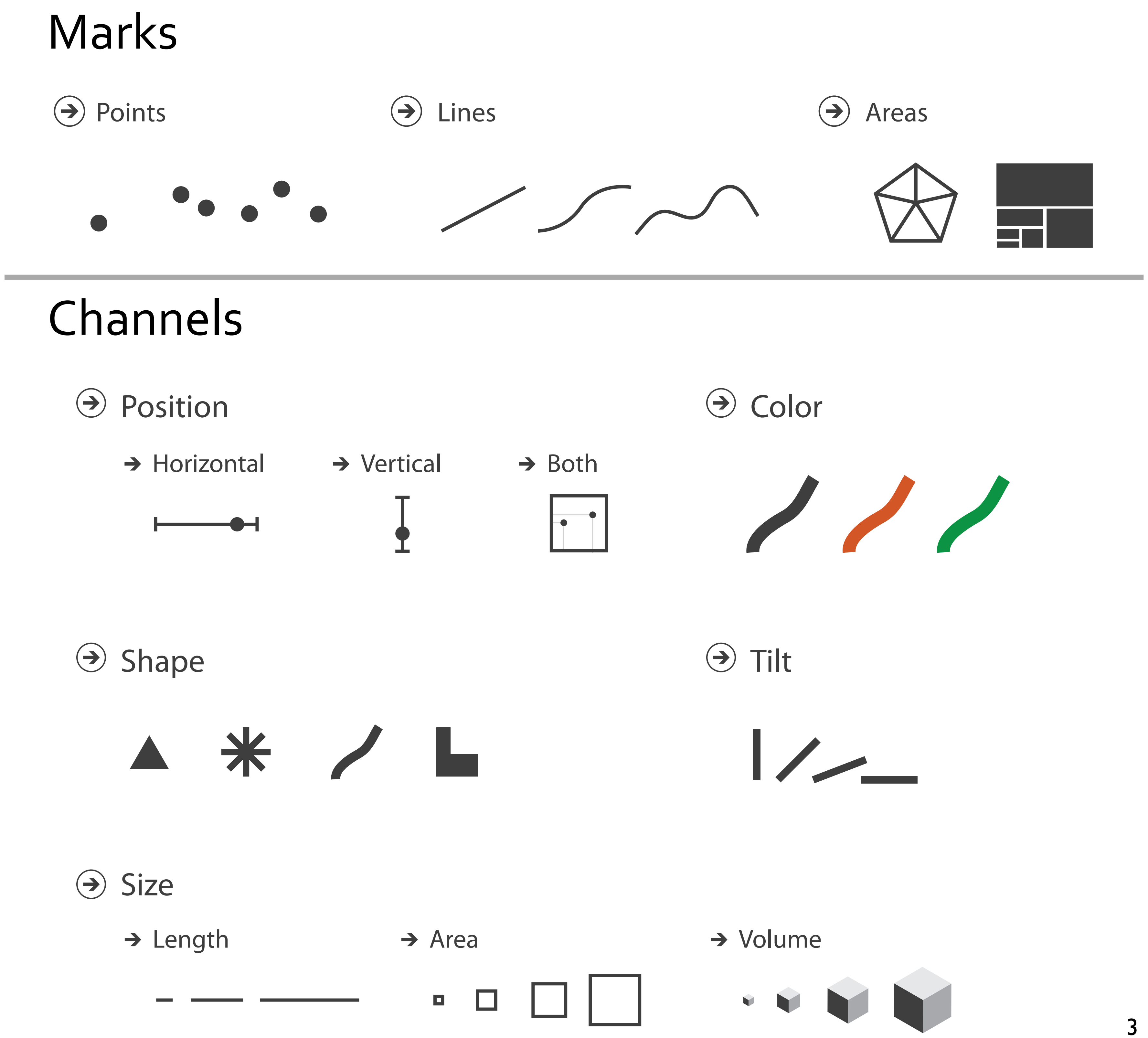
- Richard Brath
  - Uncharted Software
- Mara Solen, Francis Nguyen, Ryan Smith
  - UBC CS infovis course TAs

- also useful discussions with
  - Enrico Bertini, Hanspeter Pfister, Arvind Satyanarayan, Maureen Stone, Martin Wattenberg

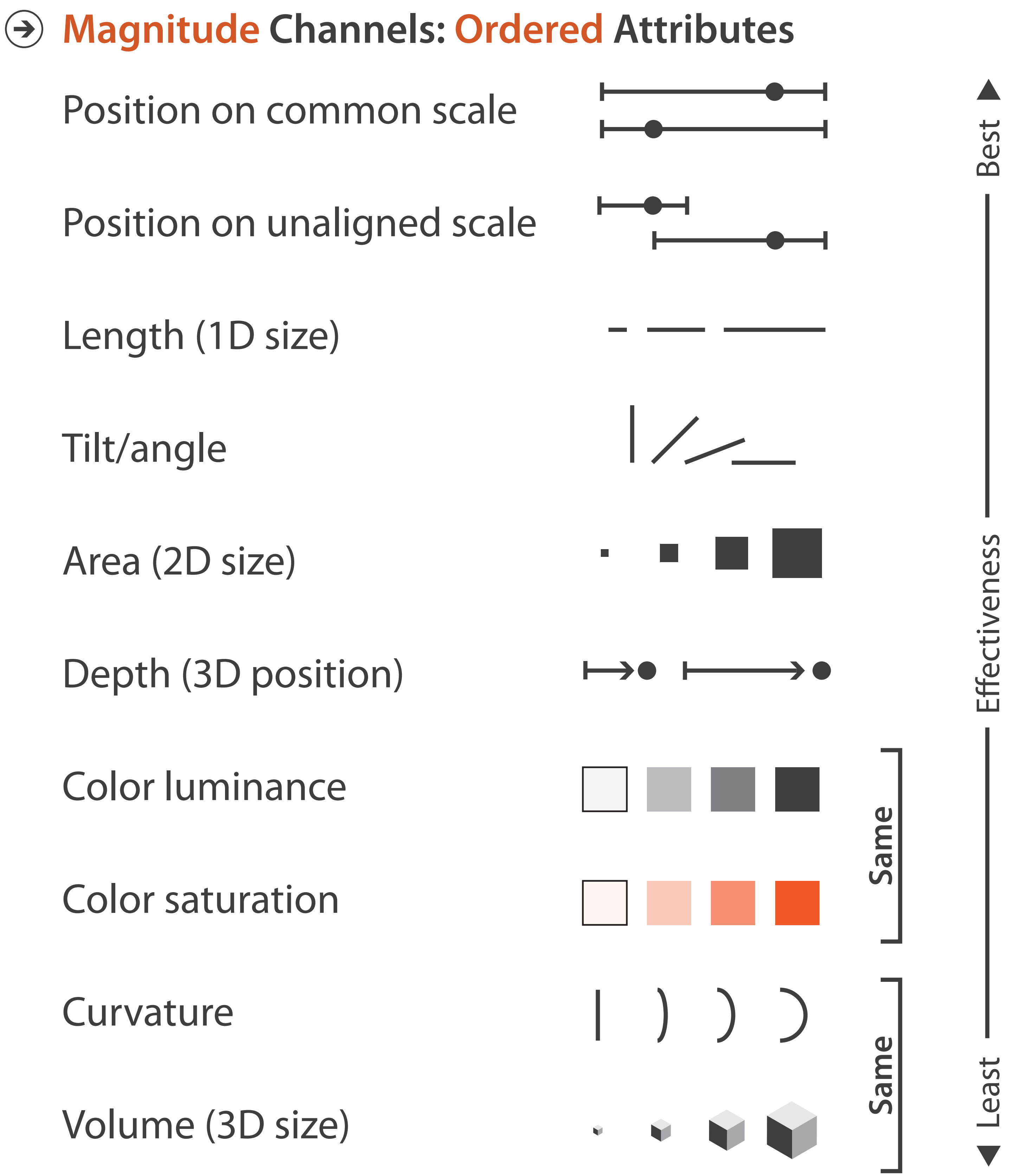
Marks and channels: Foundational model

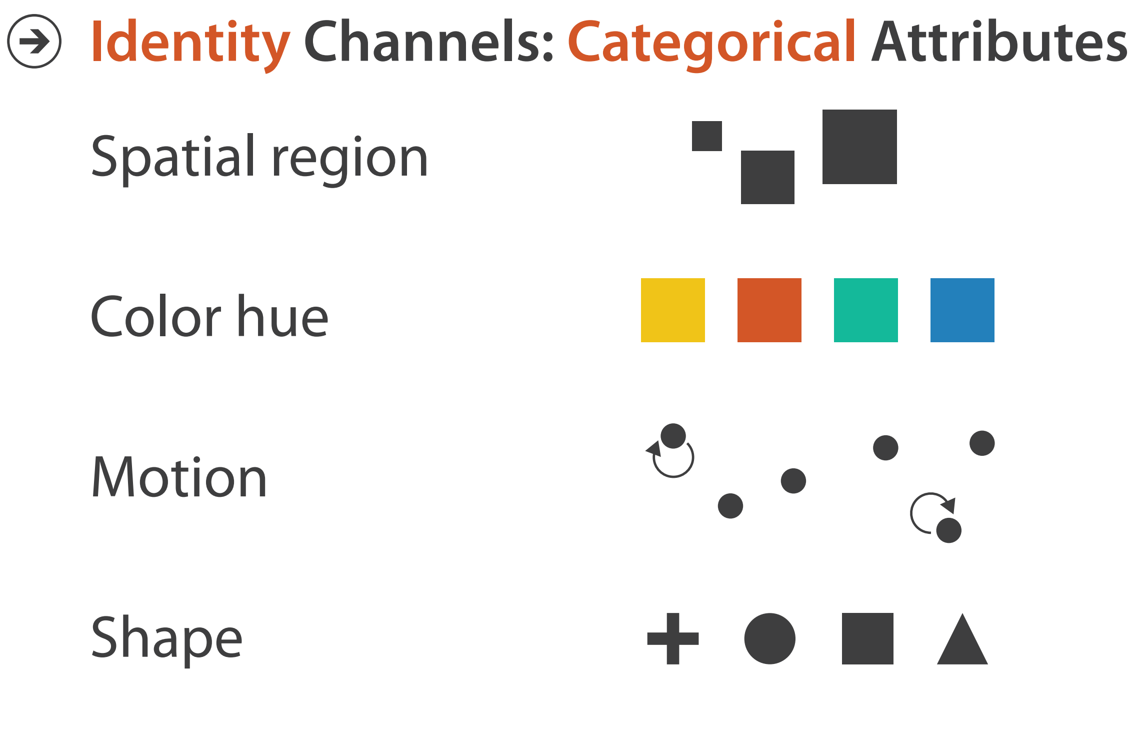
- decompose visual encoding into marks & channels
  - marks
    - geometric primitives
    - represent data items
  - channels
    - control appearance of marks
    - representing data attributes
- widely used
  - Bertin 1967
    - Semiology of Graphics





Channels: Rankings





- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
    - two-value ratio judgements, Cleveland & McGill 1987

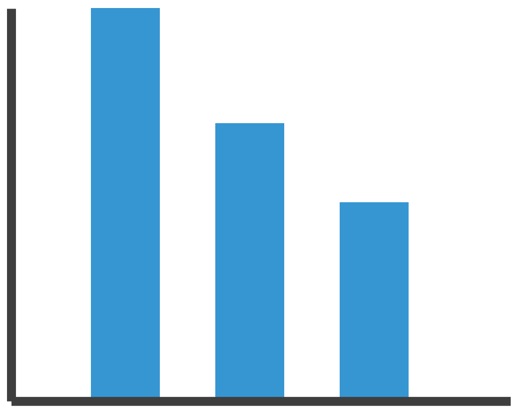
Talk outline

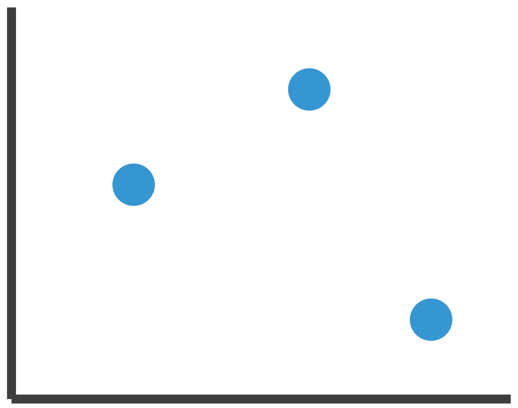
- explain current marks & channels model
- walk through many questions that arise when teaching it
- present preliminary ideas towards an alternative model

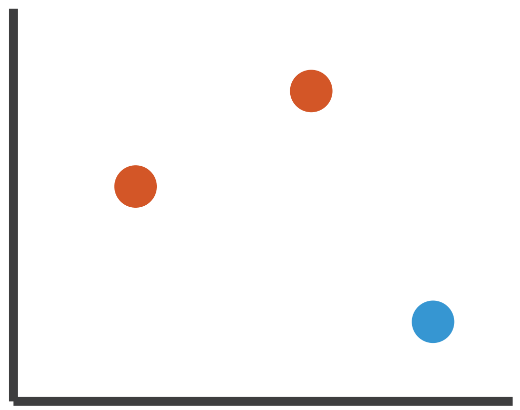
Current Marks & Channels Model

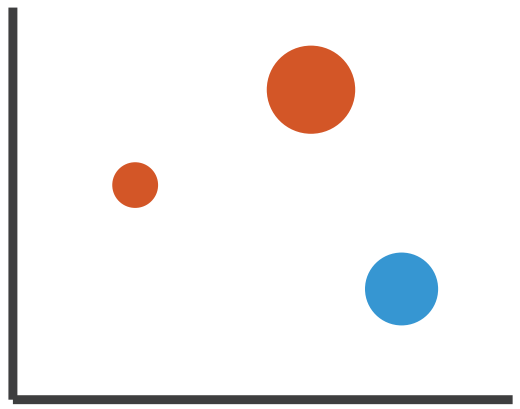
Visual encoding model

- analyze idiom structure as combination of marks and channels





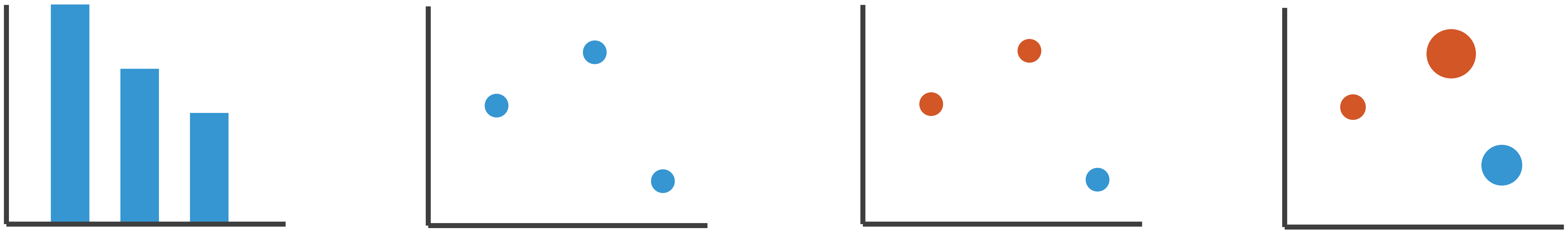




Visual encoding model

- analyze idiom structure as combination of marks and channels

idiom: bar chart



1 channel:
vertical position

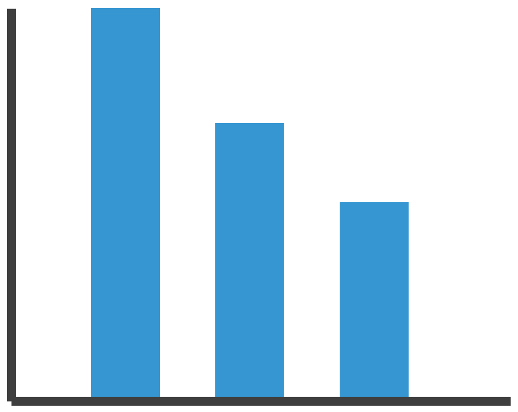
mark: line

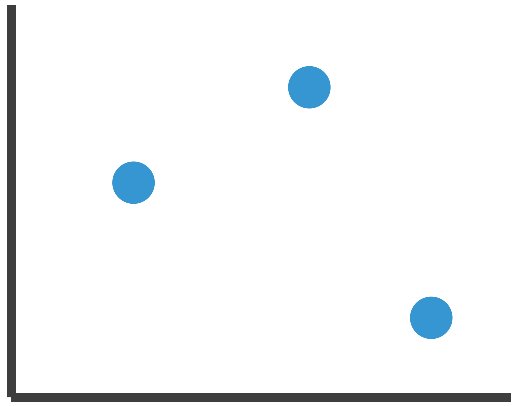
Visual encoding model

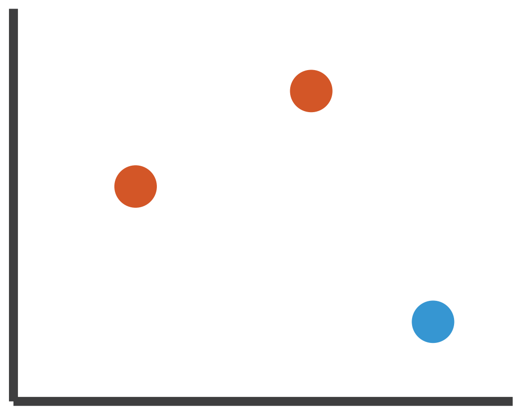
- analyze idiom structure as combination of marks and channels

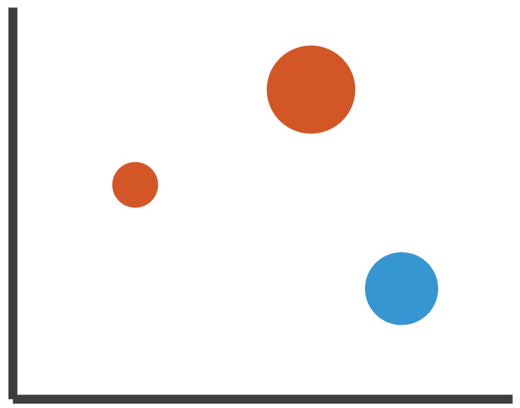
idiom: bar chart

idiom: scatterplot









1 channel:
vertical position

2 channels:
vertical position
horizontal position

mark: line

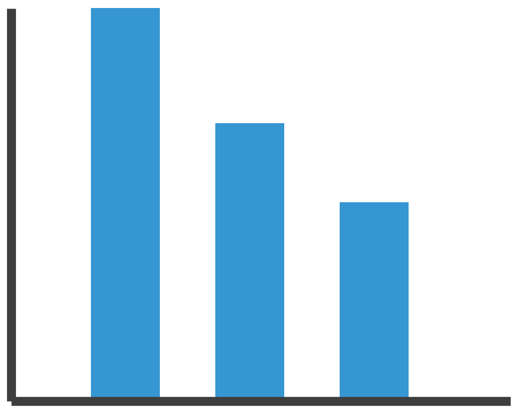
mark: point

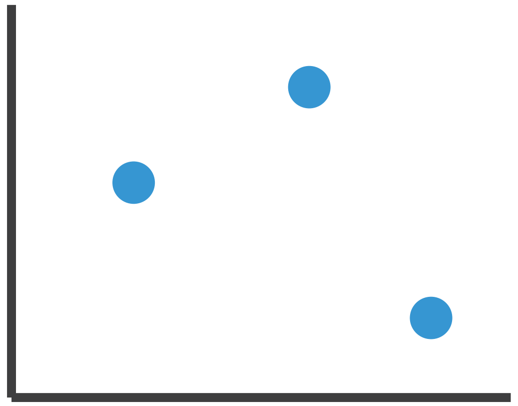
Visual encoding model

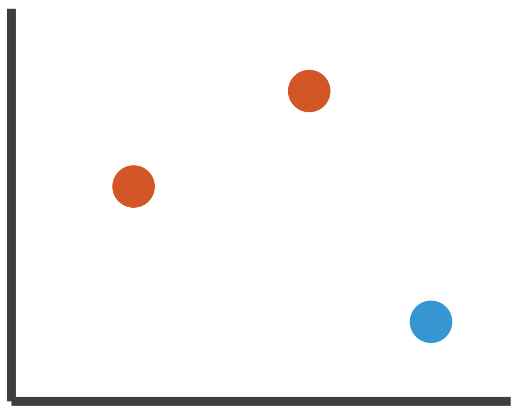
- analyze idiom structure as combination of marks and channels

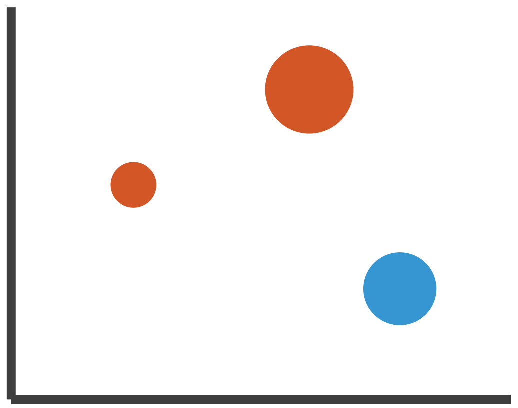
idiom: bar chart

idiom: scatterplot









1 channel:
vertical position

2 channels:
vertical position
horizontal position

3 channels:
vertical position
horizontal position
color hue

mark: line

mark: point

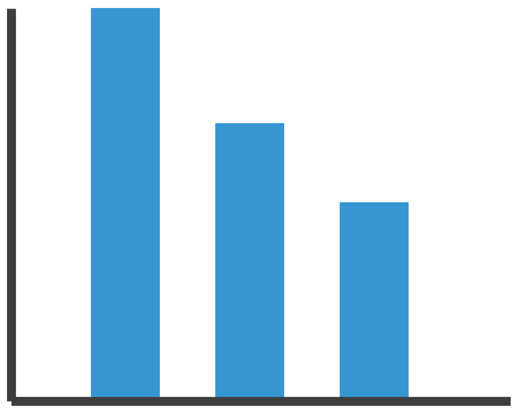
mark: point

Visual encoding model

- analyze idiom structure as combination of marks and channels

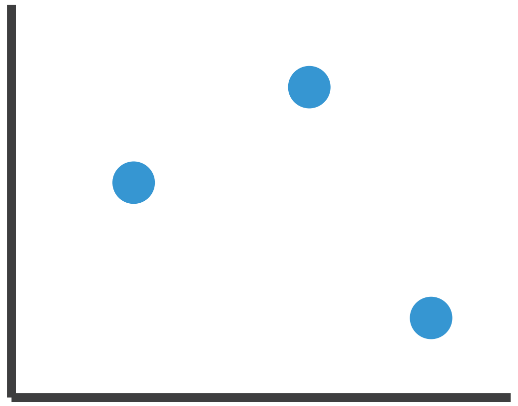
idiom: bar chart

idiom: scatterplot



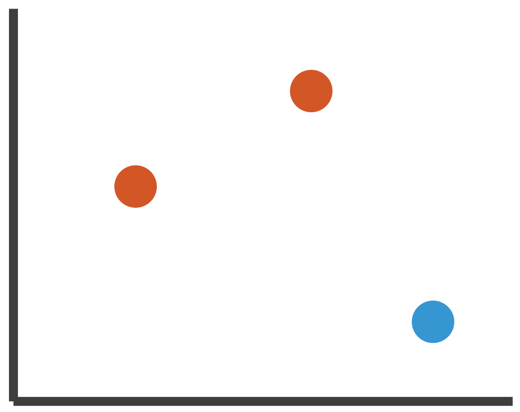
1 channel:
vertical position

mark: line



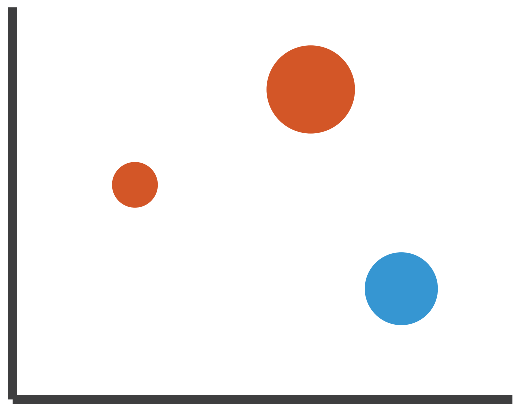
2 channels:
vertical position
horizontal position

mark: point



3 channels:
vertical position
horizontal position
color hue

mark: point

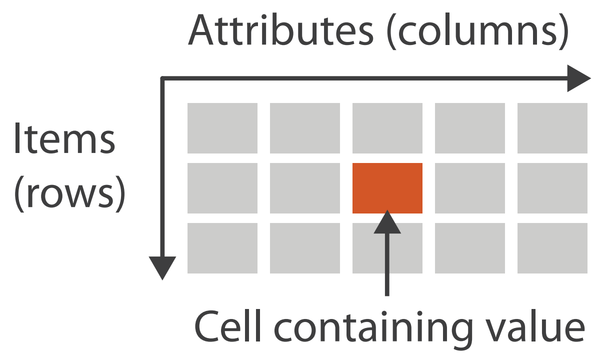


4 channels:
vertical position
horizontal position
color hue
size (area)

mark: point

Visual encoding model: Tabular data

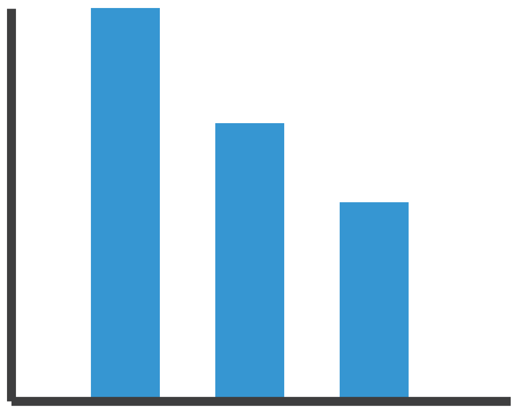
➔ Tables



- marks for items of tabular data

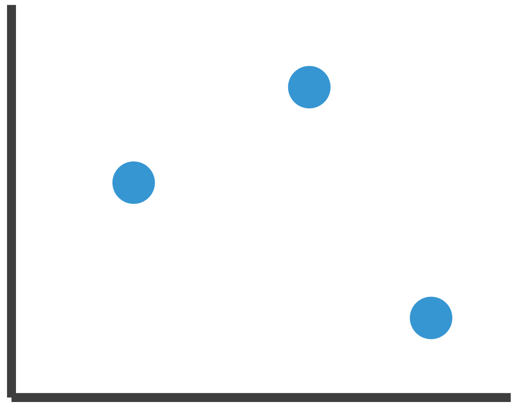
idiom: bar chart

idiom: scatterplot



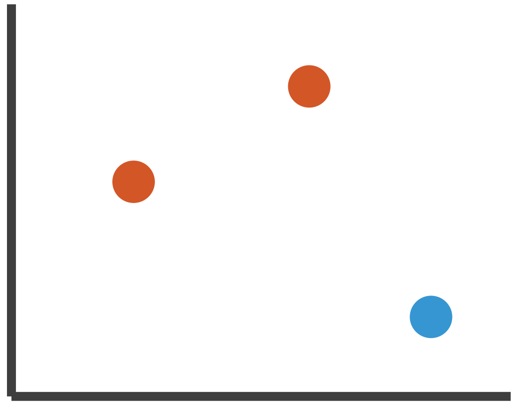
1 channel:
vertical position

mark: line



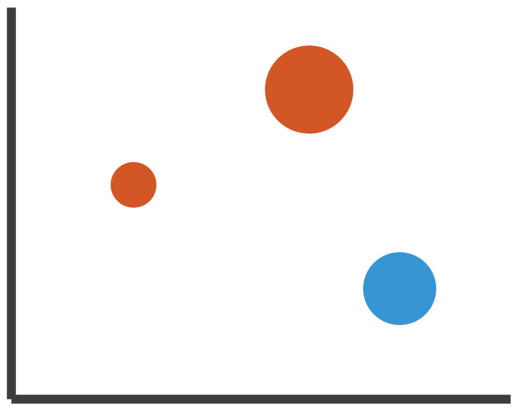
2 channels:
vertical position
horizontal position

mark: point



3 channels:
vertical position
horizontal position
color hue

mark: point



4 channels:
vertical position
horizontal position
color hue
size (area)

mark: point

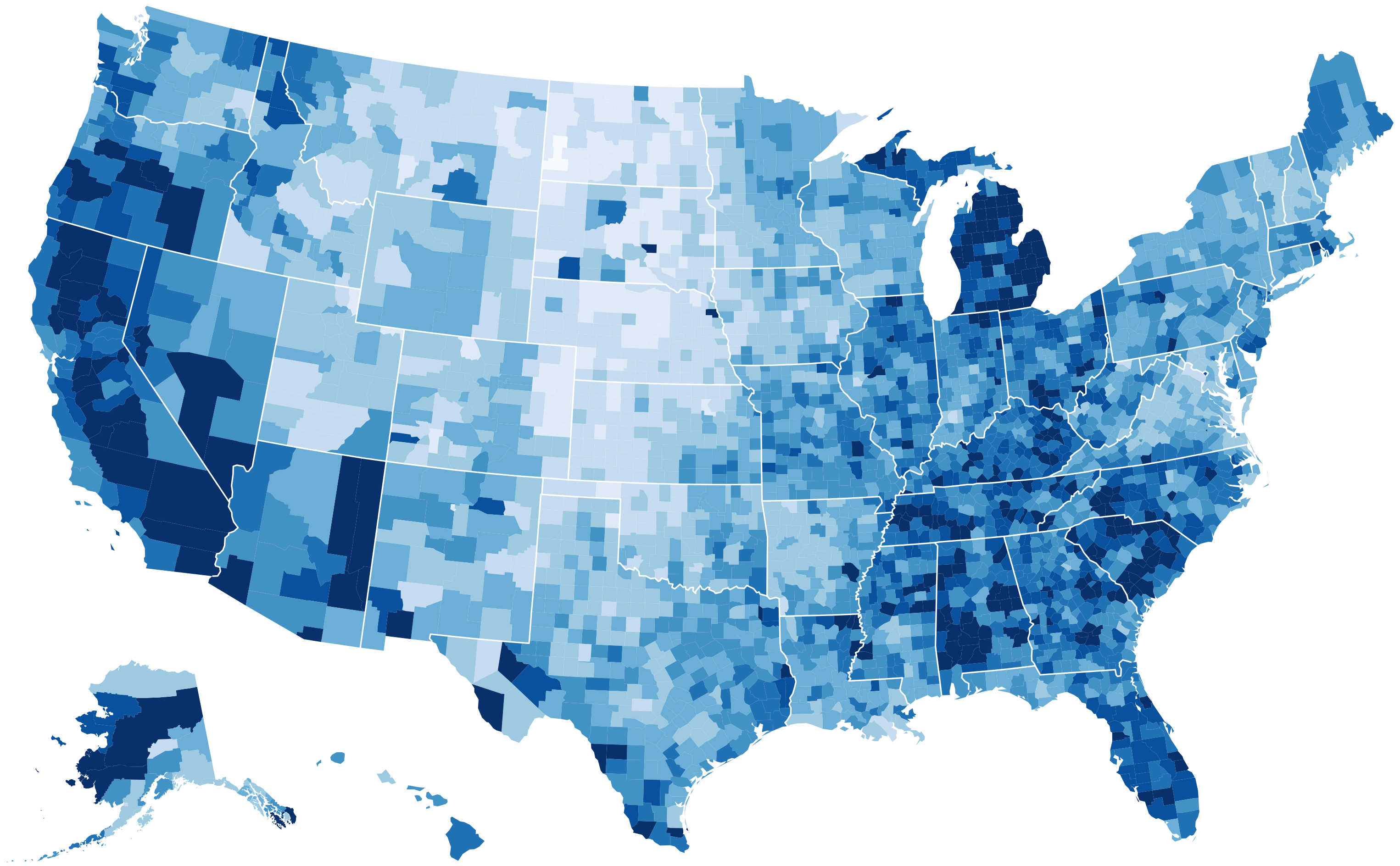
Visual encoding model: Spatial data

- marks for items of spatial data

idiom: choropleth map

channels:
position
color (saturation)

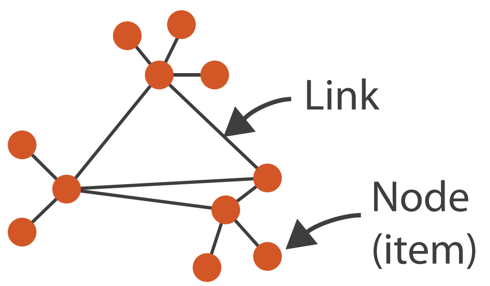
mark: area



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

Visual encoding model: Network data

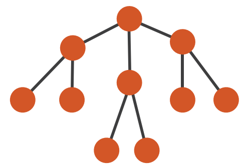
→ Networks



- marks for items and marks for links

→ Connection → Containment

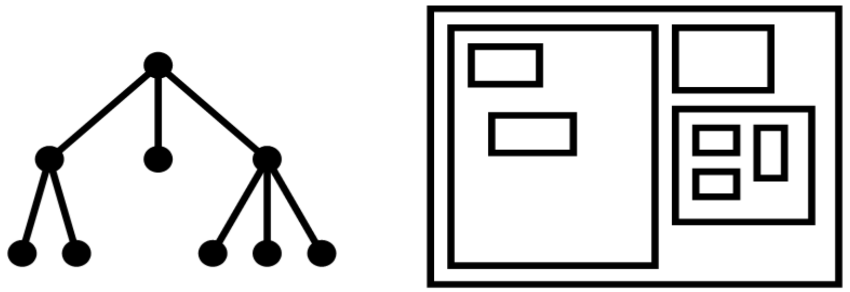
→ *Trees*

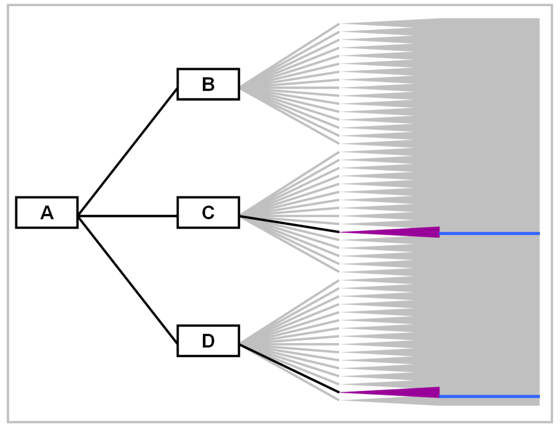


idiom: node-link diagram

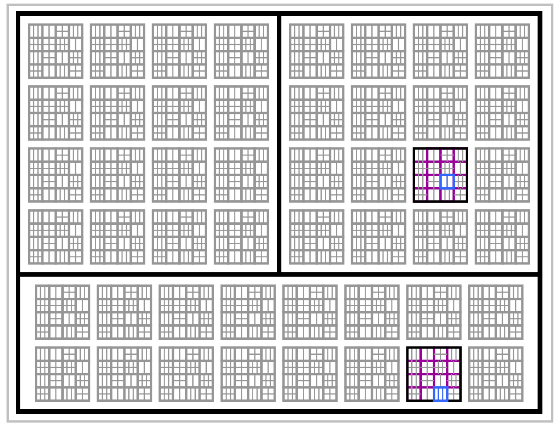
channel:
position

marks:
point for items/nodes,
connection line for links





Node–Link Diagram



Treemap

idiom: treemap

channel:
position

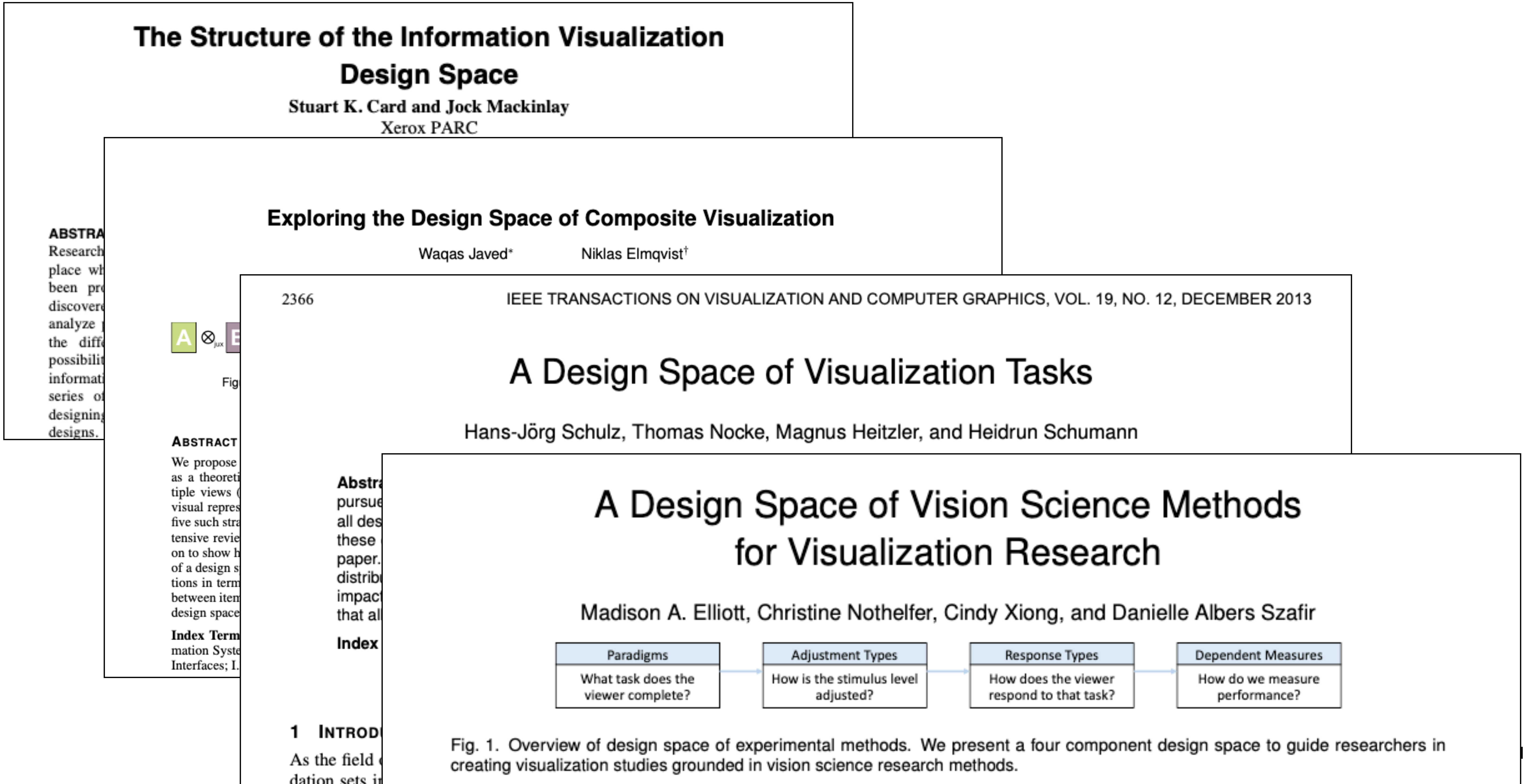
marks:
area for items/nodes,
containment area for parent-child links

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

Why analyze visual encodings?

- marks & channels model is a **design space**
  - **descriptive** power: ability to describe significant range of existing examples
  - **evaluative** power: ability to help assess multiple design alternatives
  - **generative** power: ability to help designers create new designs
    - criteria: *Michel Beaudoin-Lafon, Designing Interaction, not Interfaces. AVI 2004.*
- many names: taxonomies, typologies, classifications, frameworks, models, grammars...
  - delineate: axes / dimensions / categories
    - that are cross-cutting / independent / orthogonal
- design spaces help us reason
  - impose systematic & actionable structure on set of possibilities for specific problem
    - to support reasoning about design choices
    - capture the key variables at play
    - increase cognitive efficiency & support inferences by grouping similar instances together to facilitate reasoning about classes
      - *[Ralph. Toward Methodological Guidelines for Process Theories & Taxonomies in Software Engineering. IEEE TSE 2020]*

Design spaces in visualization: continuing theme



The Structure of the Information Visualization Design Space

Stuart K. Card and Jock Mackinlay

Xerox PARC

Exploring the Design Space of Composite Visualization

Waqas Javed* Niklas Elmqvist†

2366 IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS, VOL. 19, NO. 12, DECEMBER 2013

A Design Space of Visualization Tasks

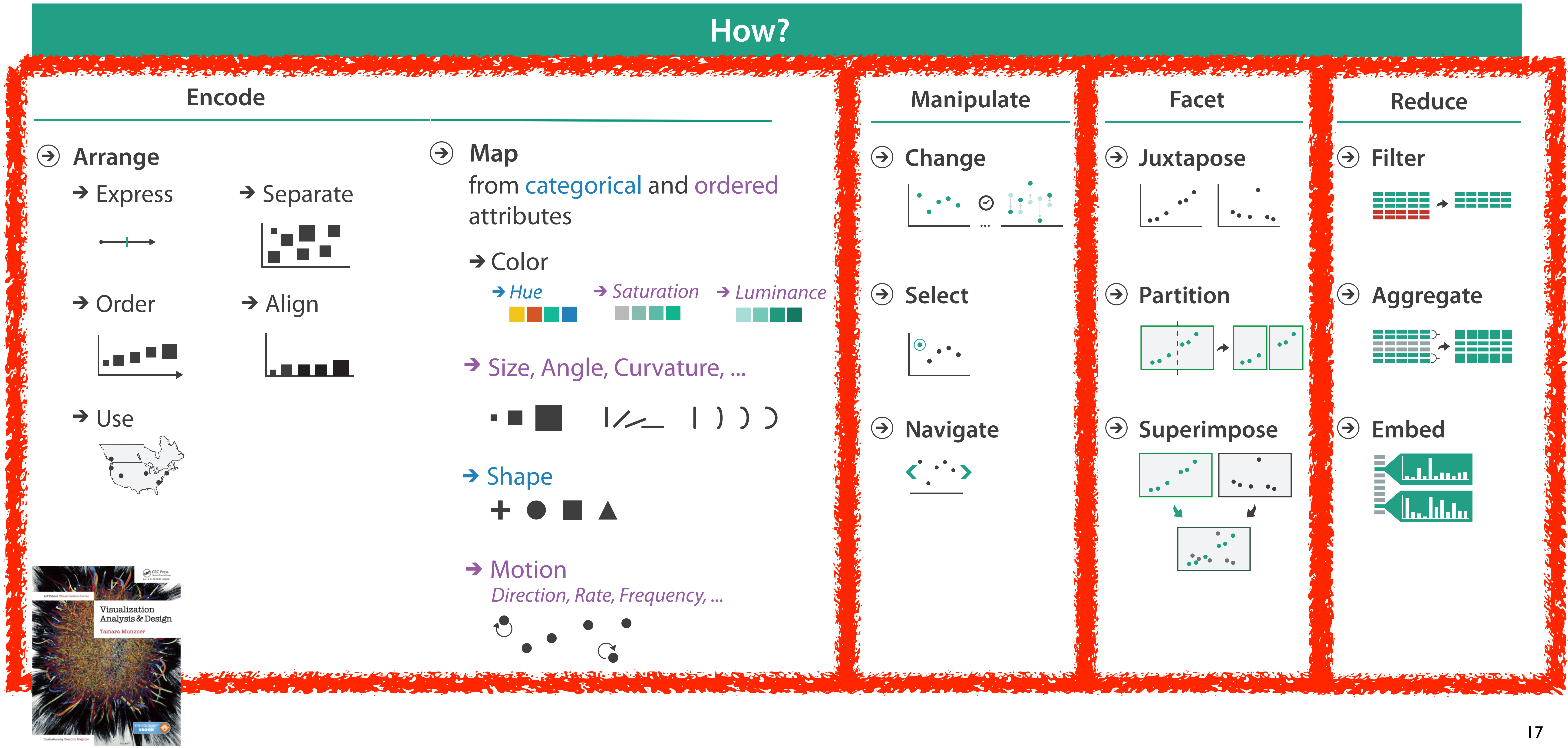
Hans-Jörg Schulz, Thomas Nocke, Magnus Heitzler, and Heidrun Schumann

A Design Space of Vision Science Methods for Visualization Research

Madison A. Elliott, Christine Nothelfer, Cindy Xiong, and Danielle Albers Szafir

Fig. 1. Overview of design space of experimental methods. We present a four component design space to guide researchers in creating visualization studies grounded in vision science research methods.

Rethinking book design space: Visualization Analysis & Design 2e



Teaching Challenges

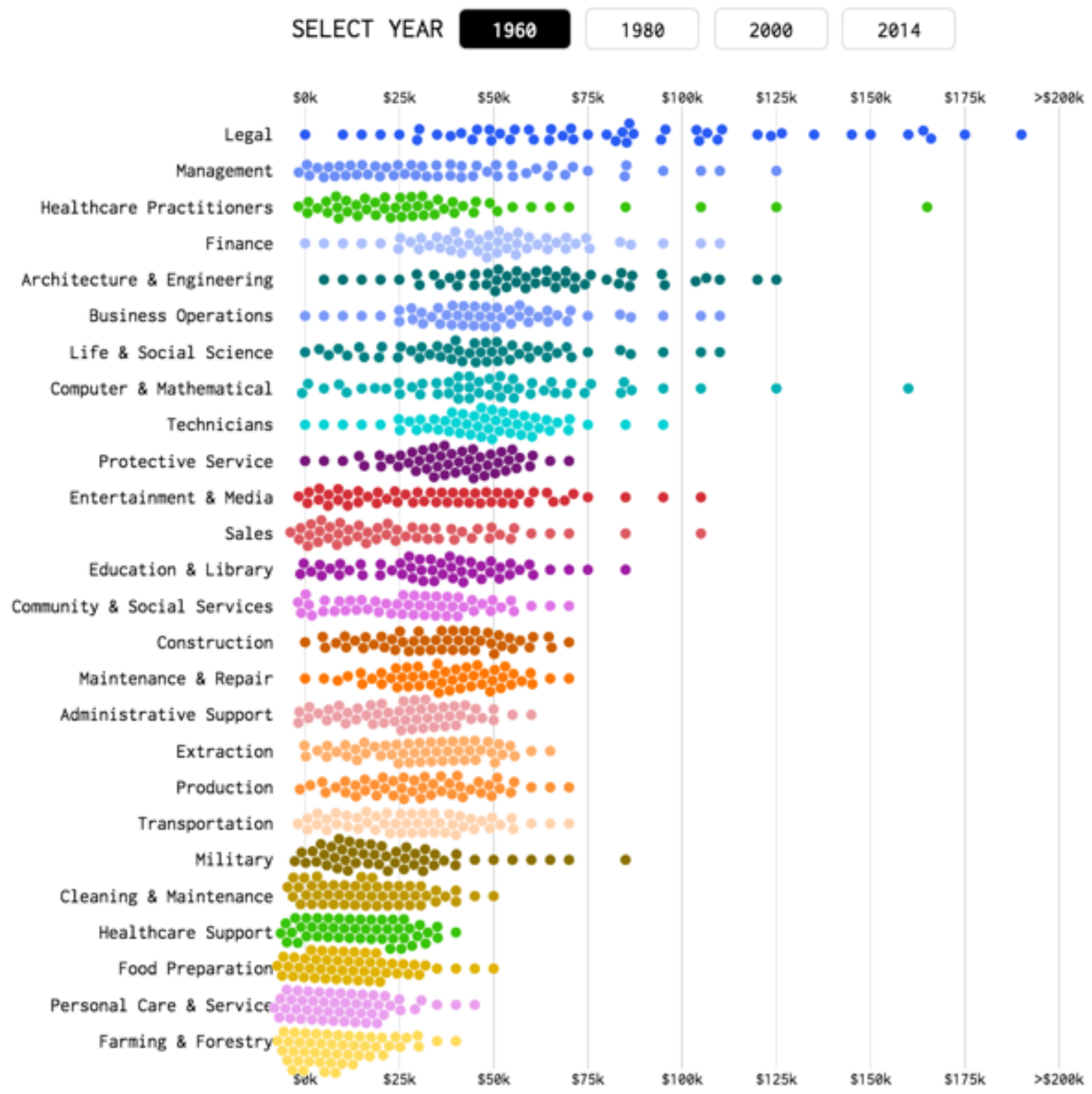
Teaching design space: analyze visual encoding & map to data

- assignment: analyze existing encoding with marks & channels
  - Visual channels used?
    - Channel X encodes attribute Y
    - Channel X encodes attribute Y
  - Marks used?
    - Mark of type X encodes item Y
    - Mark of type X encodes item Y

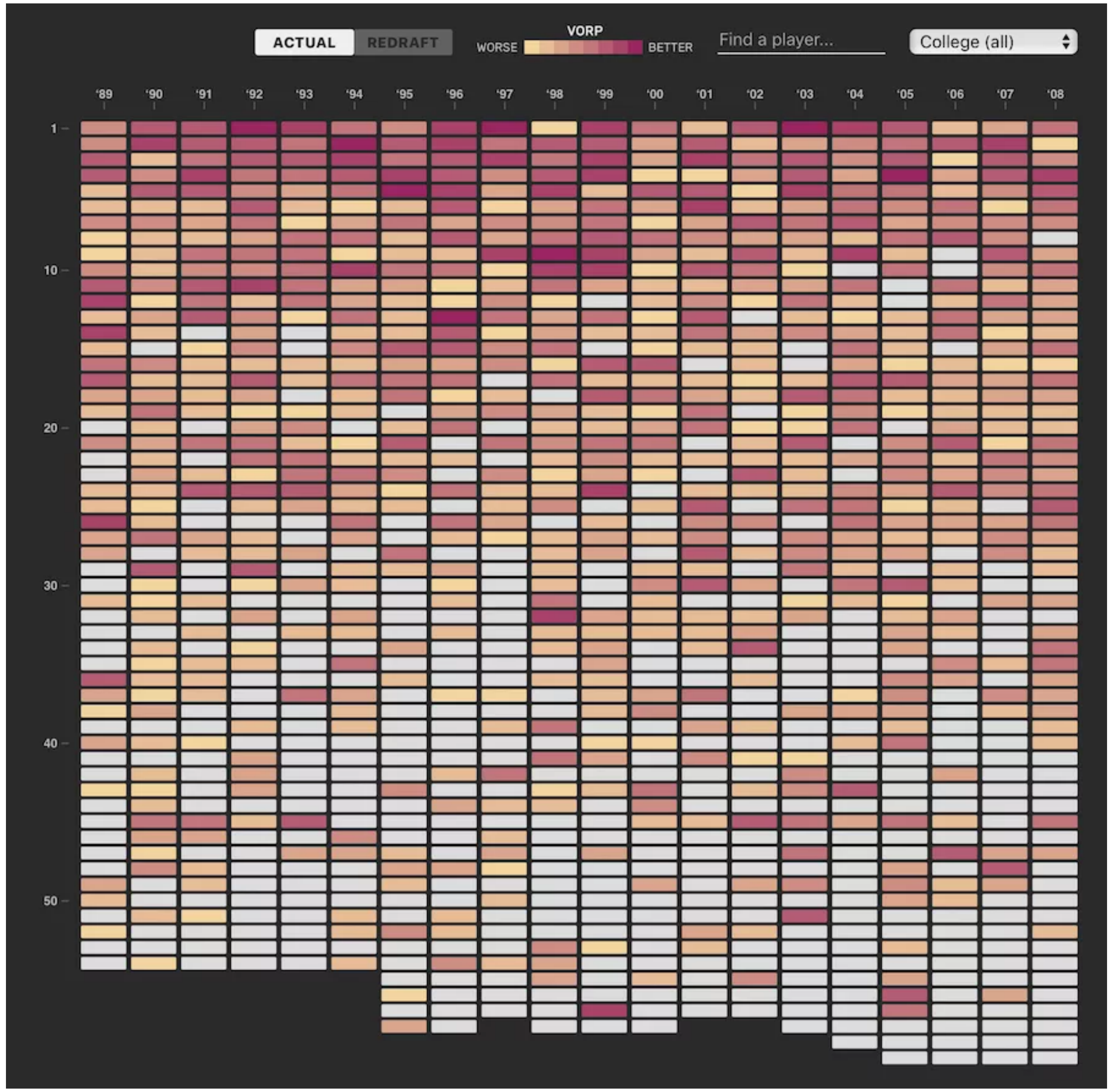
- rationale
  - reverse-engineering existing designs will help students generate future designs

Teaching: Bertini in-class exercises, catalyst for questions

- decoding marks & channels
  - https://enrico.bertini.io/teaching



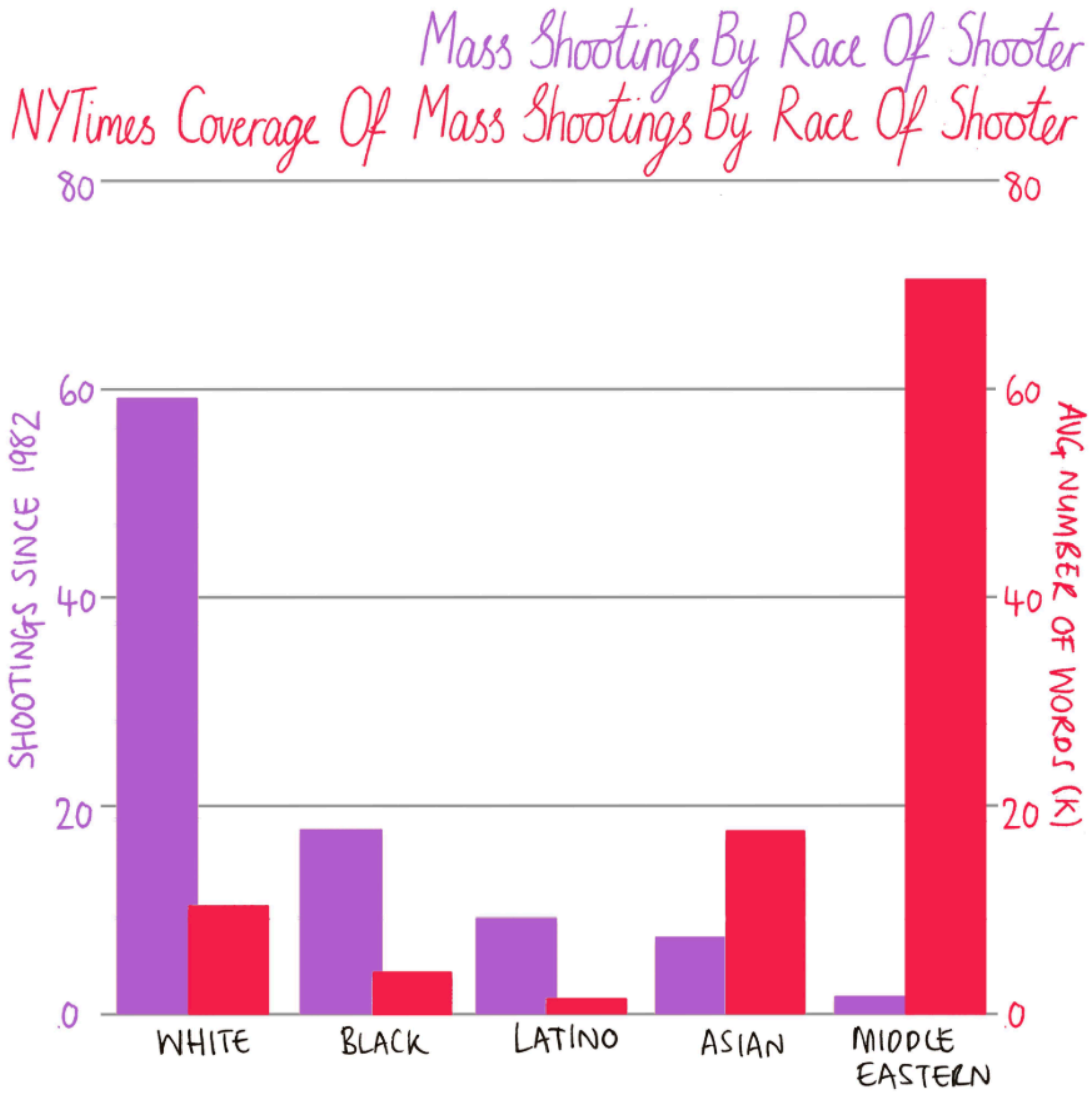
https://flowingdata.com/2016/06/28/distributions-of-annual-income/



https://pudding.cool/2017/03/redraft/

Quiz: Name marks/channels

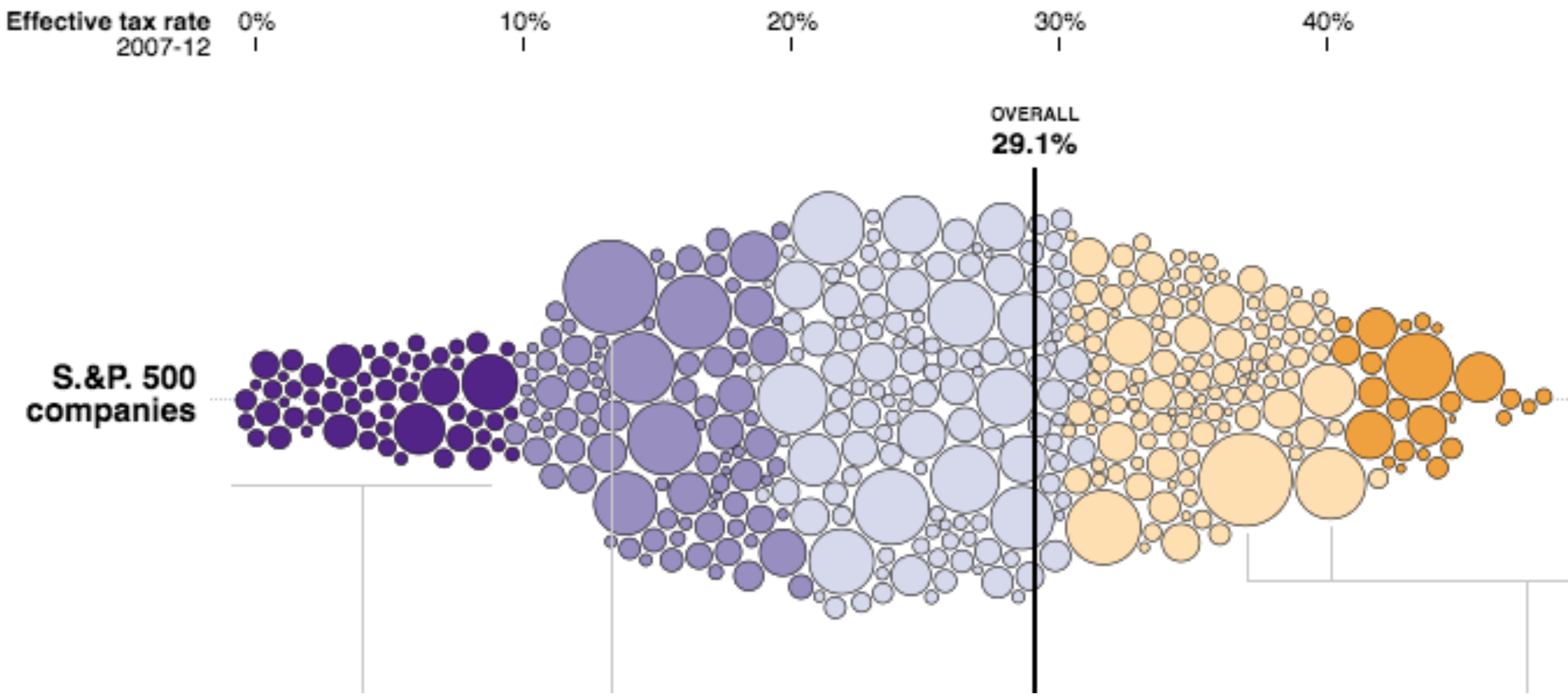
- Shooting Media Coverage
- marks
  - A: points
  - B: lines
  - C: areas
- channels
  - A: position
  - B: color
  - C: length
  - D: area
  - E: angle



https://twitter.com/MonaChalabi/status/1158779046693679106?s=20

Quiz: Name marks/channels

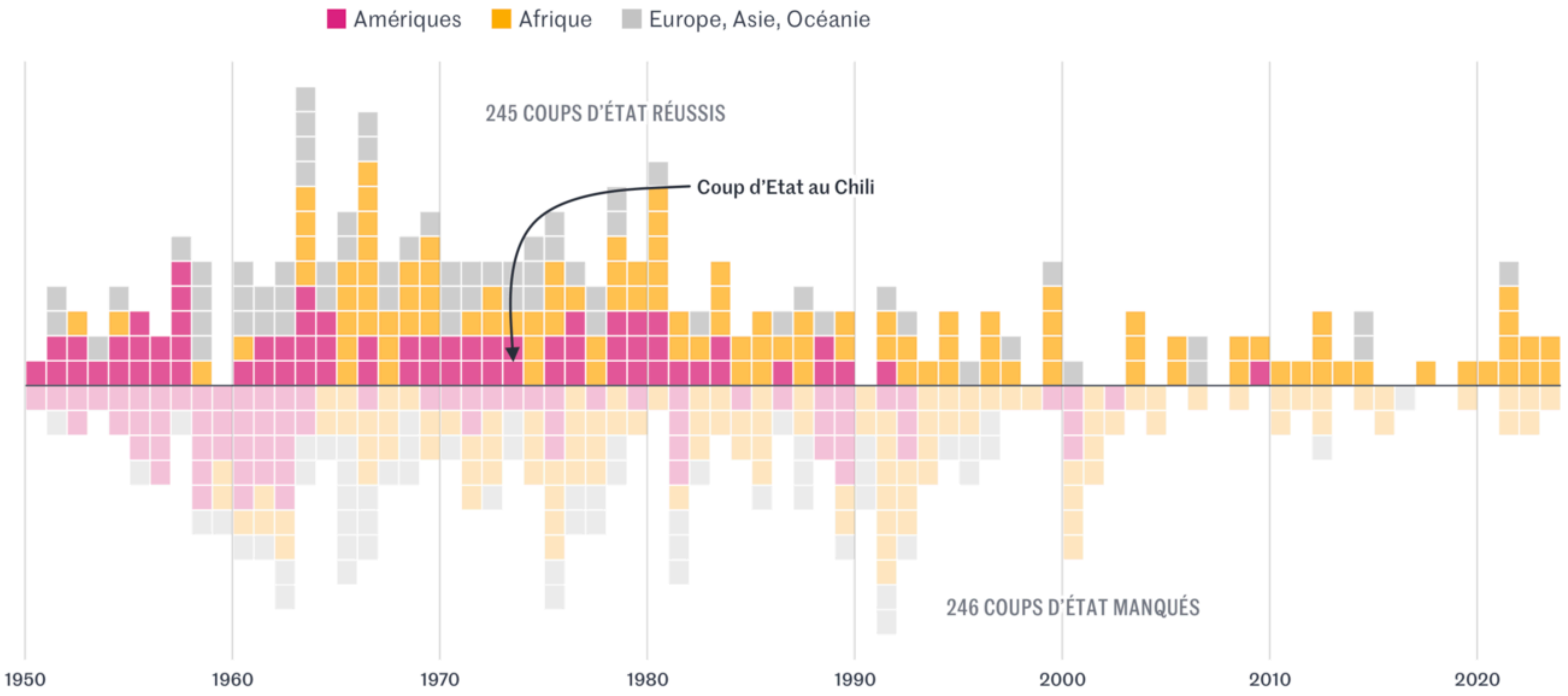
- Tax Rates
- marks
  - A: points
  - B: lines
  - C: areas
- channels
  - A: position
  - B: color
  - C: length
  - D: area
  - E: angle



https://archive.nytimes.com/www.nytimes.com/interactive/2013/05/25/sunday-review/corporate-taxes.html

Quiz: Name marks

- points? lines? areas?



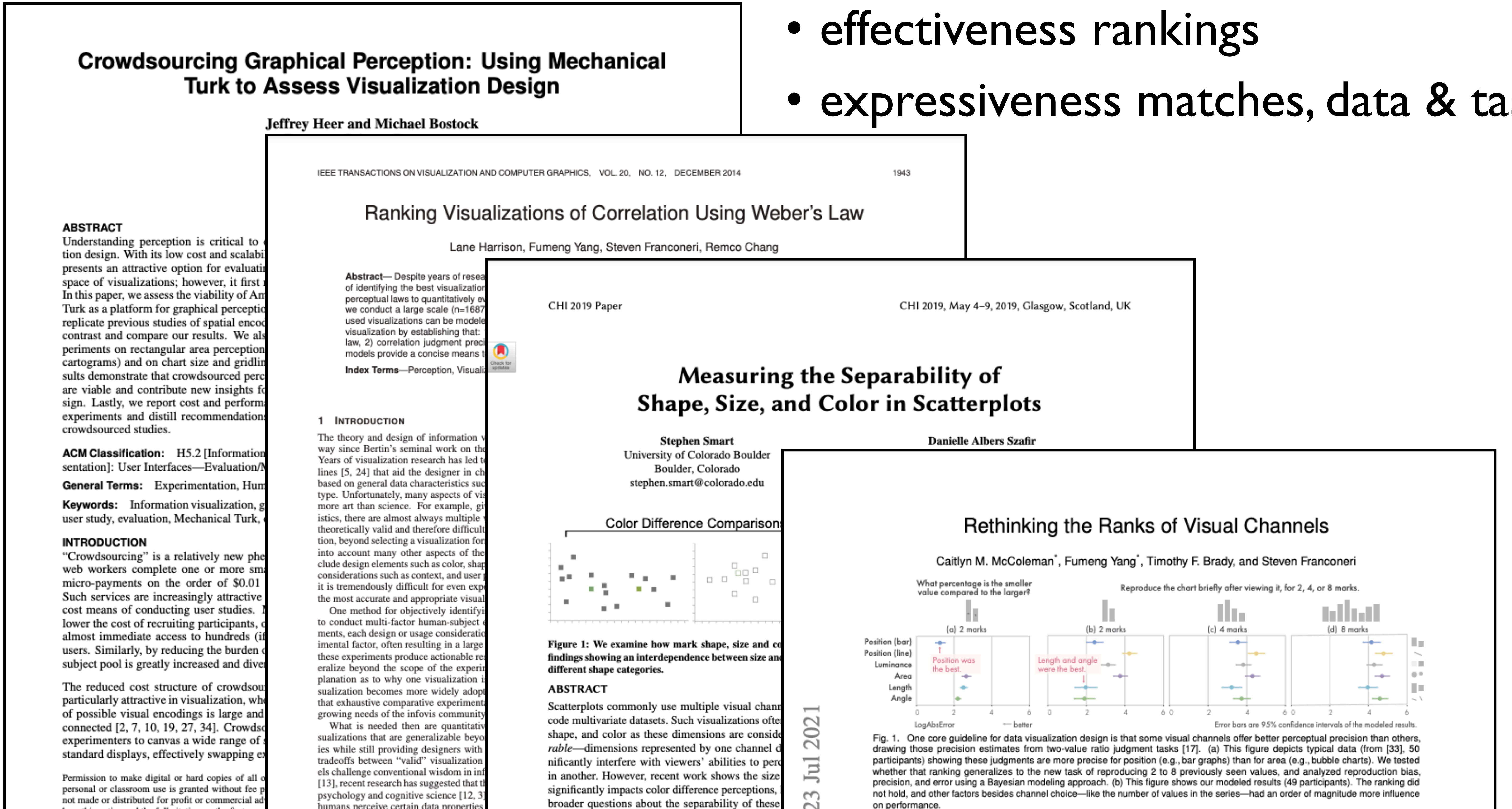
https://www.lemonde.fr/les-decodeurs/article/2023/09/11/depuis-1950-pres-de-cinq-cents-coups-d-etat-tentes-ou-reussis-surtout-en-amerique-latine-et-en-afrique_6188906_4355770.html

Many, many questions

- so what?
  - evidence that this design space could be improved!

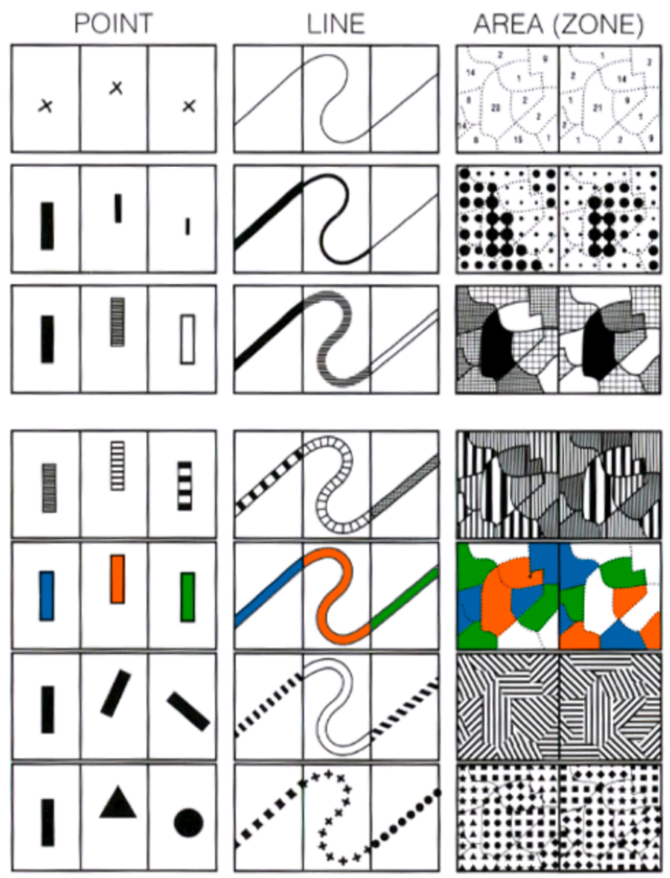
Channels: Model evolves, heavily studied

- effectiveness rankings
- expressiveness matches, data & task



Marks: Model stays static

- model inherited from Bertin (Semiology of Graphics, 1967)
  - never questioned
- geometric motivation
  - geometric primitives have dimensions
  - how could we argue with math?!

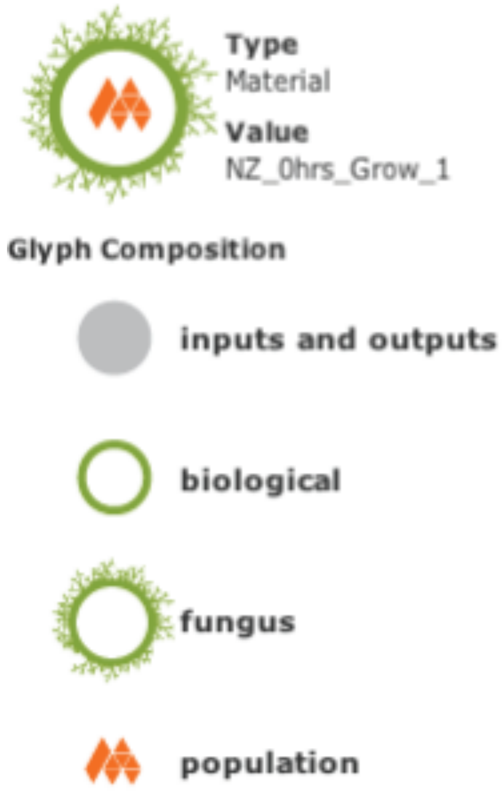


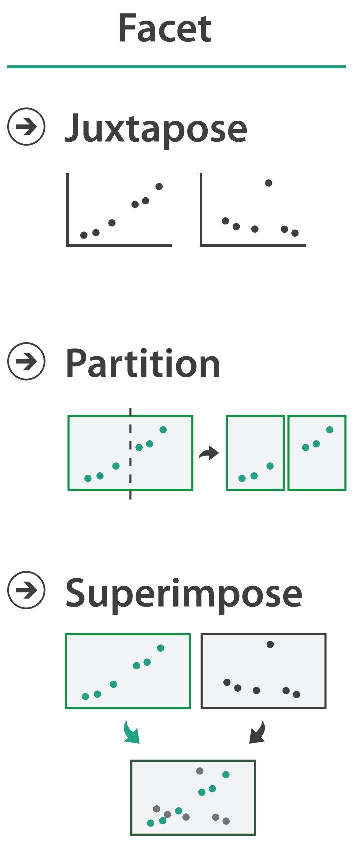
➔ Points ➔ Lines ➔ Areas ➔ Volume

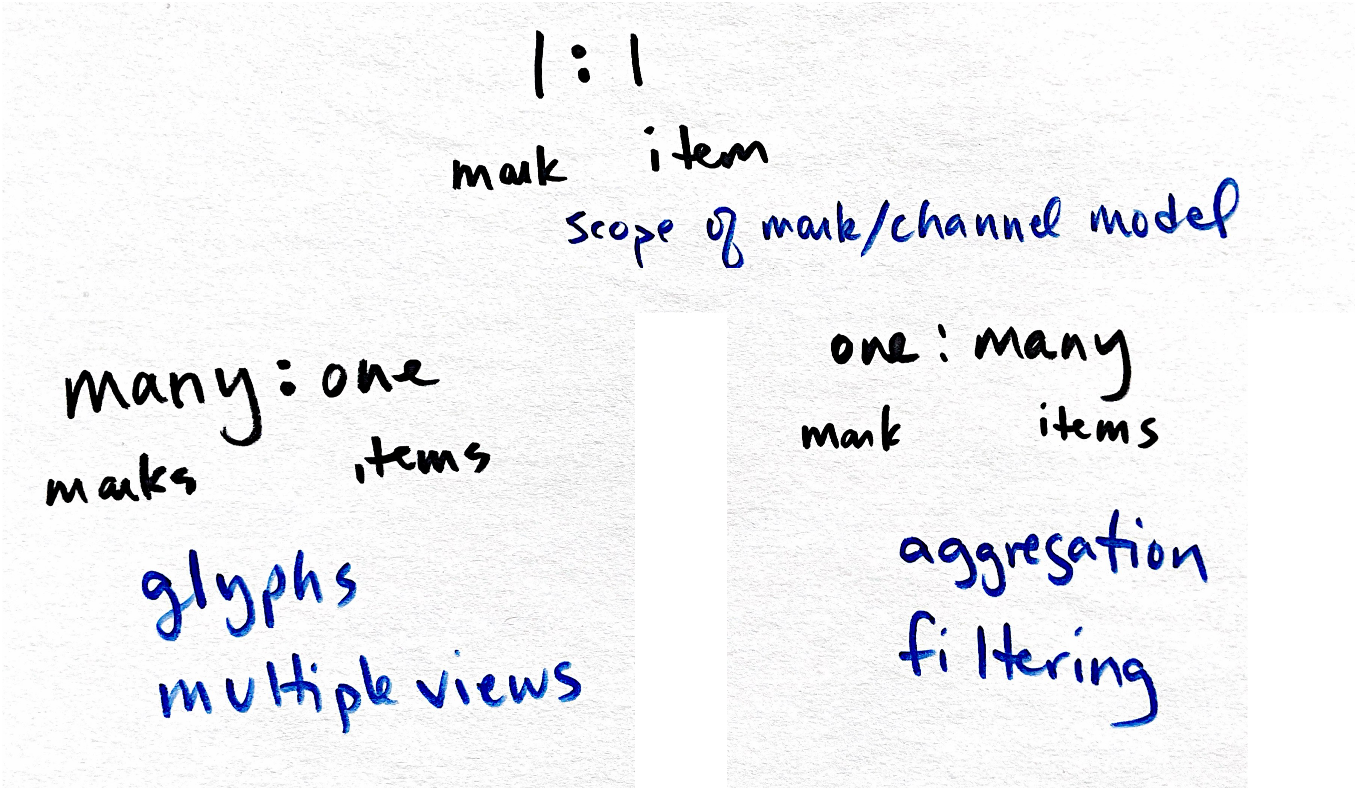
0D 1D 2D 3D

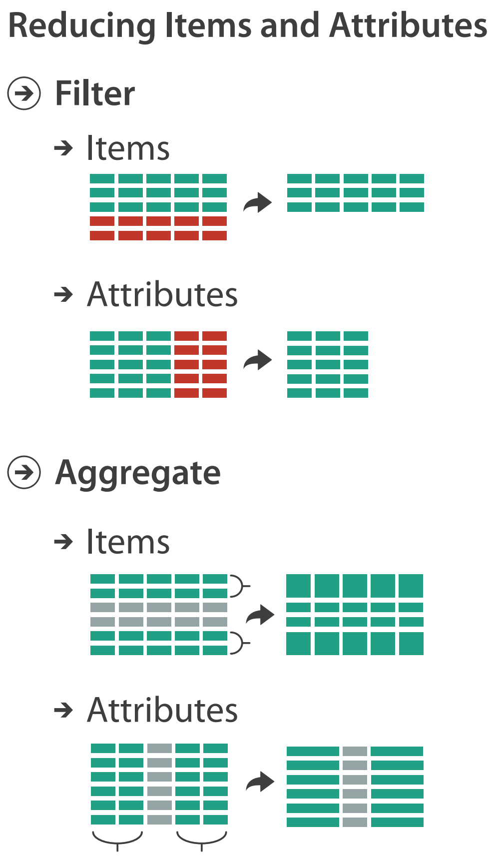
Mark/channel analysis: scope & limits

- model scope: one mark for one data item
  - multiple marks for one item: glyphs, multiple views
  - one mark for many items: aggregation, filtering









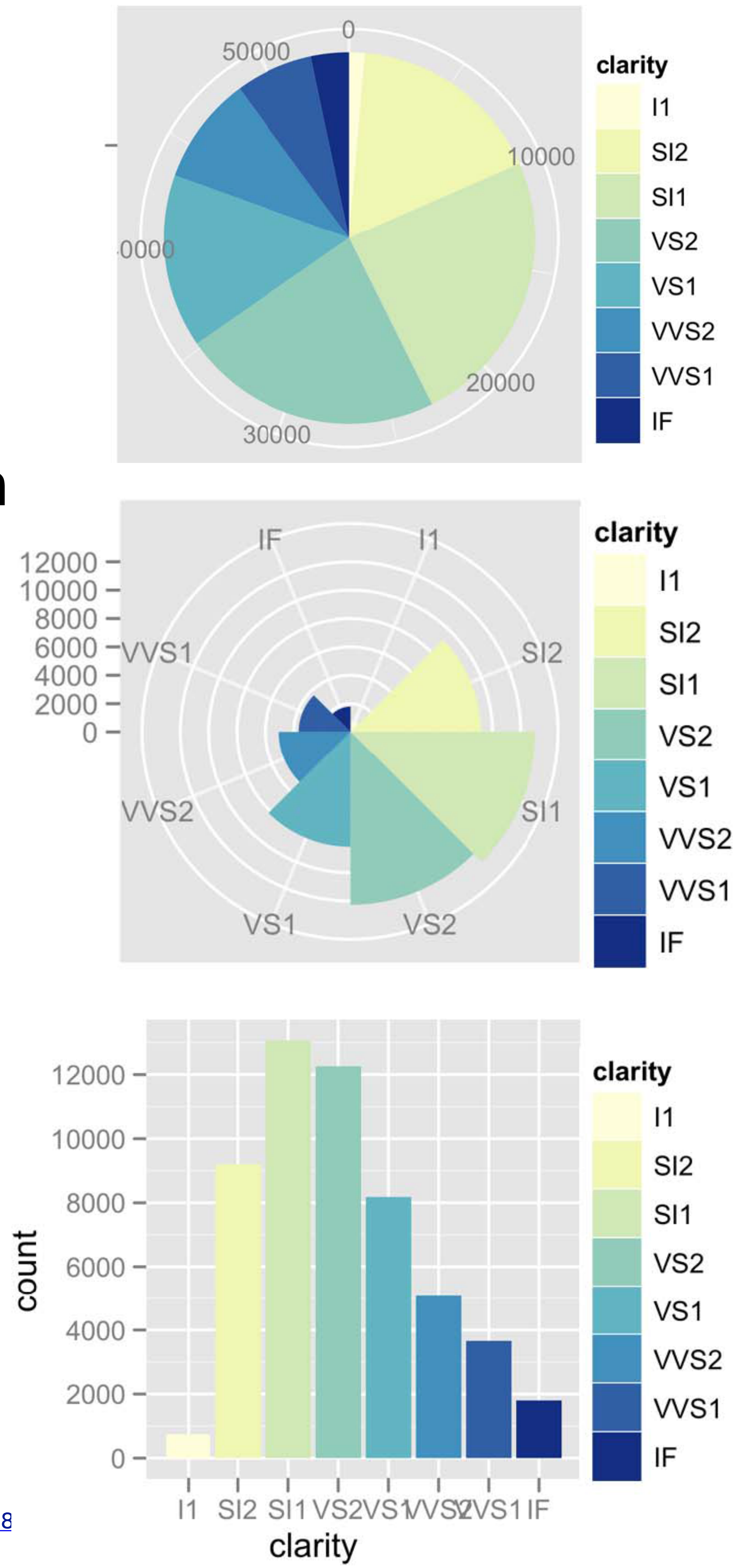
Taxonomy-Based Glyph Design—with a Case Study on Visualizing Workflows of Biological Experiments. Maguire et al. TVCG 18(12):2603-2612, 2012.

Encoding vs decoding models

- **Encoding** model: what should visualization **designer** do?
  - prescriptive model, providing guidance for design
- **Decoding** model: how will visualization **viewer** interpret?
  - predictive model, informed by vision science & perception research
  - predicting viewer response differs from inferring or reverse-engineering designer intent when encoding!

Encode vs decode: Where do models diverge?

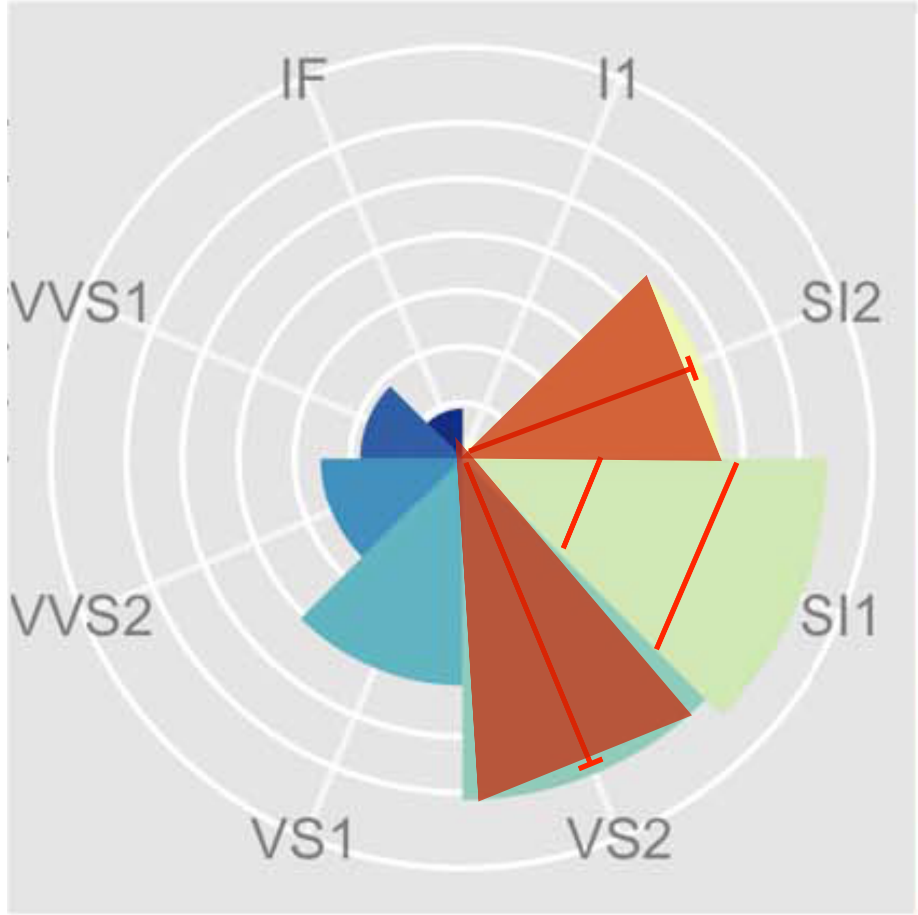
- idiom: pie chart
  - **encode:** area marks with angle channel: **2D area varies**
    - ordered radially, uniform length
  - accuracy: area less accurate than rectilinear aligned position/length
  - **decode**: not angle! probably arc length, maybe also area
    - https://eagereyes.org/blog/2016/an-illustrated-tour-of-the-pie-chart-study-results
- idiom: coxcomb chart
  - **encode:** marks with length channel: **1D length varies**
    - ordered radially, uniform width
    - more direct analog to bar charts, but using radial layout
  - what's the mark type?
    - line, because it's length coded?
    - area, because area varies too?



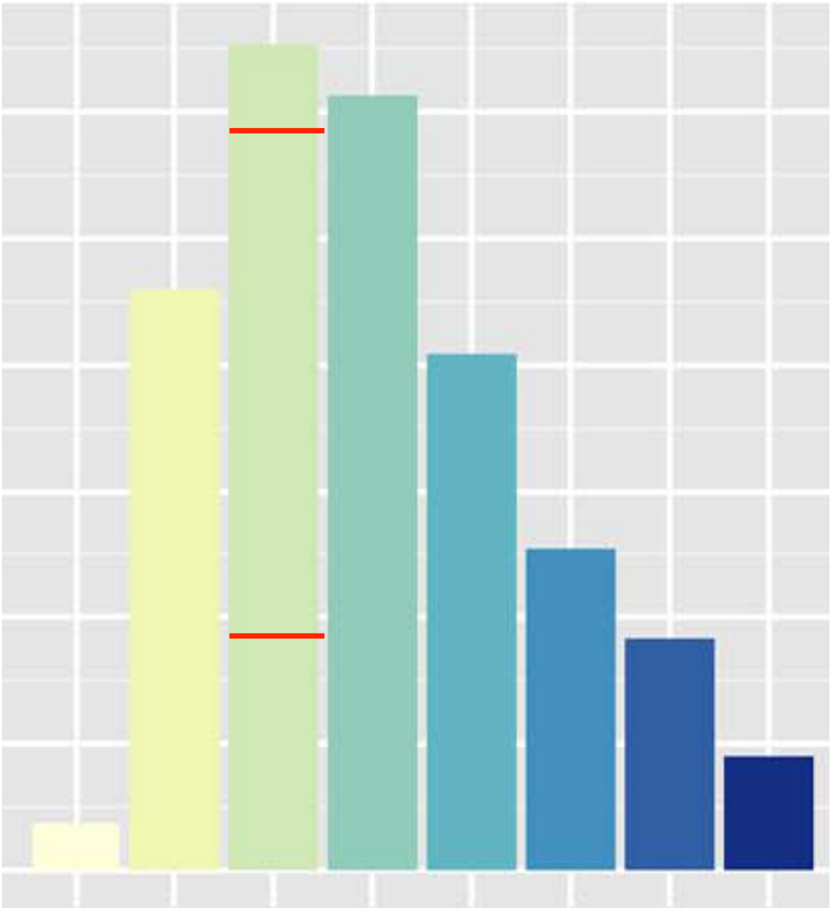
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28

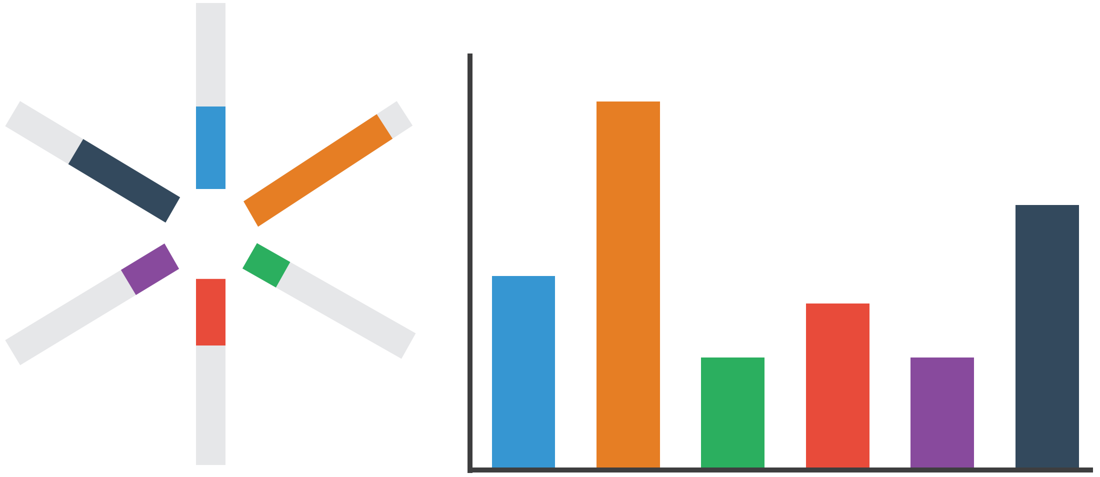
Encode vs decode: Where do models diverge?

- encode: 1D size (length)
- decode/perceive: 2D area
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt mark length!
- bar chart safer
  - uniform width, so area is linear with mark length
    - both radial & rectilinear cases
- encode vs decode divergence
  - if channels differ, which "wins"?



nonuniform width as length increases


uniform width as length increases


radial & rectilinear bars: uniform width as length increases

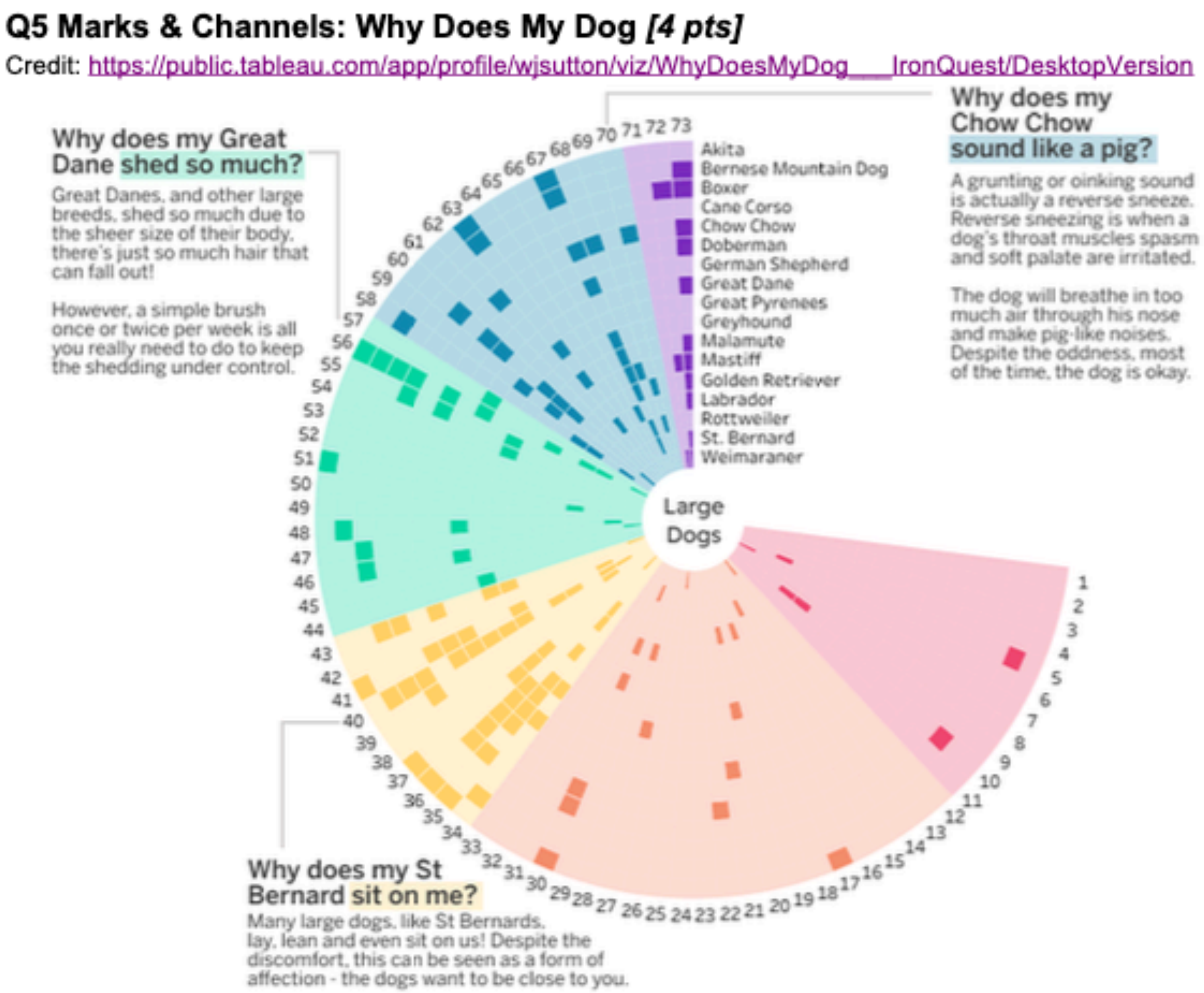
Alternative Ideas

Constraints

- consider marks and channels as imposing constraints
  - when does mark type constrain channel use?
  - when does using one channel constrain another channel?

Channel use: what does it mean?

- Does channel size encode attribute?
  - yes? sizes differ
    - according to dog name in alphabetical order
  - no! size differences not meaningful
    - just emerges from choice of layout, radial vs rectilinear
    - not a "real" attribute encoding
- Can we use size channel to encode another attribute?
  - no! not free
  - it's "taken" already, would change meaning
- Size channel is Unavailable



https://public.tableau.com/app/profile/wjsutton/viz/WhyDoesMyDog___IronQuest/DesktopVersion

Channel Availability Model

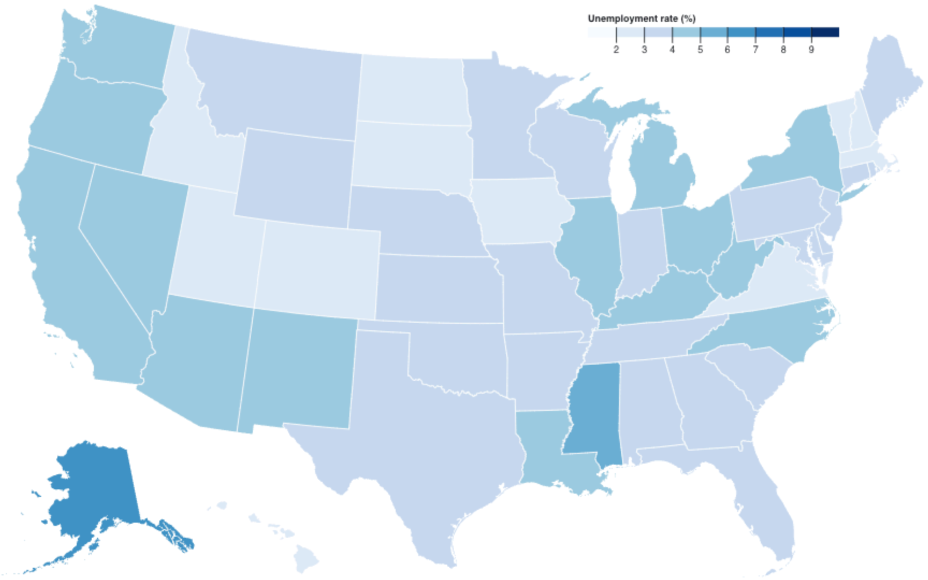
- Encoded: which channels directly used to encode attributes?
  - clear meaning
  - multiple channels can be directly used for redundant encoding
- Free: which channels free to encode another attribute?
  - without changing usability of existing encoding
- Unavailable: which channels unavailable / precluded / taken?
  - because of mark type?
  - because of idiom/algorithm design specifics?
  - because other channels used?

Area marks: Rethinking

- area marks is a terrible name
  - other marks all have graphical area too
    - allowing us to encode with color
    - computer graphics point of view: they're all just polygons
  - there's also an "area" channel, which is confusingly different
  - area is not the only channel in play with these marks!

Area marks

- obvious example: choropleth maps
- what can we do to California? could we encode additional data?
  - cannot shrink/grow (size channel)
  - cannot translate (position channel)
  - cannot rotate (orientation channel)
  - cannot reshape (shape channel)
  - why not?
    - would lose meaning of that mark: boundary is the data
    - also lose meaning for other occluded marks
- "area" mark is not specific enough
  - AreaPositionOrientationShape mark??? nah...
  - idea: **interlocking**

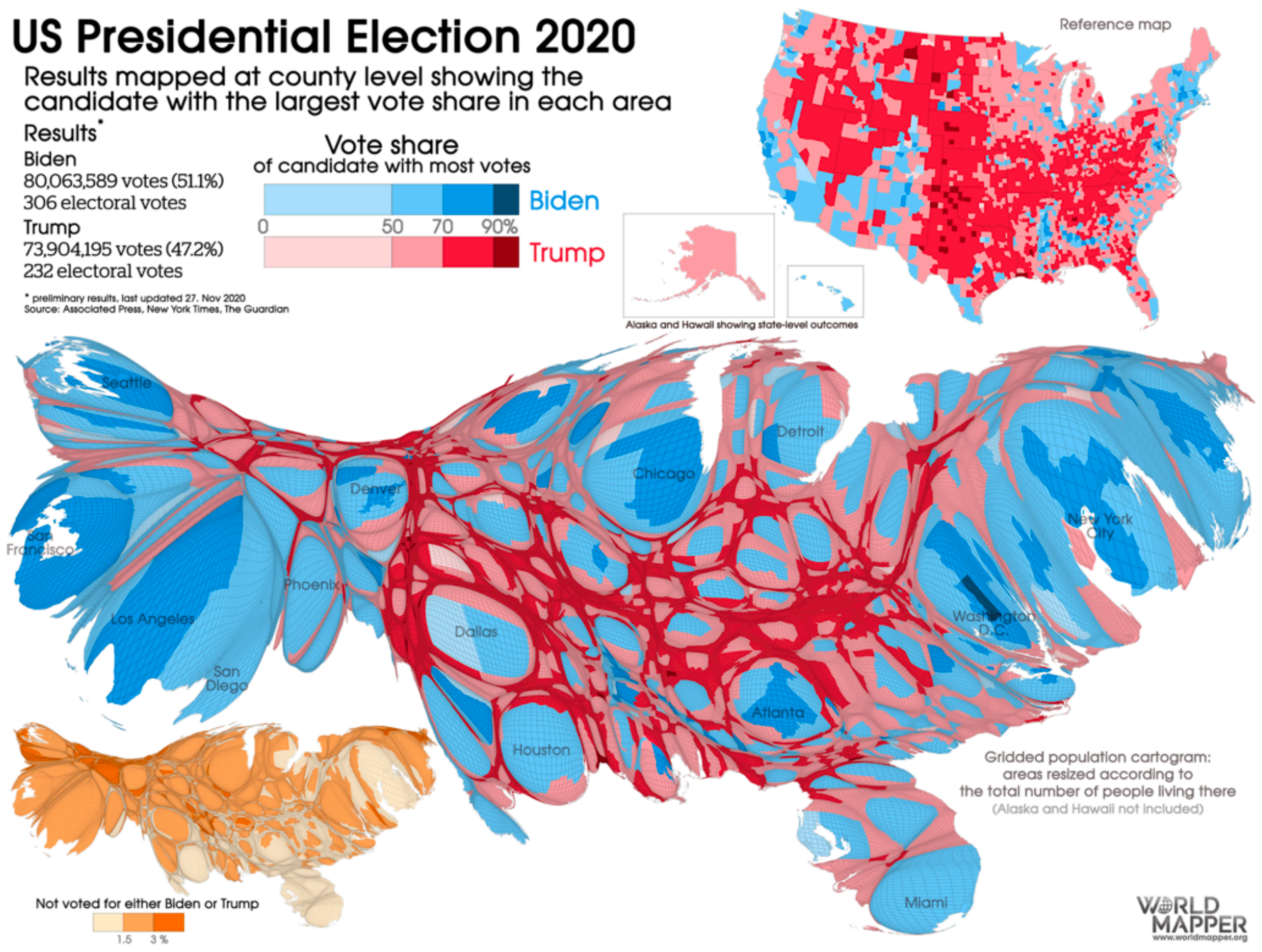


https://observablehq.com/@d3/us-state-choropleth

Interlocking (area) marks

- many channels locked down with interlocking marks
  - boundary encodes meaning
  - cannot change size, shape, position, orientation
  - **mark type imposes constraints**
- but...

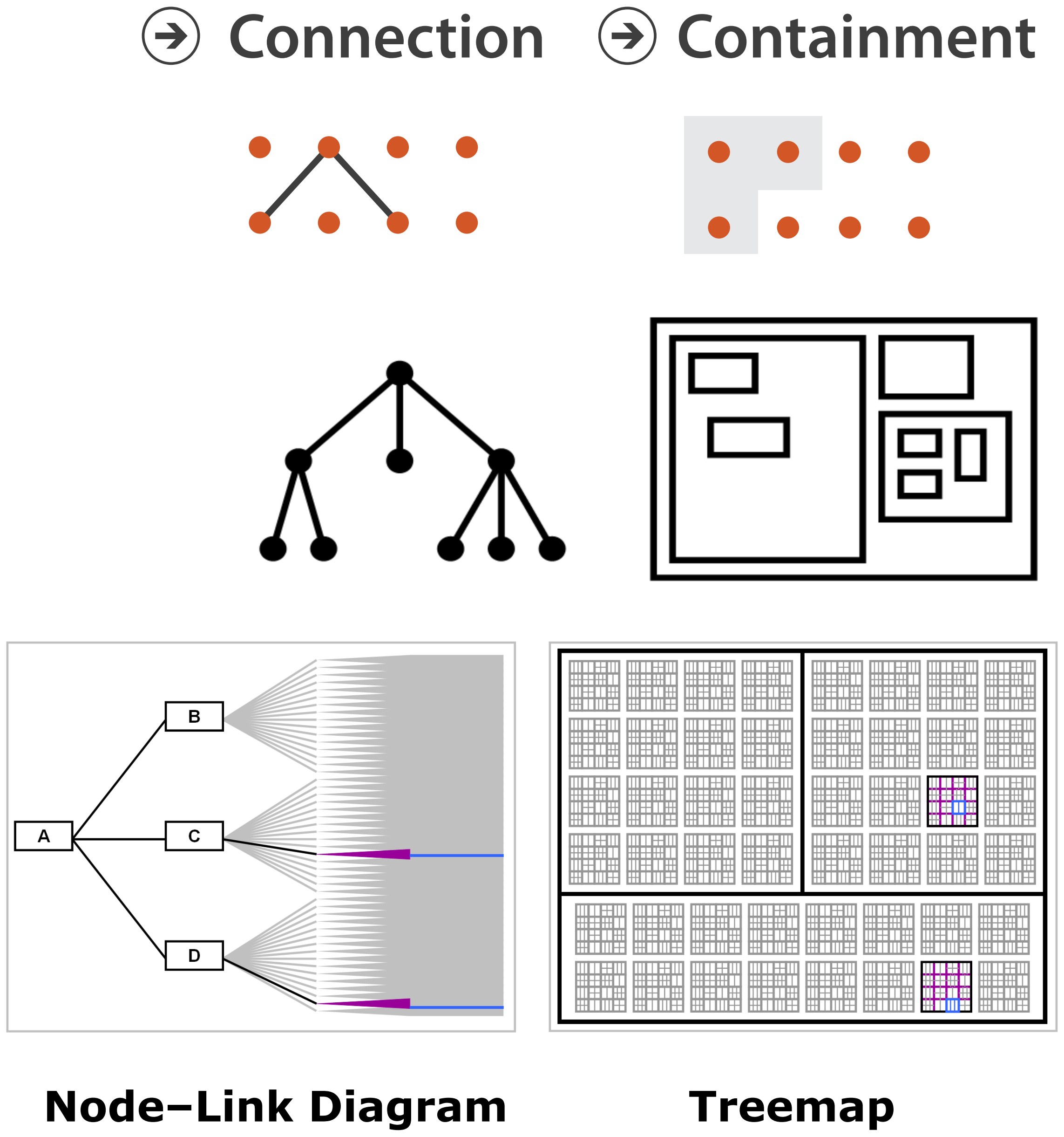
  what about cartograms?
  - cannot change just one mark (California)
  - but could change them all!
- interlocking marks as global constraint:
  - cannot change just one independently
  - but can change all simultaneously!
    - typically with algorithm



https://worldmapper.org/us-presidential-election-2020/

Interlocking marks: Non-spatial

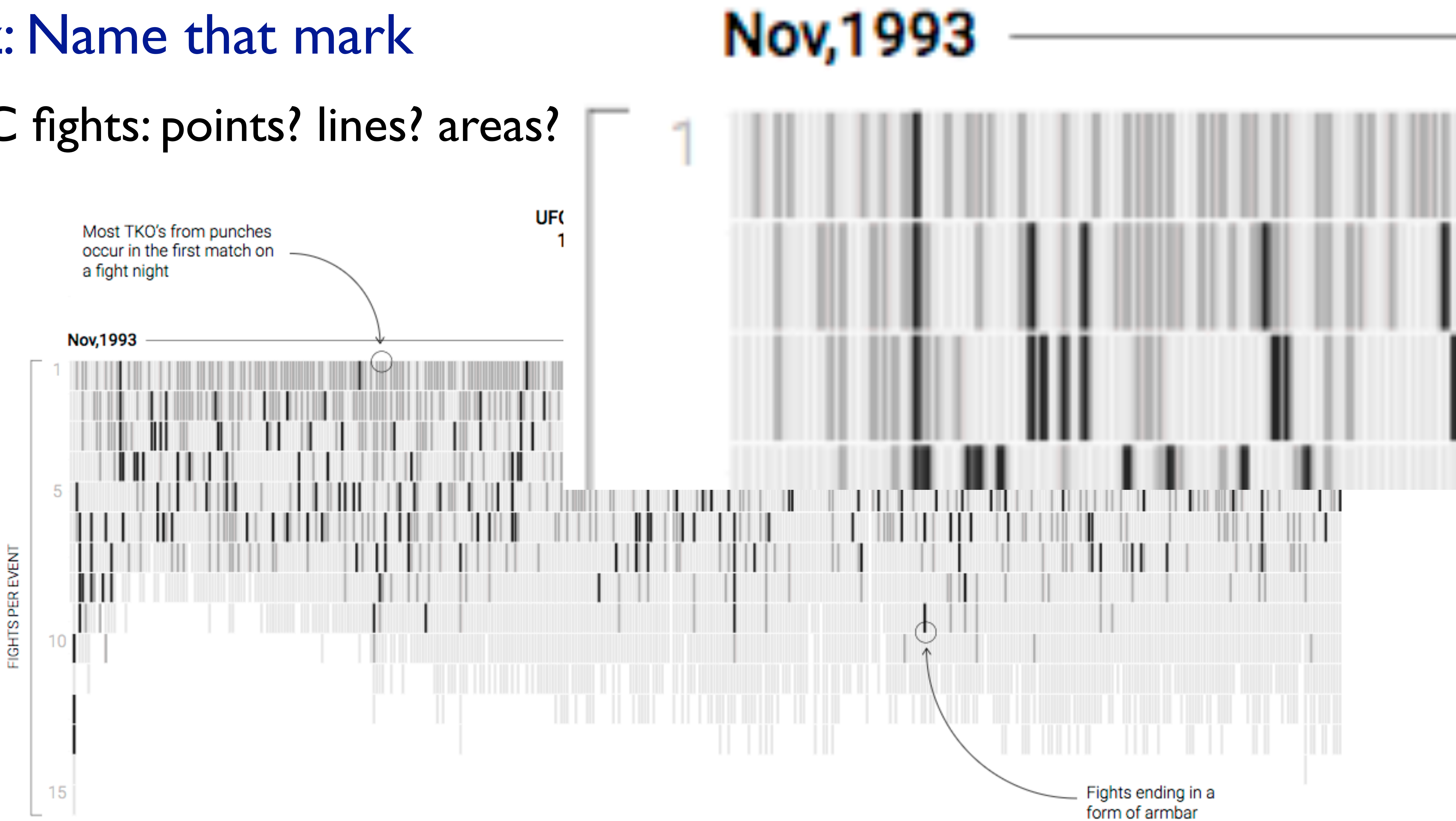
- example with non-spatial data?
- treemaps
  - show hierarchy with containment, not connection
  - encode additional attribute with area/size
- again, cannot change just one mark alone
  - but could recompute layout to change all at once
- combined layout of all marks together carries meaning
  - unlike spatial data mark boundaries
    - individual mark boundaries have no intrinsic meaning



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

Quiz: Name that mark

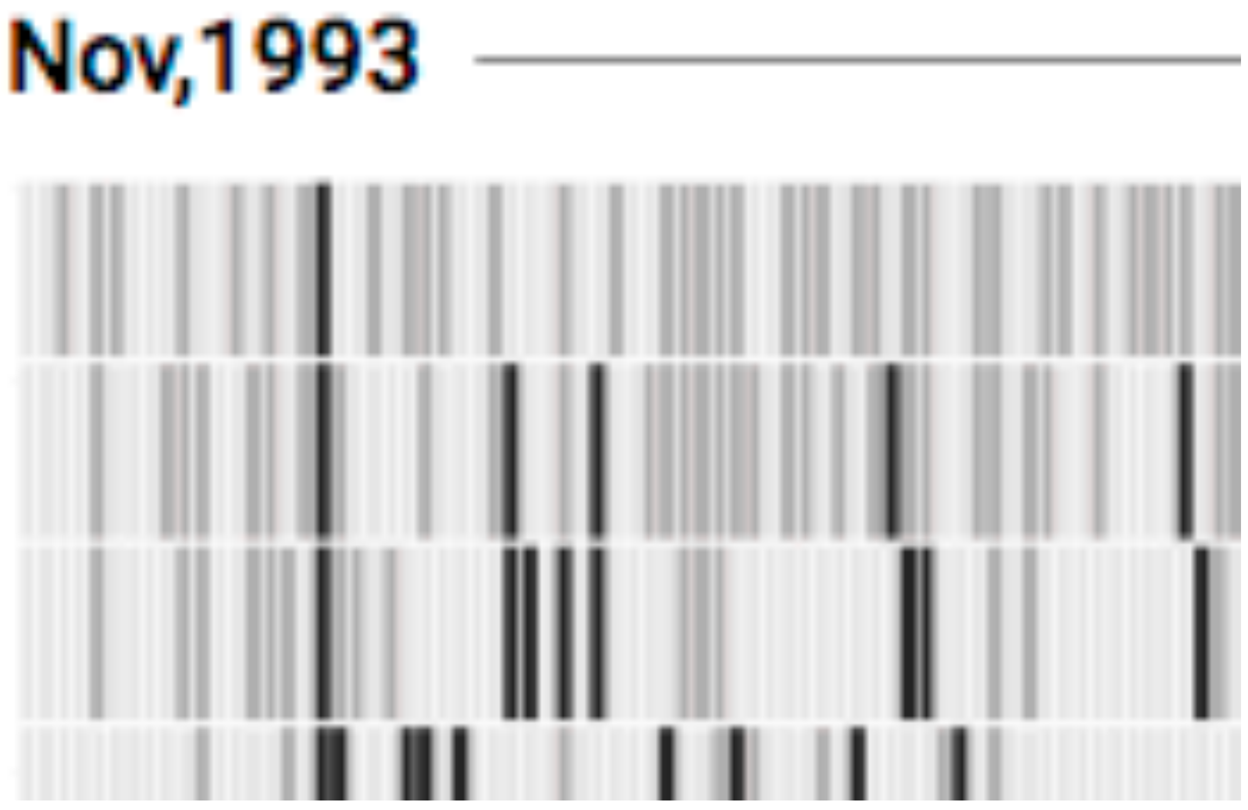
- UFC fights: points? lines? areas?



https://multimedia.scmp.com/infographics/sport/article/3010883/bruce-lee-and-mixed-martial-arts

Analyzing marks

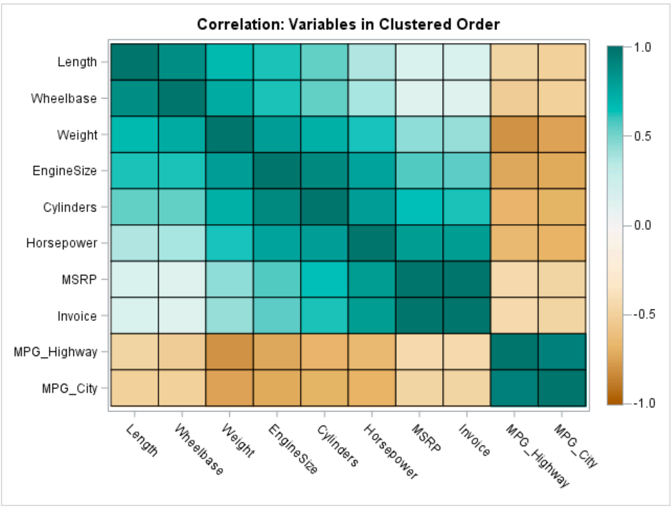
- what type of mark?
  - line?
    - no, not length coded
  - point mark with rectangular shape?
    - 2020: yes!
    - 2023: no!
      - cannot change position / size / orientation
  - area?
    - 2020: no, area/shape does not convey meaning
    - 2023: yes!
      - fully interlocking
      - position, size, shape, orientation all locked



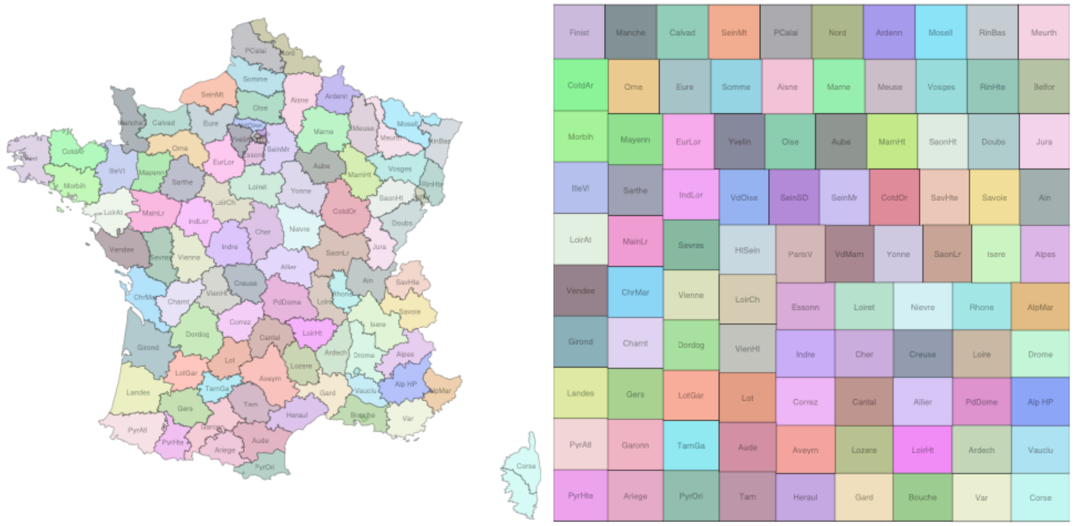
https://multimedia.scmp.com/infographics/sport/article/3010883/bruce-lee-and-mixed-martial-arts/

Interlocking marks: Tile heatmaps

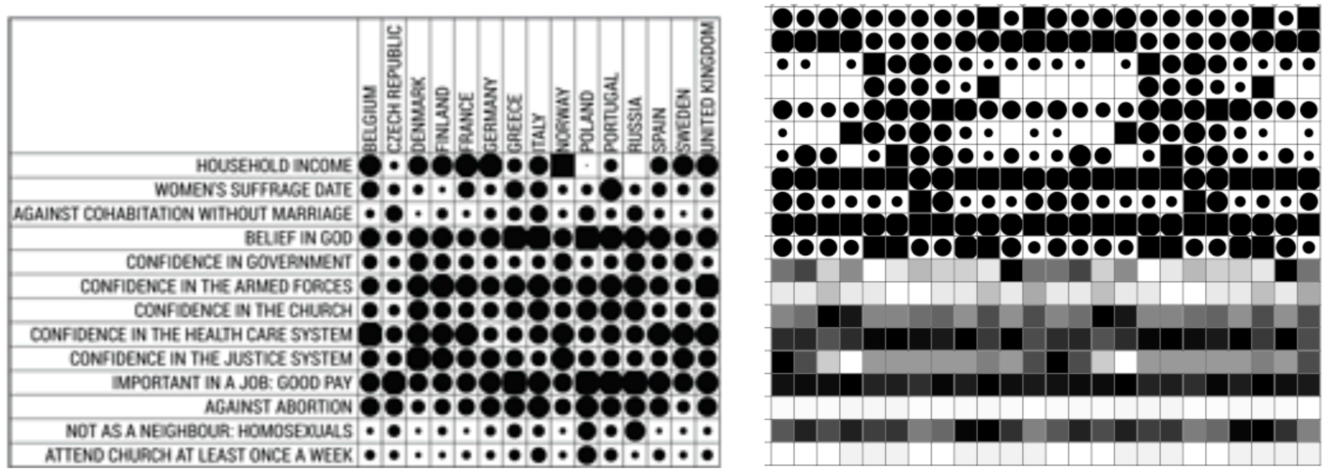
- 2D matrix/grid as index
  - position in use as index
  - size/area & shape & orientation all equal (& locked down)
- simplest possible case of interlocking marks?
  - more regular than choropleths or treemaps
  - but underlying similarities
- full extent of cell used for color coding
  - different from using a point mark within the cell



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



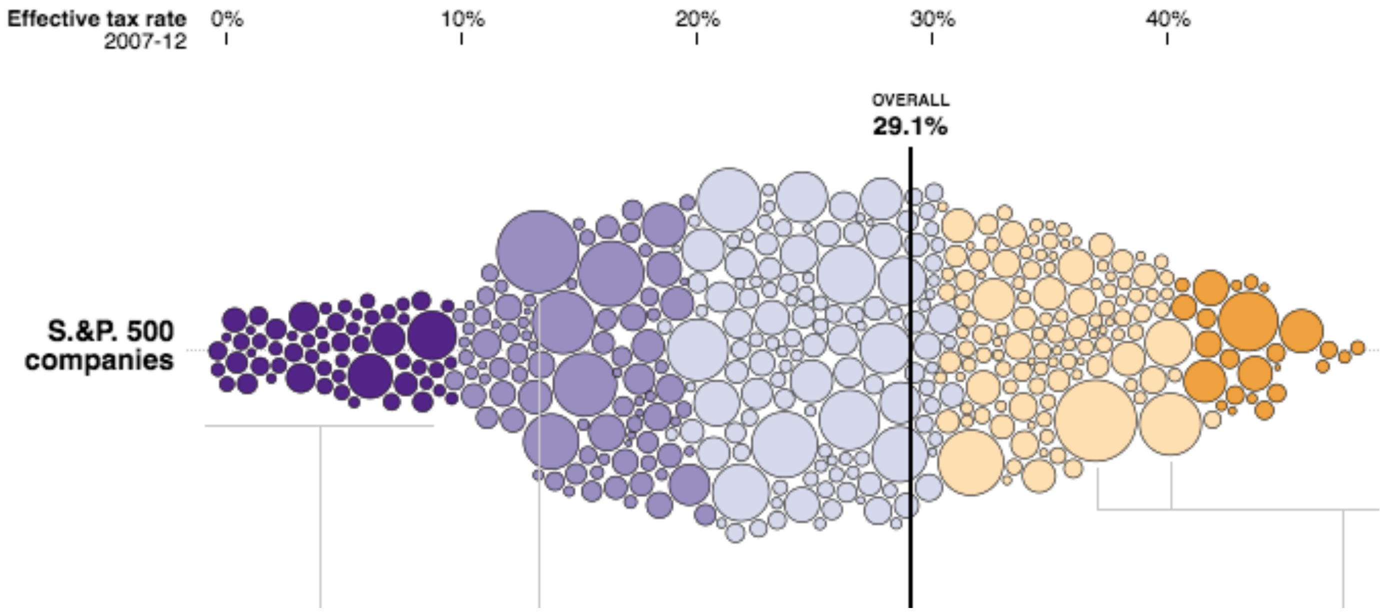
Spatially ordered treemaps.
Wood and Dykes.
IEEE TVCG (Proc. InfoVis) 14(6):1348-1355, 2008.



Bertifier. Charles Perin, Pierre Dragicevic, Jean-Daniel Fekete (2014).
Revisiting Bertin's Matrices: New Interactions for Crafting Tabular Visualizations. TVCG, VIS' 2014.

Interlocking marks: Circle packings

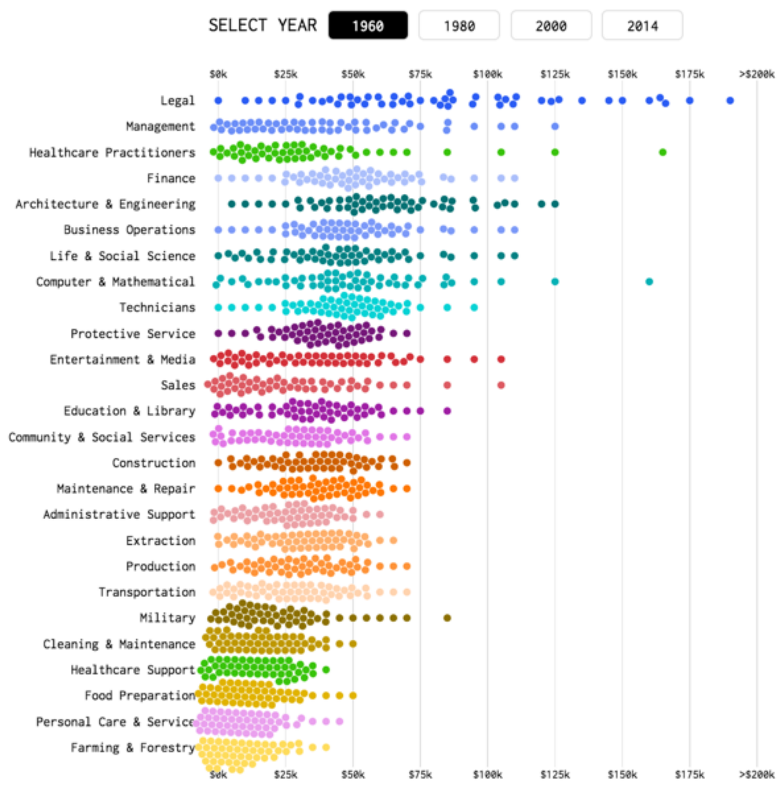
- also are interlocking marks, **not** size-coded point marks
  - more like treemap than scatterplot!
- channel availability analysis: customized circle packing
  - Encoded channels
    - horizontal position: encodes tax rate
    - color: rate, redundant with horizontal position
    - size (2D area): market cap
  - Free channels
    - motion
  - Unavailable channels
    - vertical position: used by algorithm to avoid overlap & minimize gaps
    - shape & orientation equal and unavailable: can't just change, would need to redo layout



https://archive.nytimes.com/www.nytimes.com/interactive/2013/05/25/sunday-review/corporate-taxes.html

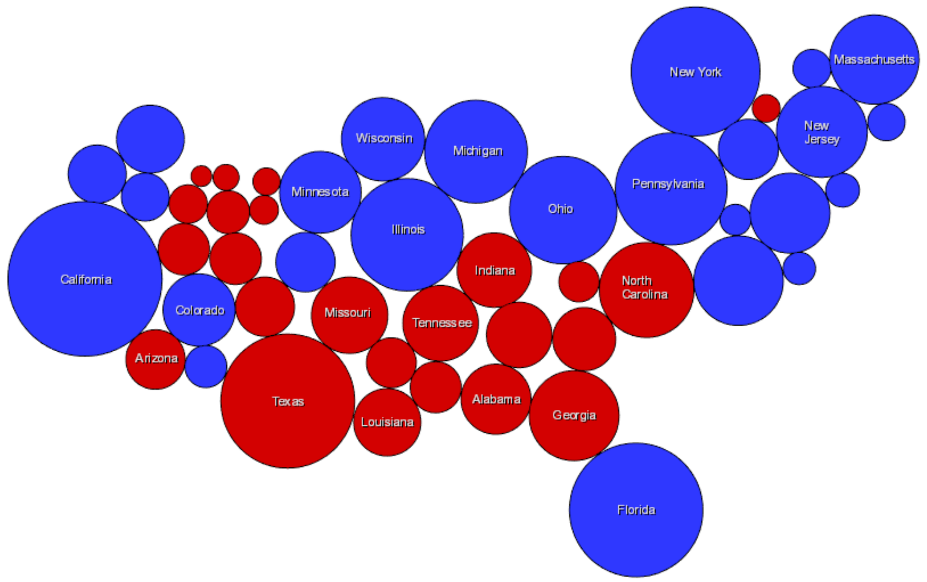
Interlocking marks: Circle packings

- customized circle packings are special case
  - including beeswarm plots
- general circle packing
  - algorithmic constraint: no overlaps, minimal gaps
    - position unavailable since used by algorithm



https://flowingdata.com/2016/06/28/distributions-of-annual-income/

- Dorling cartogram
  - can treat as special case of circle packing, with additional constraints to maintain relative position from geographic location
  - throw away shape by regularizing to circles
  - add size coding

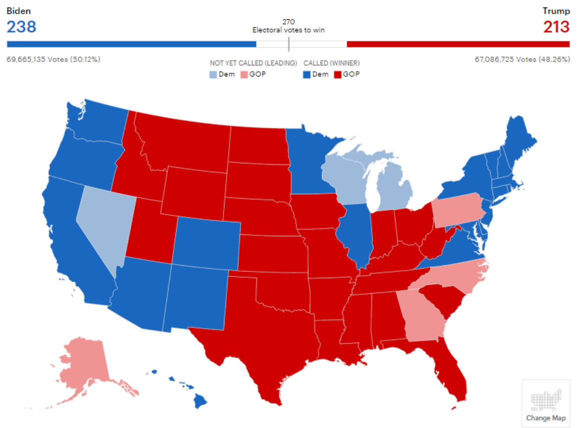


https://www.arcgis.com/apps/StorytellingTextLegend/index.html?appid=b686a7679cb747e9825d1d1bb6b26046

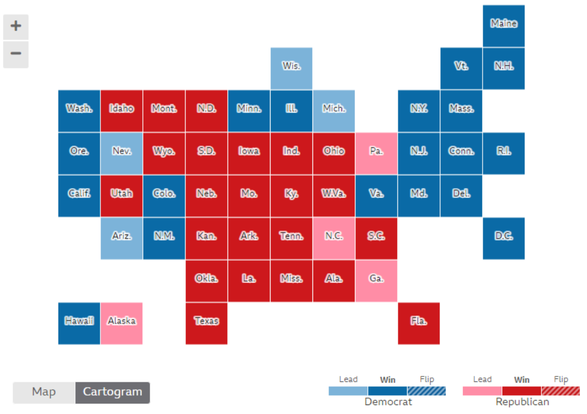
Interlocking? Election maps roundup

- yes interlocking
  - A: already covered
  - B/C: equal-area alg algorithm simplifies shape

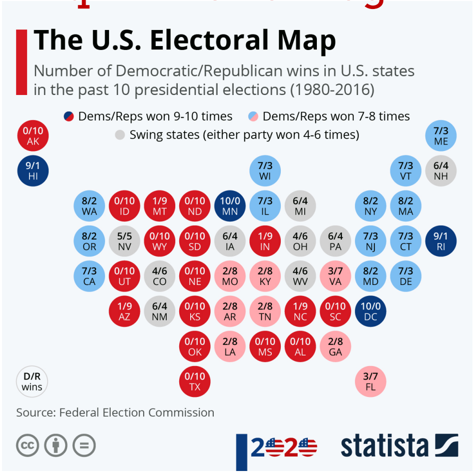
A. Standard Choropleth



B. Equal-area cartogram



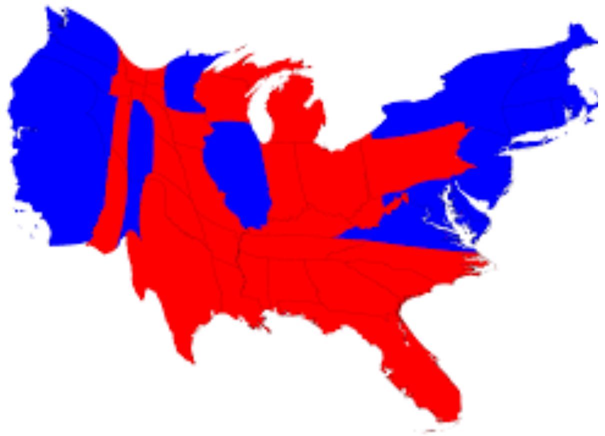
C. Equal-area cartogram



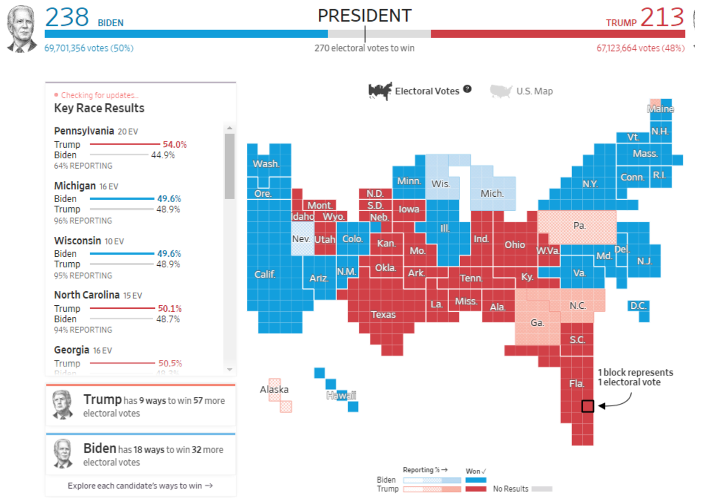
Area not encoding election data

- yes interlocking
  - E/F multi-level
  - top level: interlocking marks
  - bottom level: square units
    - E/F: countability for votes
    - F whitespace: population density

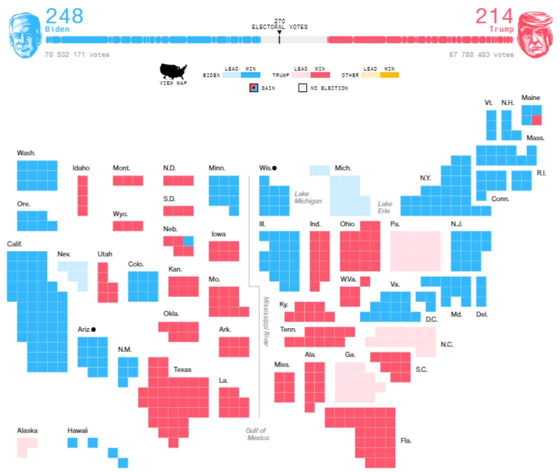
D. Area-proportional continuous cartogram



E. Units assembled into state-like shapes



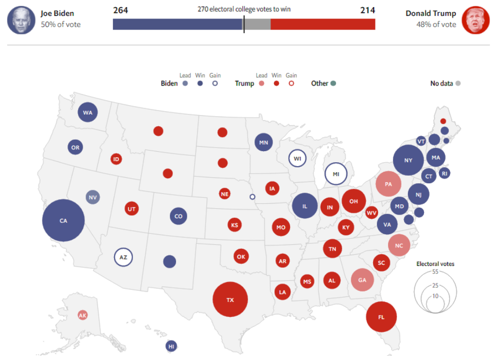
F. Units in state-like shapes spaced apart



Area encoding election data

- no, point marks
  - size coded by area

E. Map with bubbles

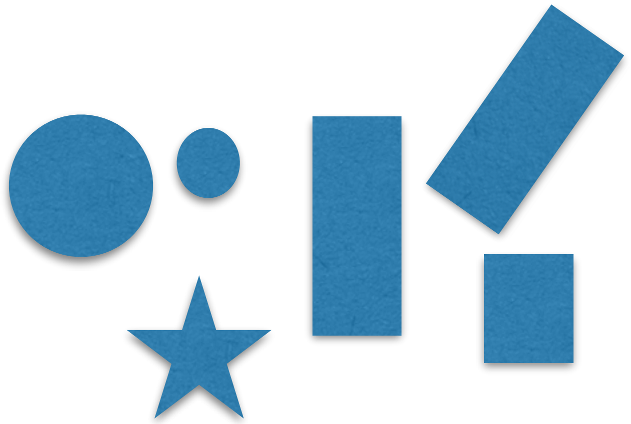


https://www.anychart.com/blog/2020/11/06/election-maps-us-vote-live-results/

Distinguishing marks through constraints

- highly constrained: interlocking marks
  - many channels unavailable: size, position, shape, orientation
  - proposal: rename from "area" to "interlocking"

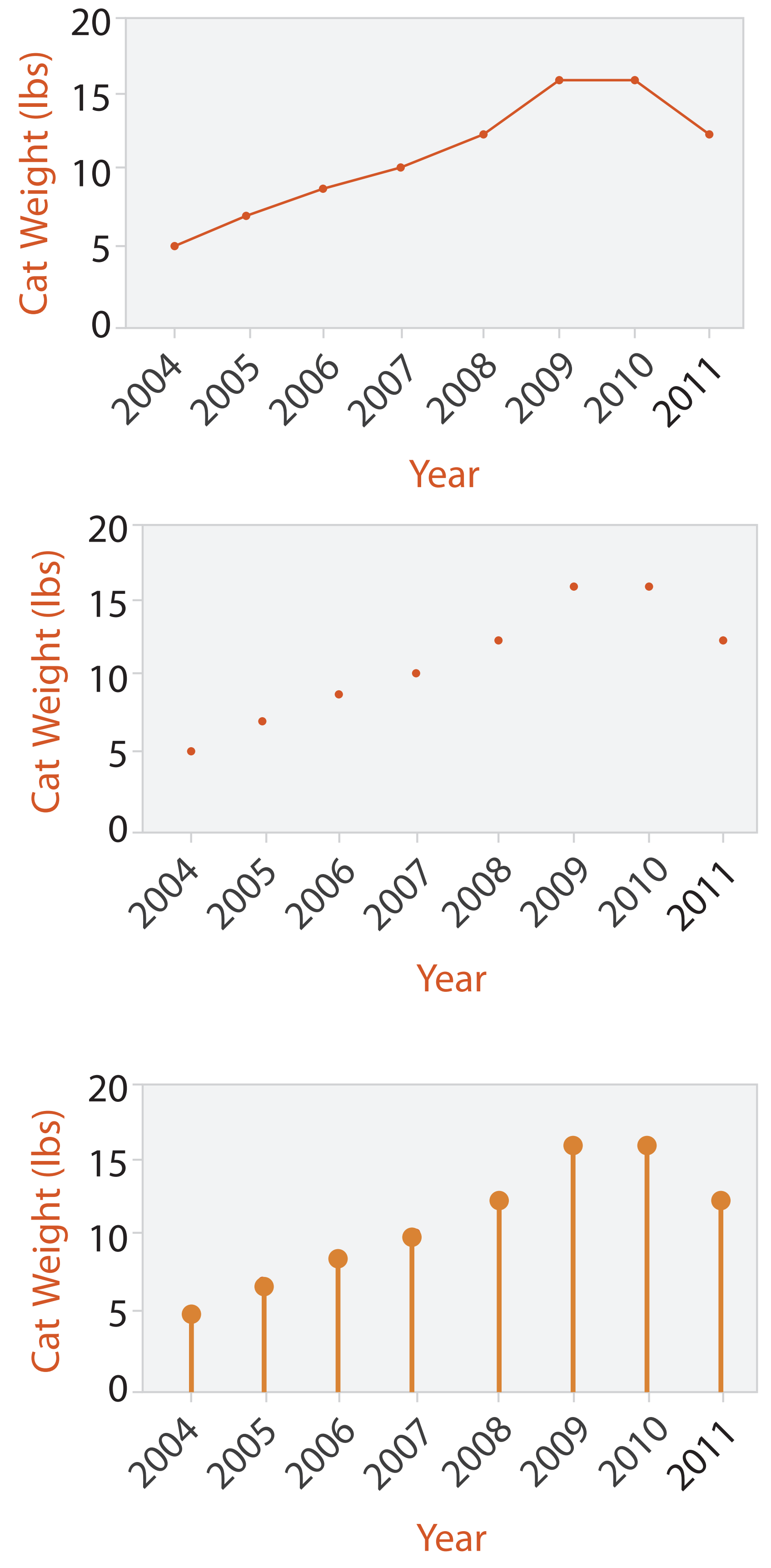
- unconstrained: point marks
  - can encode more info with any channel at all!
    - size, position, shape, orientation
    - color, motion, ...
  - does "point" imply circular shape?
    - proposal: is "unconstrained" a better / more evocative name?



- so... what about line marks?

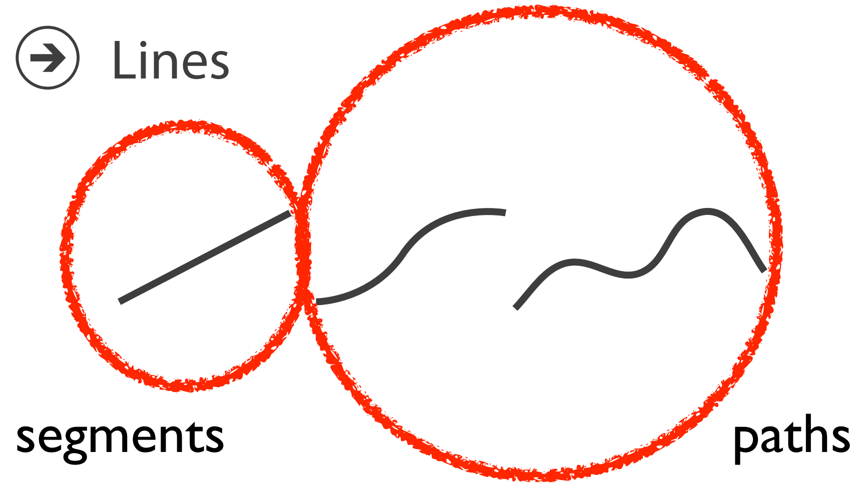
Line marks: Rethinking

- do line charts use line marks?
  - construct connections between points
    - trend task: emphasize relationships between items
    - may or may not show points explicitly
  - no! not like bar charts or lollipop charts do...
  - **line chart encodes many items, not just one**
    - with many piecewise-linear segments or smooth curve



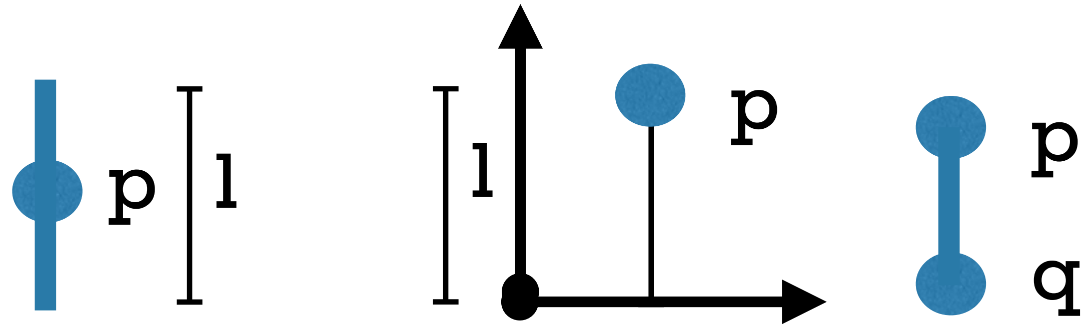
Line marks: Naming two cases separately?

- line segments showing single item, vs curved lines showing multiple items
  - should we reason about them separately instead of analyzing them together?
  - line segment: express single quantitative attribute for one item with length
    - single mark represents single item of data
    - proposal: call these "segments"
  - curved / complex lines
    - proposal: call these "paths"
    - single mark represents many items of data

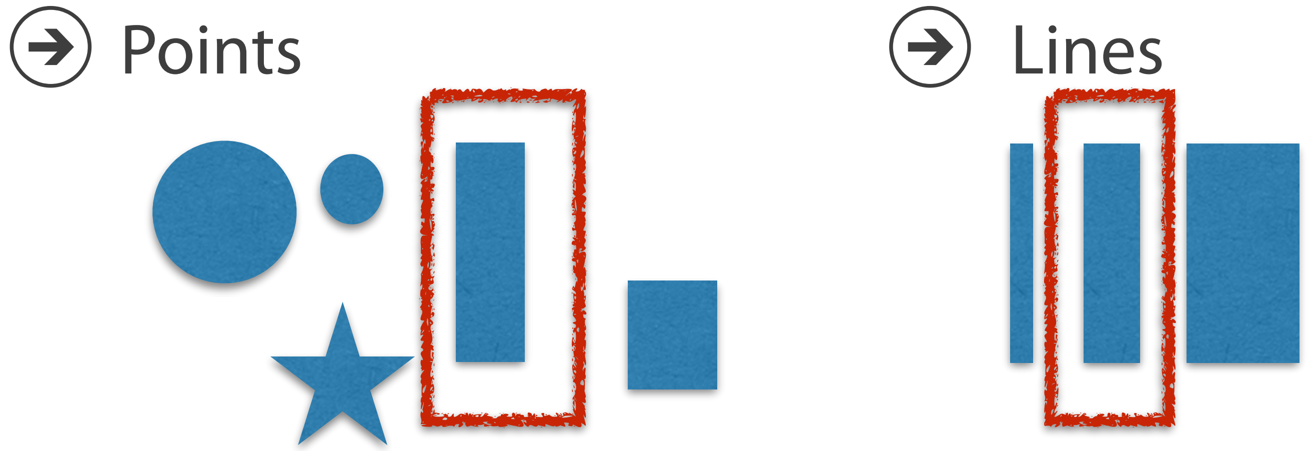


Line marks vs point marks

- what's relationship between length channel and length of line?
  - exactly the same? confusingly different?
- how does line segment differ from "length-coded point mark"?
  - two numbers, either centroid/length or max/min

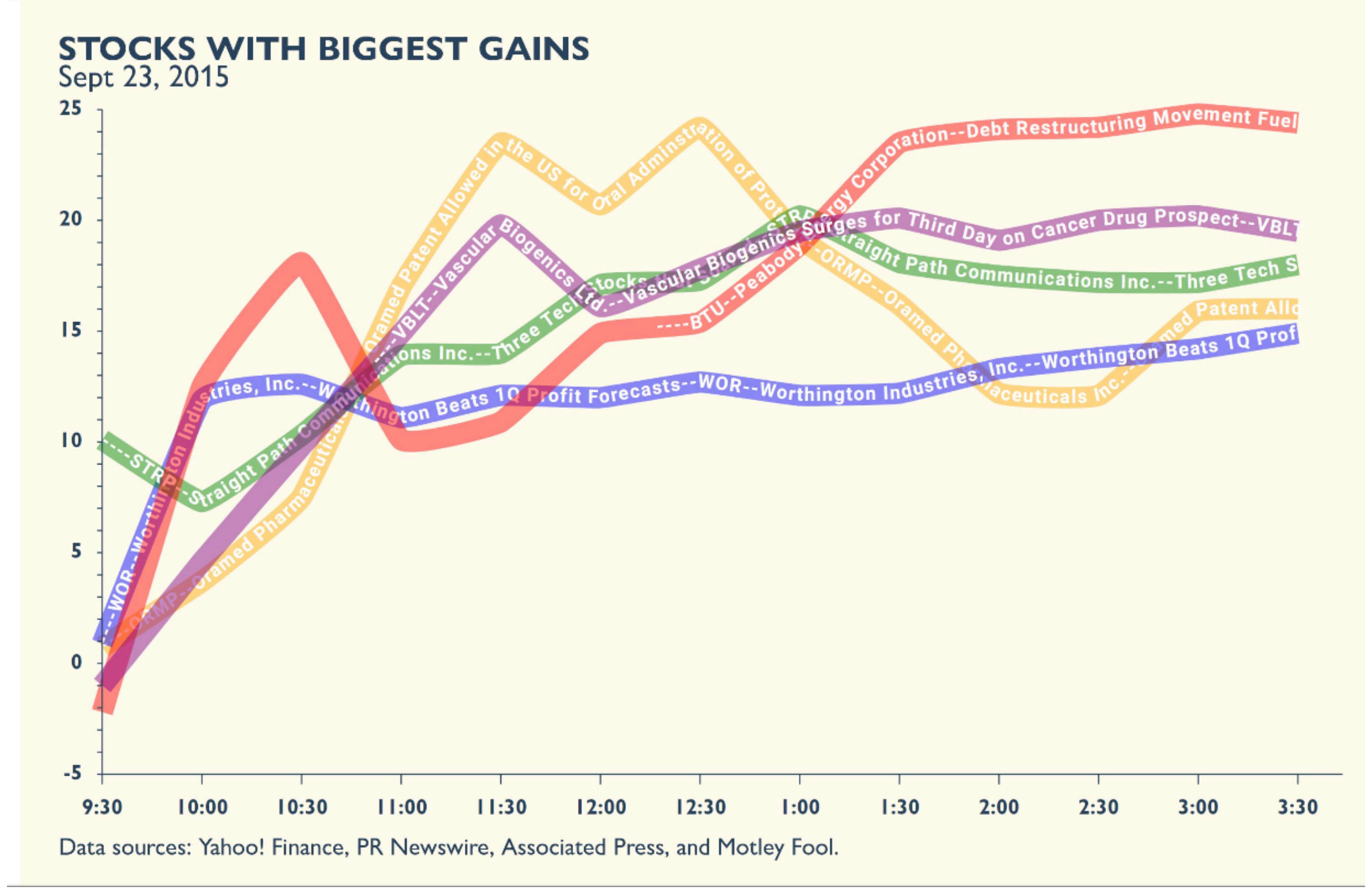


- proposal: what if line segment marks and point marks belong in same "singleton" category?
  - to distinguish from multi-item marks



Line marks vs area marks

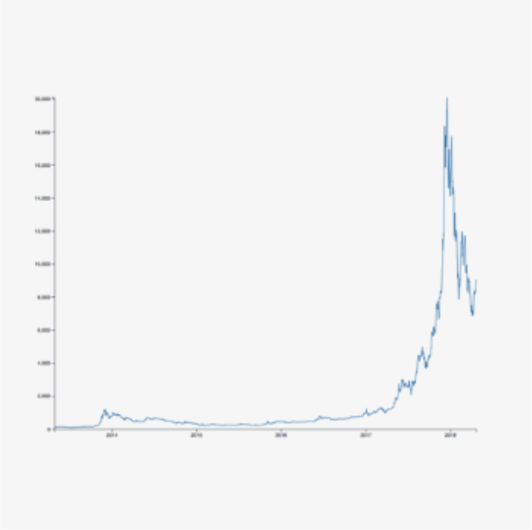
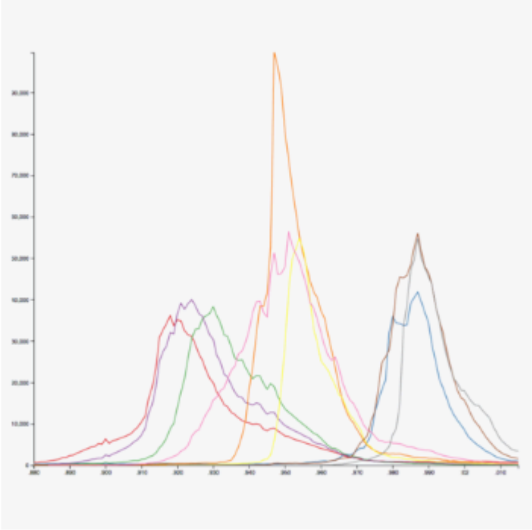
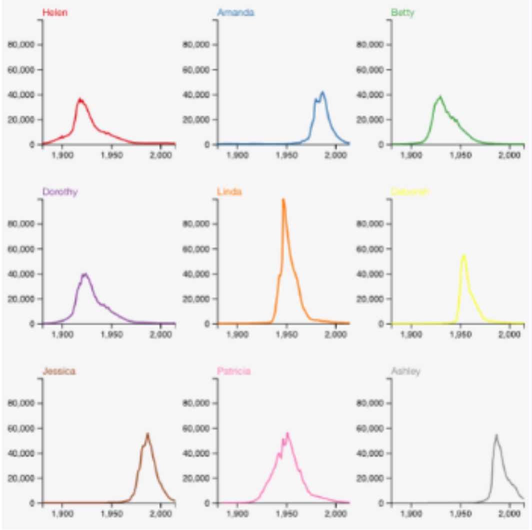
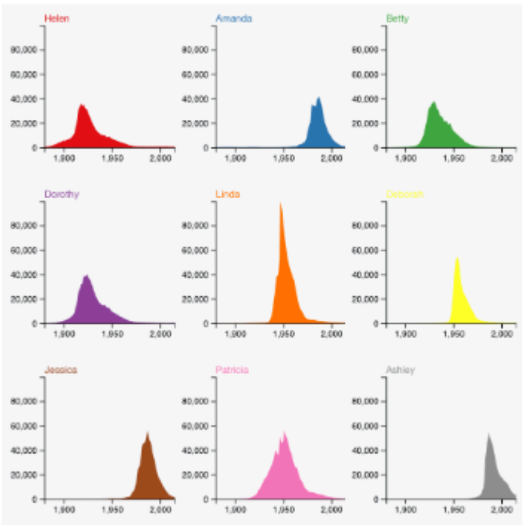
- what's the border between line path marks and area marks?
  - if path is wide enough, is it an area?
  - what if there's information shown in region inside path, within its boundary?
    - different color for inside vs outside, or even text?
- what about the region below path?...

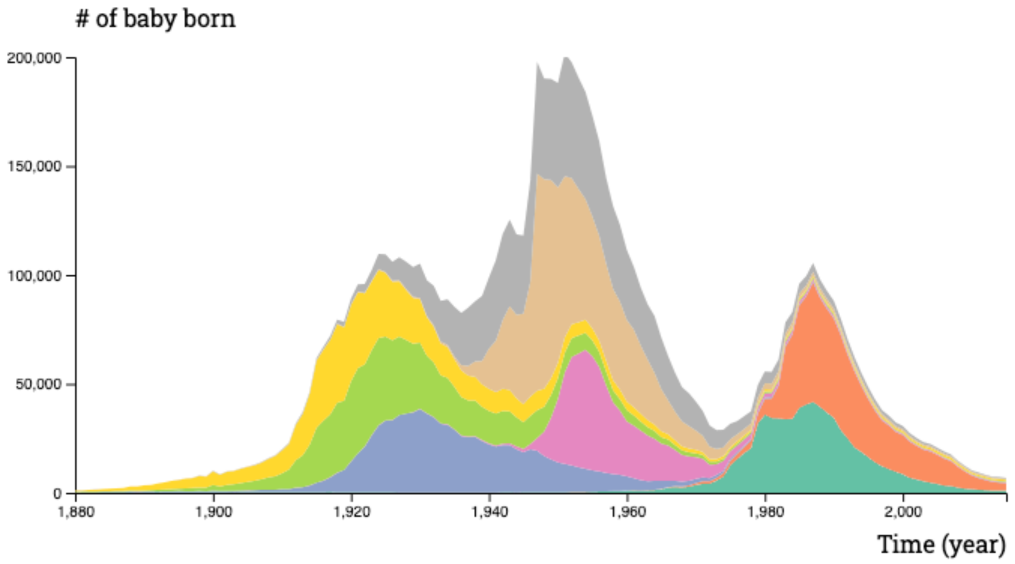


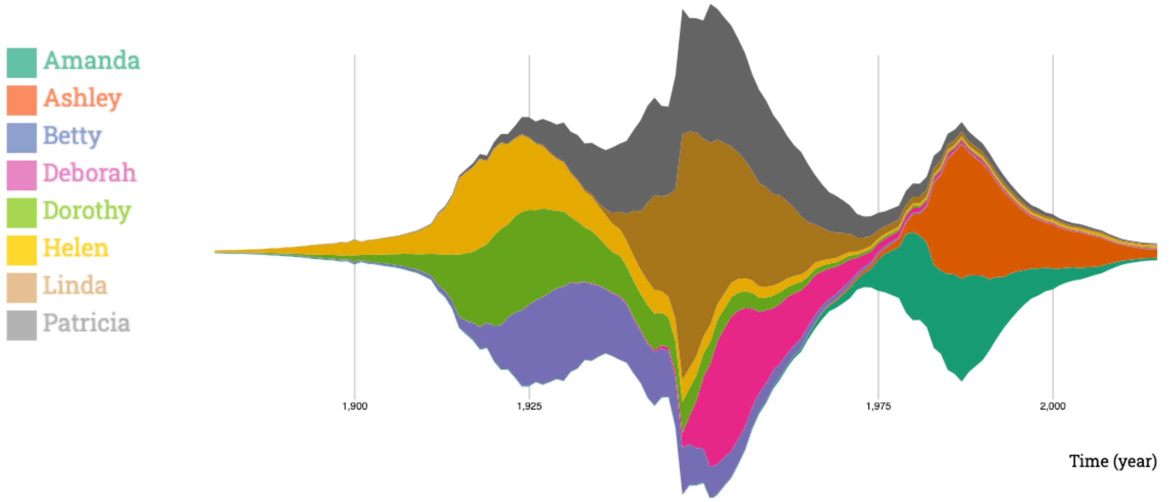
Brath. Visualizing with Text (Fig 7.14). CRC Press, 2020.

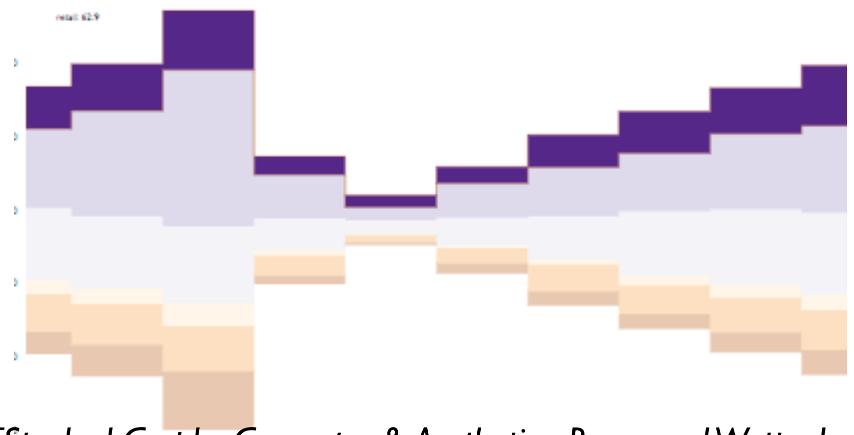
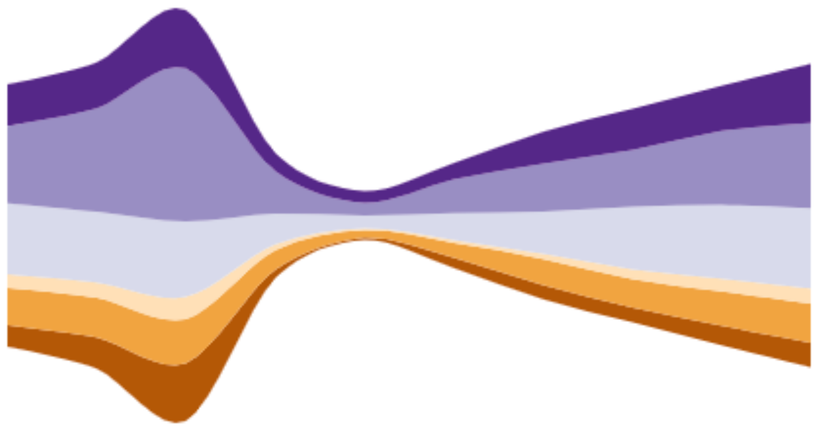
Line charts vs filled area charts

- should we reason differently about
  - line chart boundary vs filled area chart interior?
  - stacked area charts vs streamgraphs?
  - discrete stacked bar charts vs continuous streamgraphs?
- what matters?
  - boundary vs interior?
  - discrete vs continuous
  - occlusion?





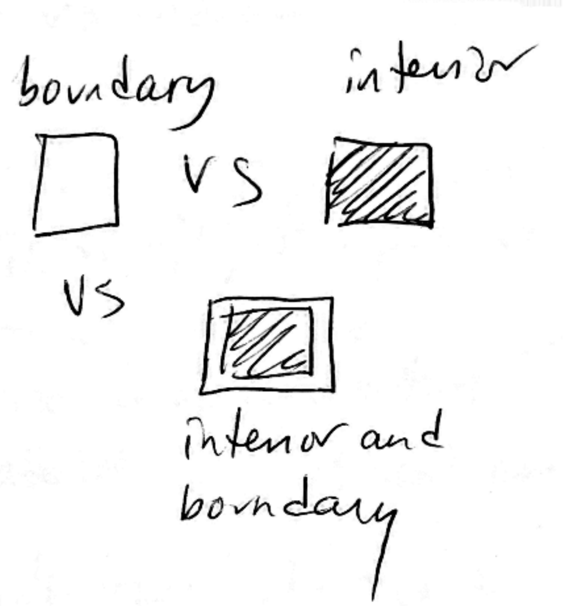



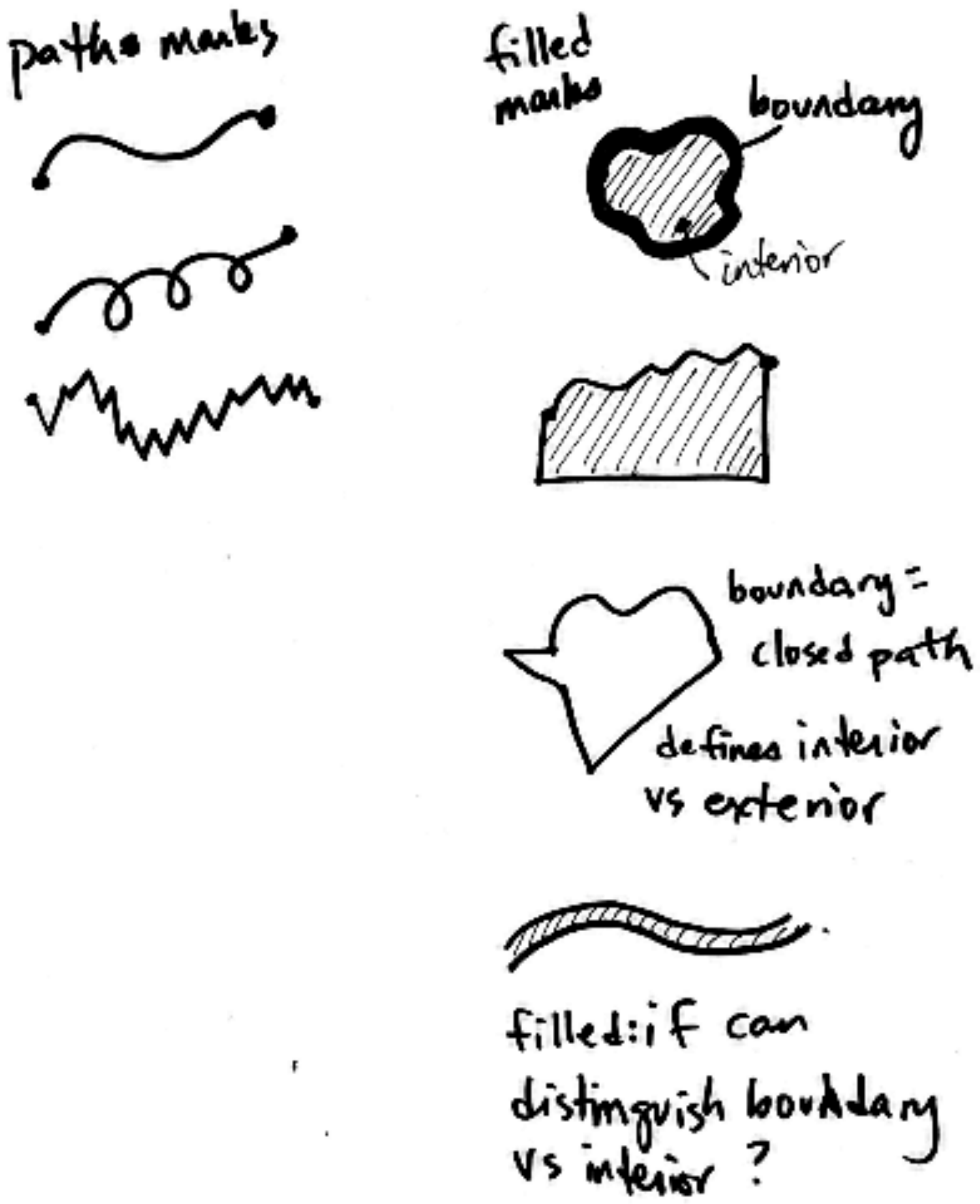
https://d3-graph-gallery.com/line.html
https://d3-graph-gallery.com/area.html
https://d3-graph-gallery.com/stackedarea.html
https://d3-graph-gallery.com/streamgraph.html

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

Boundaries vs interiors

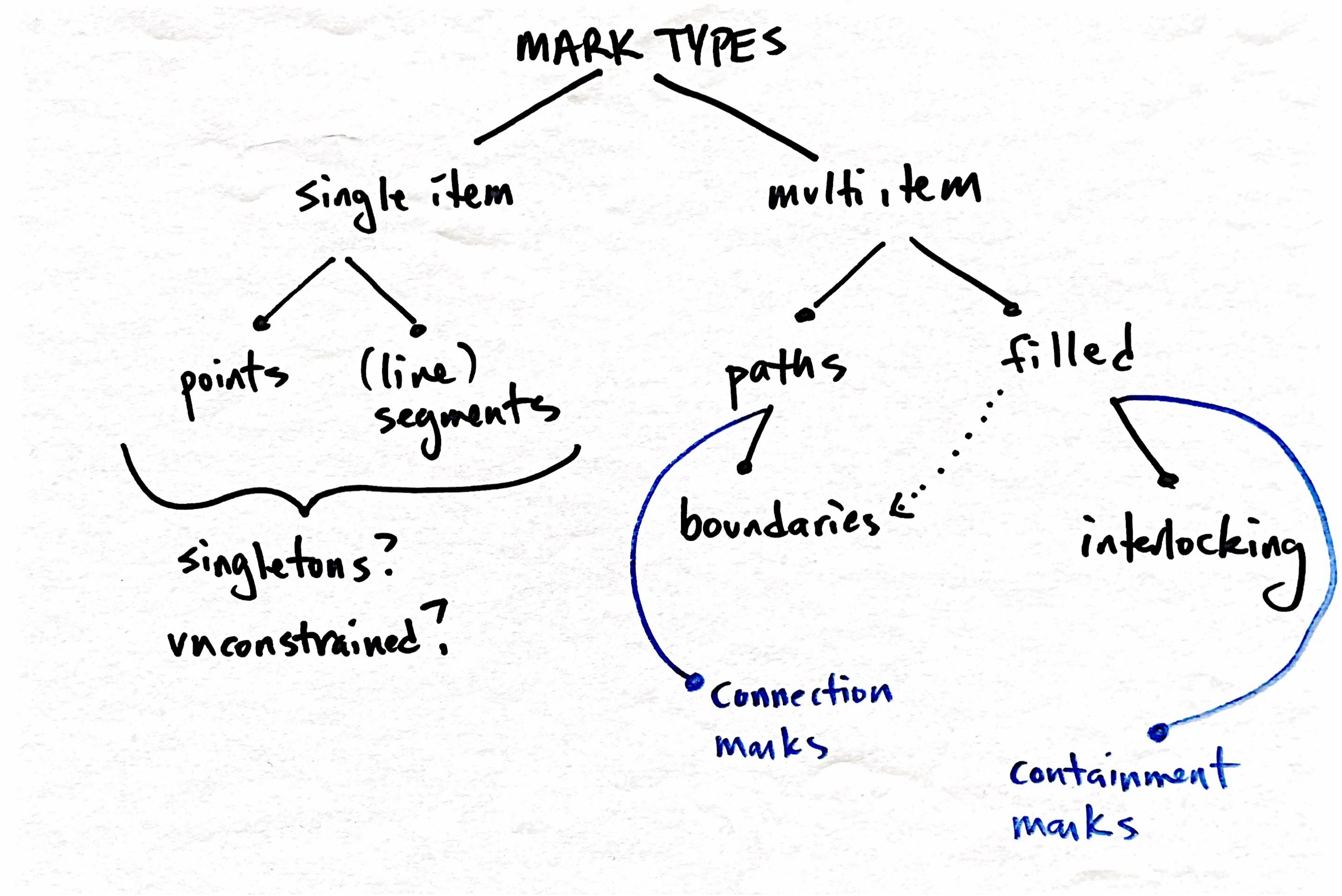
- proposal: if path is closed, call it a "boundary"
  - (maybe also if path is infinite)
  - all boundaries also define "interior" region
  - distinction may or may not be visually highlighted

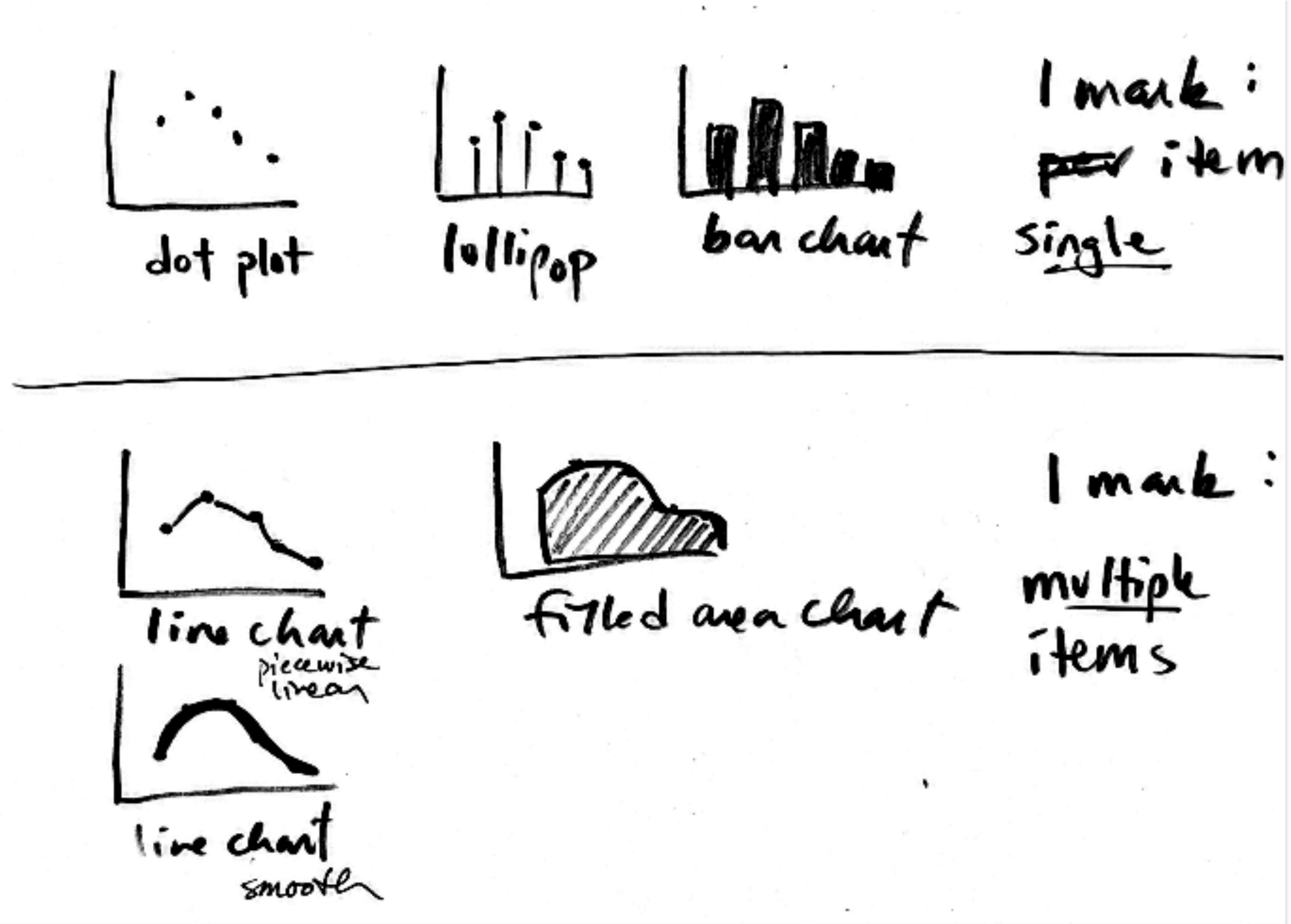




- proposal: use name "filled" mark instead of "area"
  - then interlocking marks are a special case of filled marks

Alternative mark types model



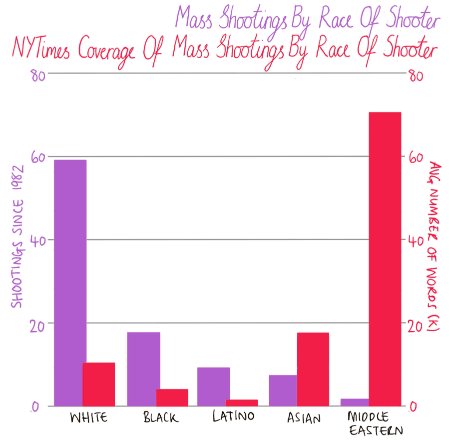


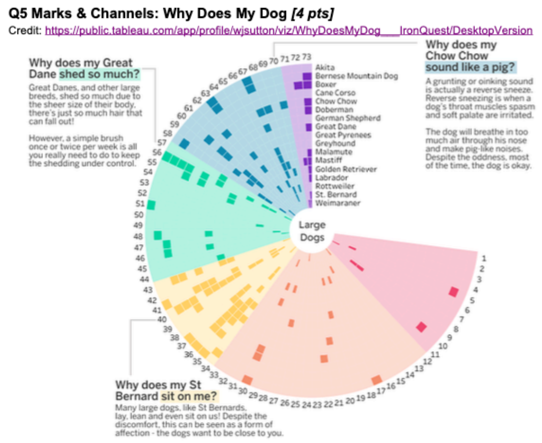
Constraints & Channel Availability

- consider marks and channels as imposing constraints
  - when does mark type constrain channel use?
  - **when does using one channel constrain another channel?**
- Channel Availability Model
  - Encoded: which channels directly used to encode attributes?
    - clear meaning
    - multiple channels can be directly used for redundant encoding
  - Free: which channels free to encode another attribute?
    - without changing usability of existing encoding
  - Unavailable: which channels unavailable / precluded / taken?
    - because of mark type?
    - because of idiom/algorithm design specifics?
    - **because other channels used?**

General dependencies: Position

- need fine-grained ability to specify for adequate descriptive power
  - rectilinear (horizontal and/or vertical)
    - high precision because perceptually aligned
      - depth (3D position): very low precision
  - radial (angular position and/or radial distance)
    - lower precision, no perceptual alignment
- general dependencies for unavailability?
  - cannot use both rectilinear and radial simultaneously
    - in same layer, using one type precludes other
  - but horizontal doesn't preclude vertical & vice versa
- position is shared / global
  - with respect to specific coordinate frame shared across many marks



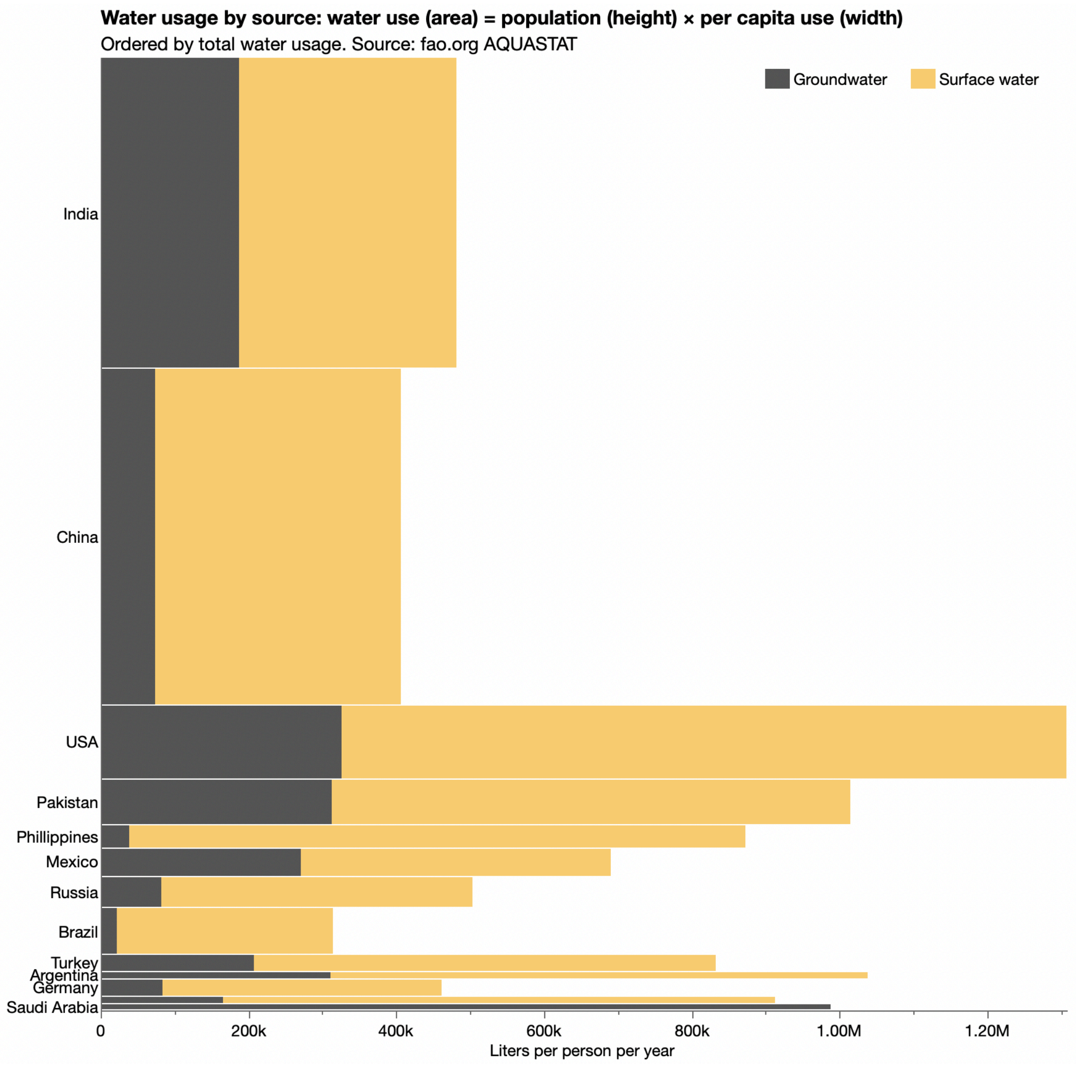


General dependencies: Size

- 1D (length) << 2D (area) << 3D (volume)

- dependencies for unavailability?
  - larger dimension subsumes smaller ones
    - encode with area channel means length channel unavailable
    - volume means area & length unavailable
  - but not vice versa: can augment from length to area
    - add second attribute for 1D size coding in other direction

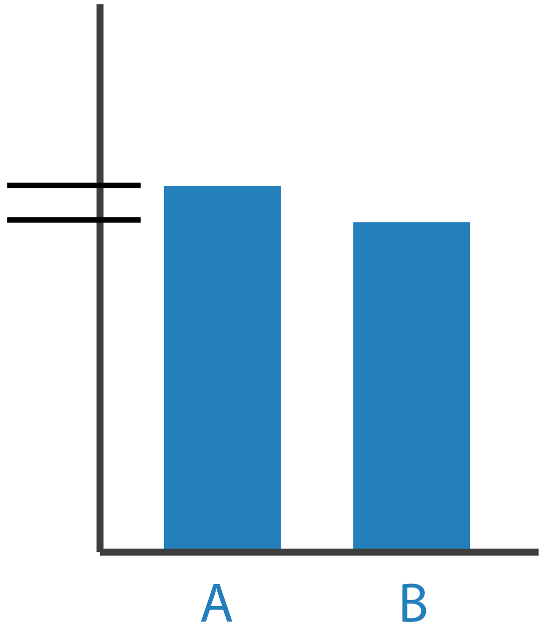
- size is local, in contrast to shared position
  - can be independent across marks



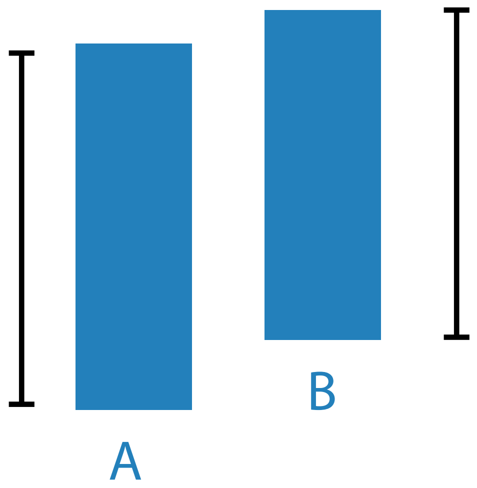
https://www.forthgo.com/blog/2019/12/18/bar-mekko-chart-study/

General dependencies: Position vs length

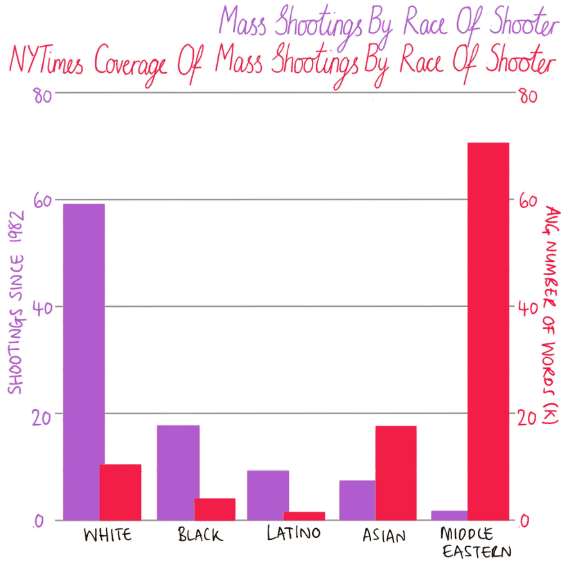
- alignment
  - position (horizontal and/or vertical) is usually shortcut for "aligned position", highest precision channel of all
    - reference frame of explicit axis
    - implicit boundaries of view / window / region
- general dependencies: position (1D) vs length (1D size)?
  - for line marks, position encoded implies length encoded
  - but not vice versa: can have length without position



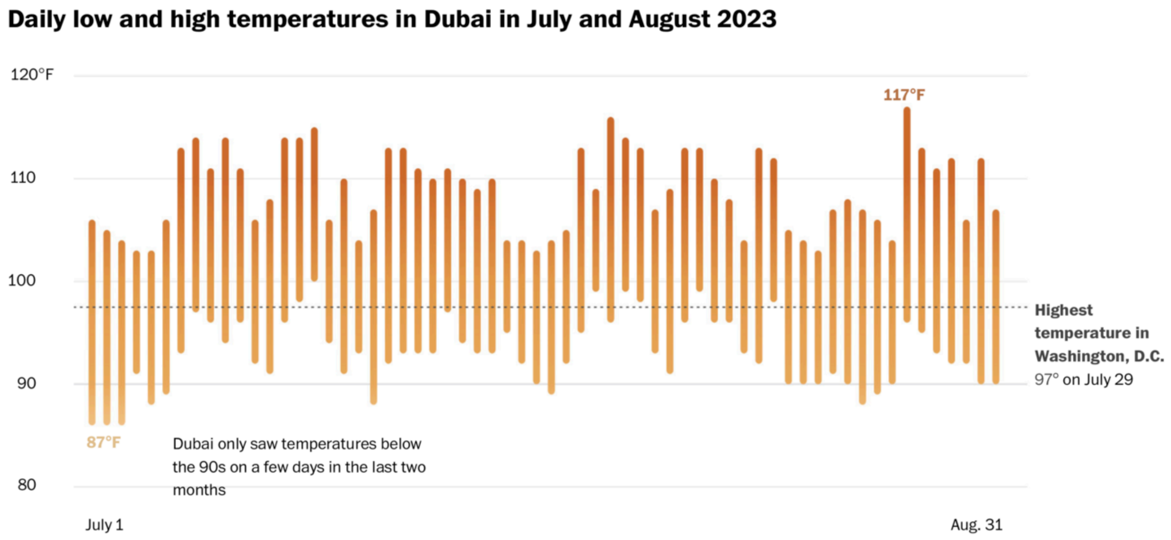
position along aligned scale



length



https://twitter.com/MonaChalabi/status/1158779046693679106



https://www.washingtonpost.com/world/2023/09/10/dubai-heat-staying-cool

Channel Dependencies/Hierarchy proto-model musings

position (shared)

- rectilinear

  - horizontal pos (aligned)
  - vertical pos (aligned)
  - depth

OR

- radial

  - angular position

  - radial distance

- parallel

- size (local)
  - 1D length
  - 2D area
  - 3D volume

uses

uses

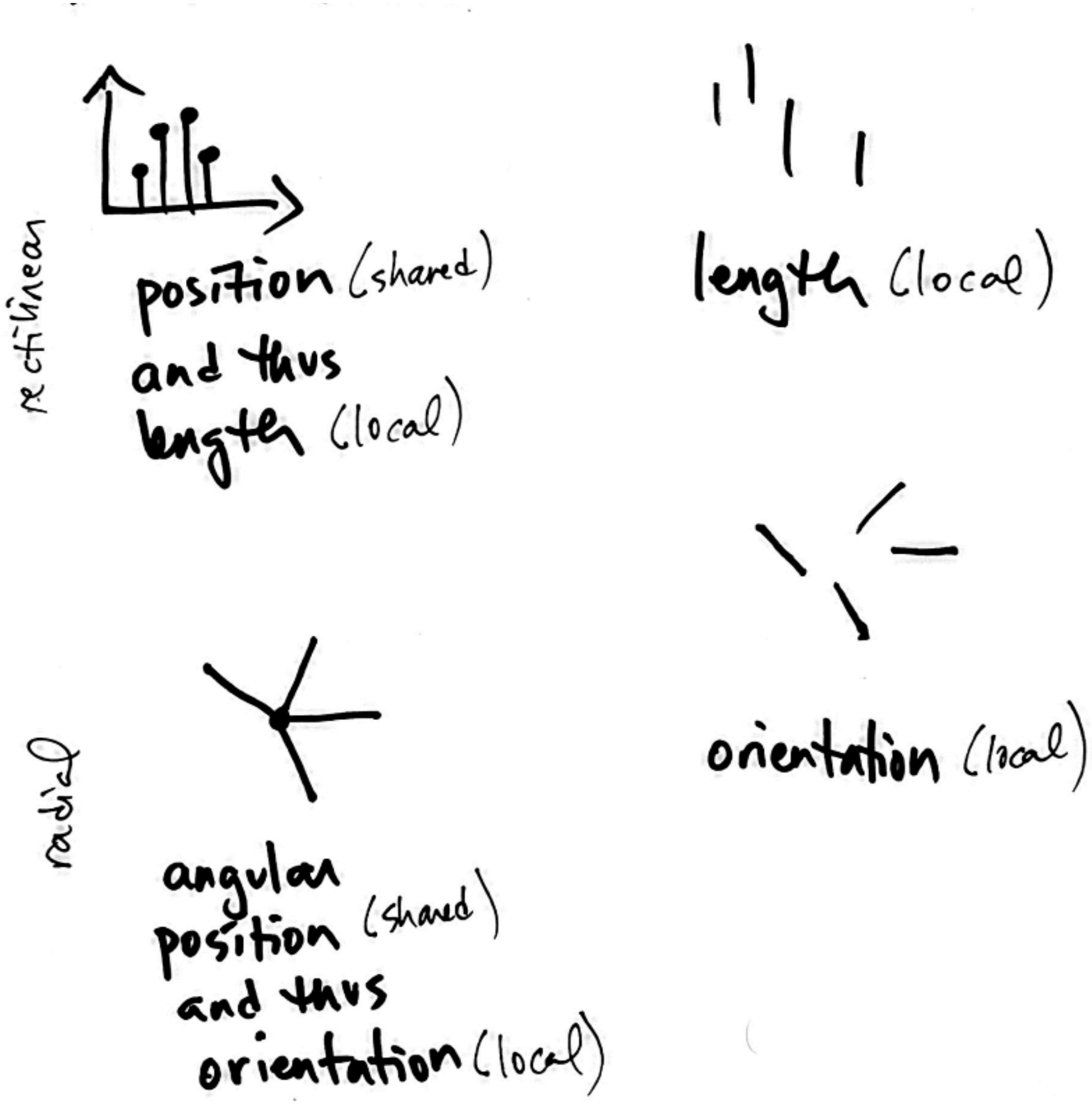
- orientation (local)

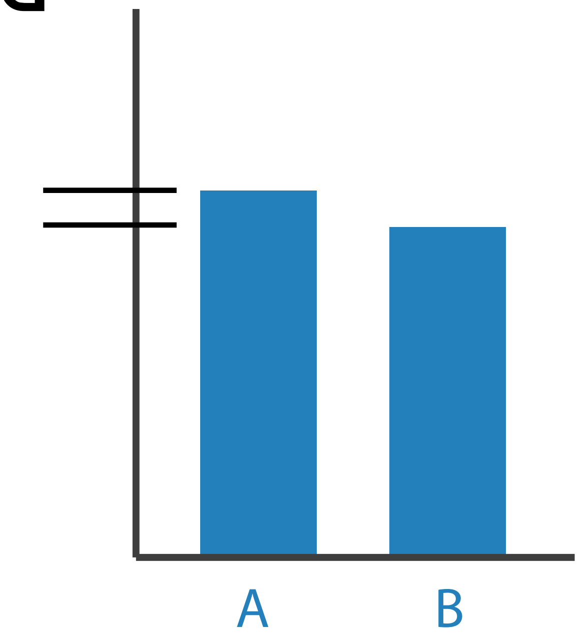
- color
  - hue
  - saturation
  - luminance

- shape
- motion

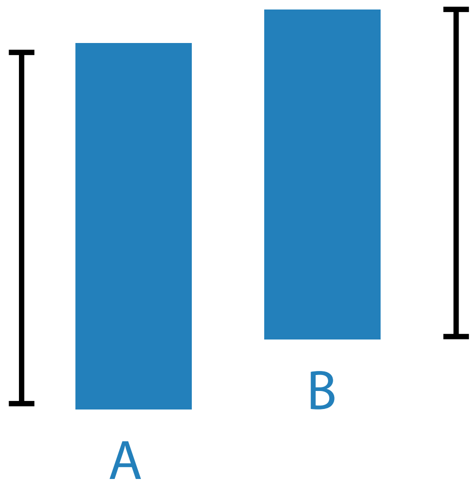
Shared vs local example

- shared locks down local, but can use local without shared





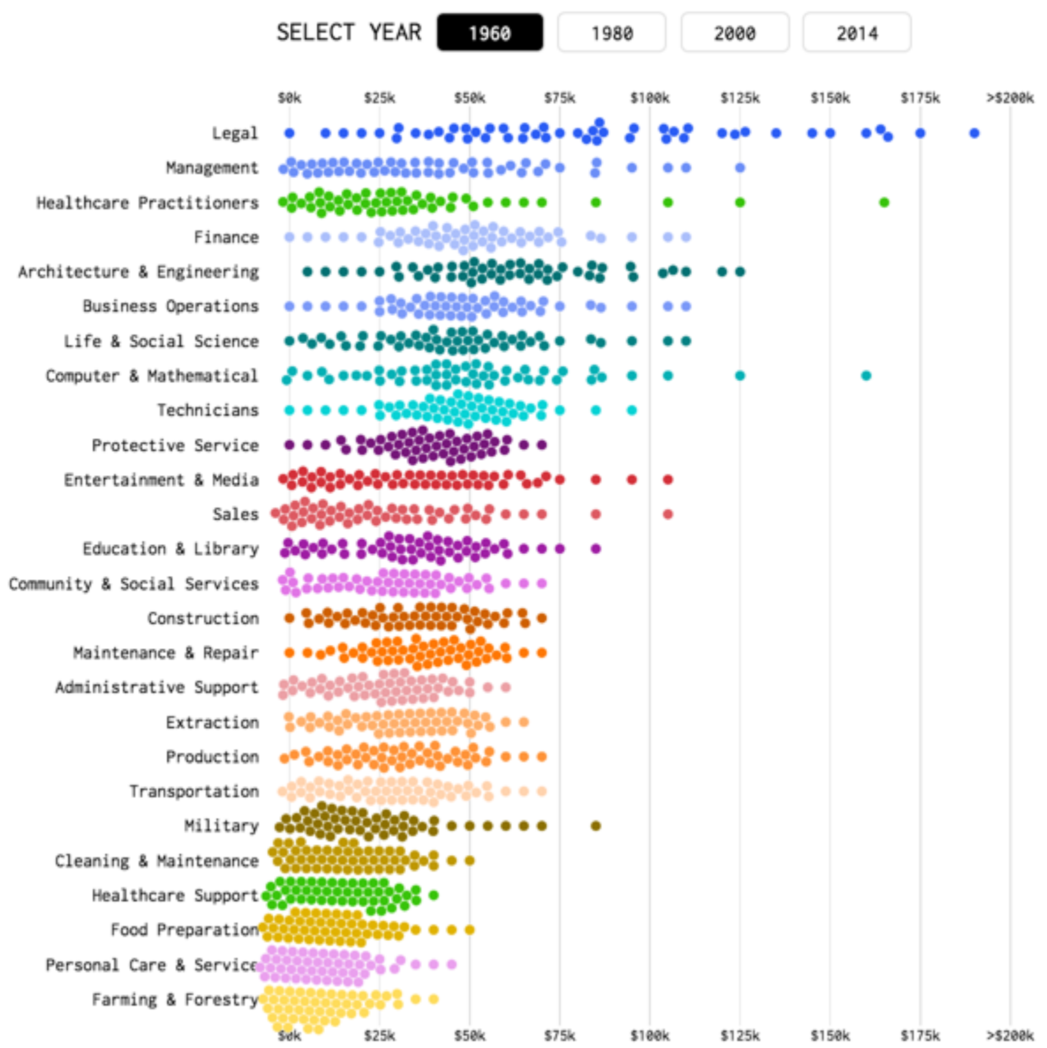
position along
aligned scale



length

Multi-level analysis required for many cases

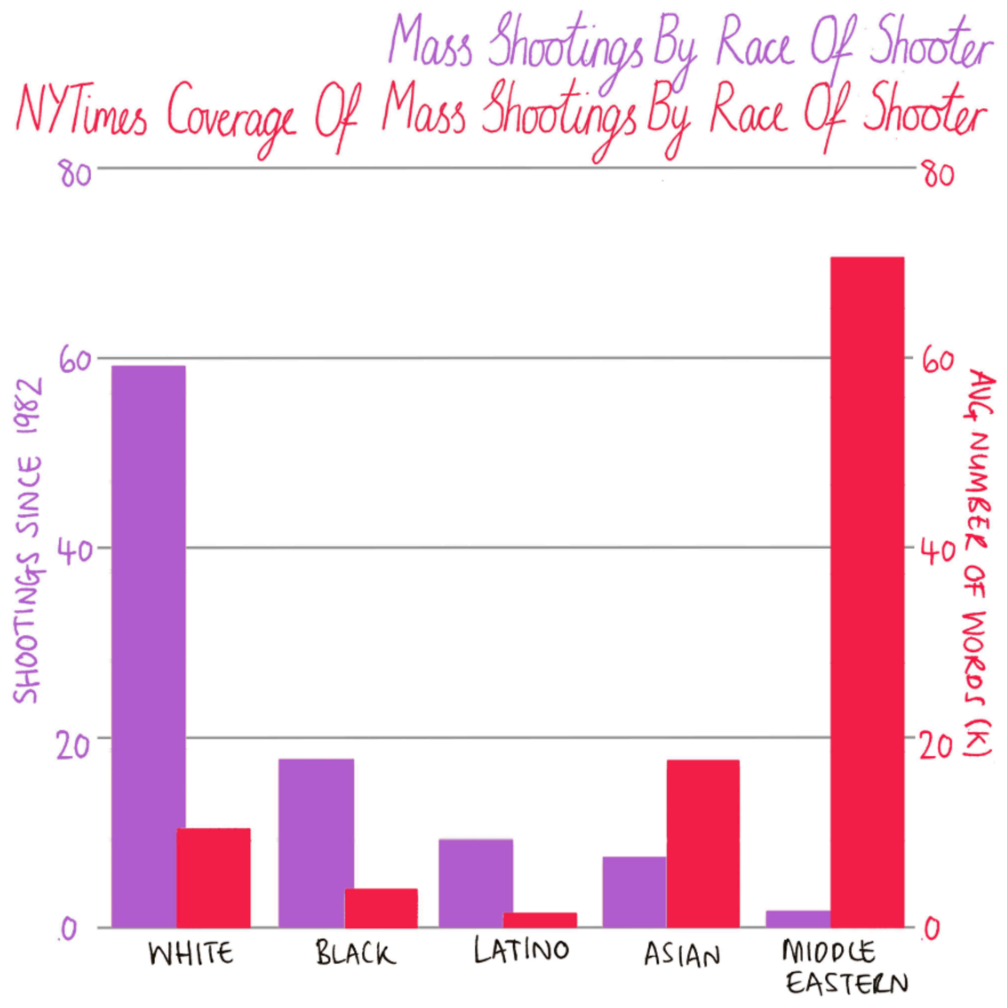
- small multiples: juxtaposed views
  - vertical position within row: algorithmic, avoid occlusion
  - vertical position across rows: encodes job type attribute



https://flowingdata.com/2016/06/28/distributions-of-annual-income/

Multi-level analysis needed: Grouped bar charts

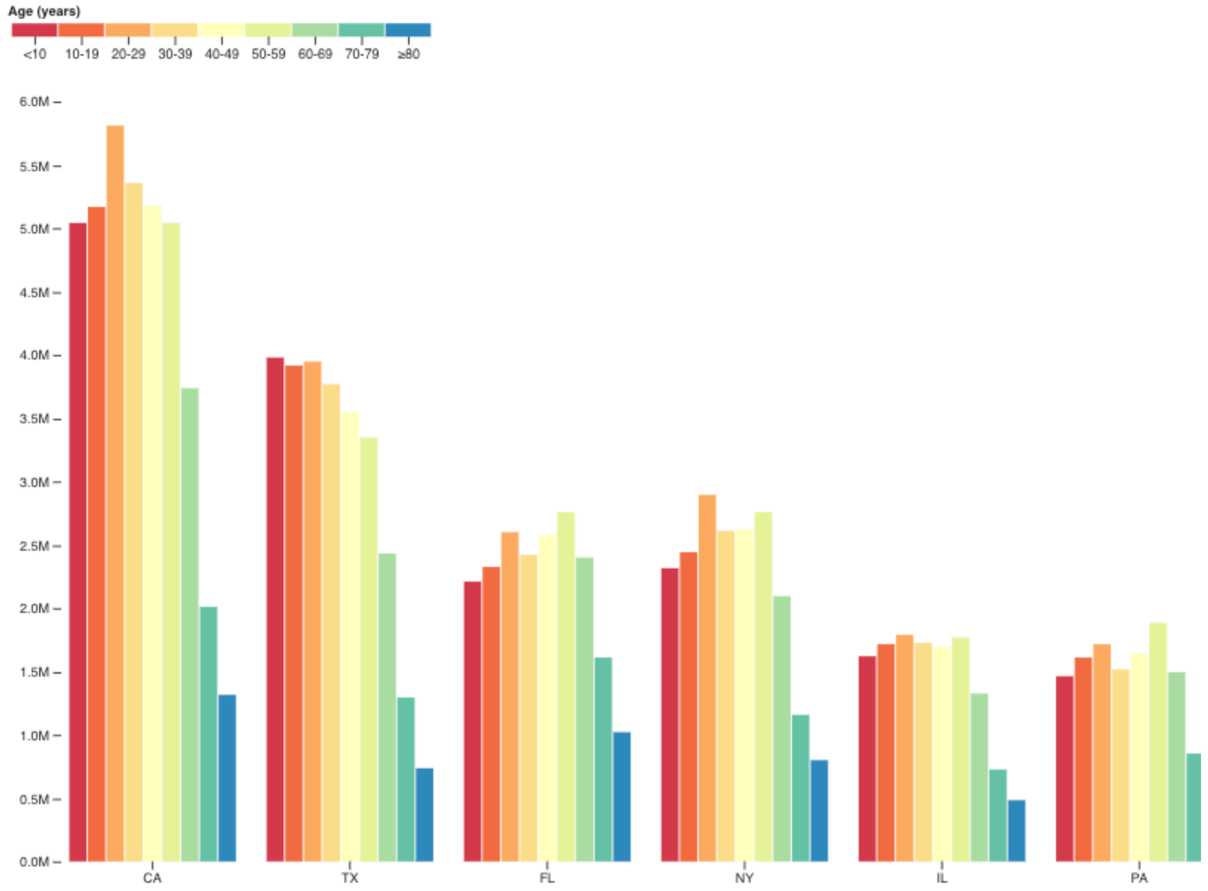
- Encoded
  - vertical position encodes quantitative attributes
    - shootings & coverage counts
  - length (1D size) redundantly encodes same thing
  - color encodes categorical attrib (shooting vs coverage)
  - horizontal position
    - low-level (within group) encodes counts, redundant w/ color
    - high-level (across groups) encodes race (shooting & coverage)
- Unavailable
  - any other position channel (radial) precluded
- Free
  - motion, shape, ...



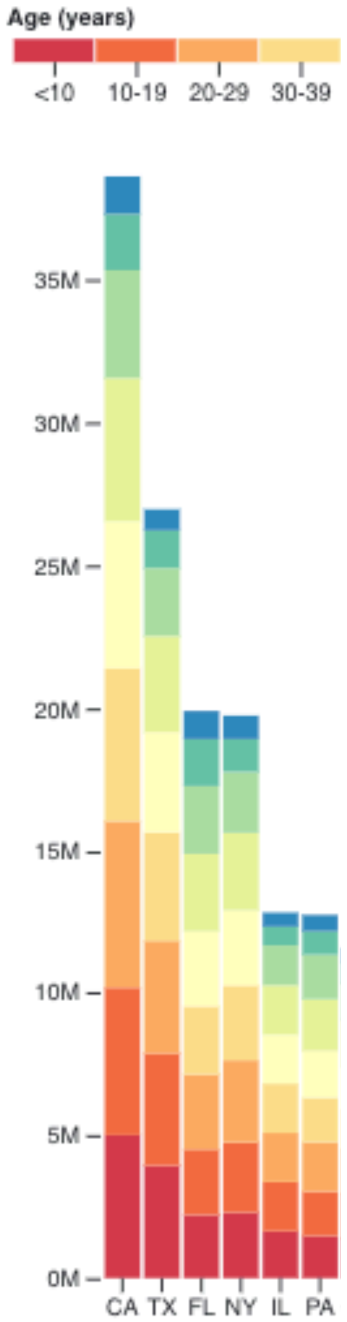
https://twitter.com/MonaChalabi/status/1158779046693679106?s=20

From marks to glyphs: multiple marks/item

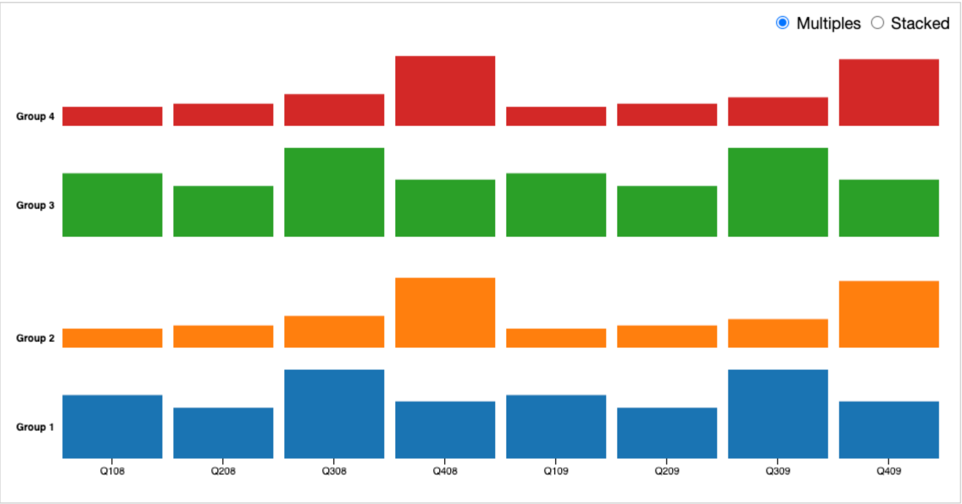
- glyphs: more than one mark per item
  - grouped bars
  - stacked bars
- multiple views
  - bar chart small multiples

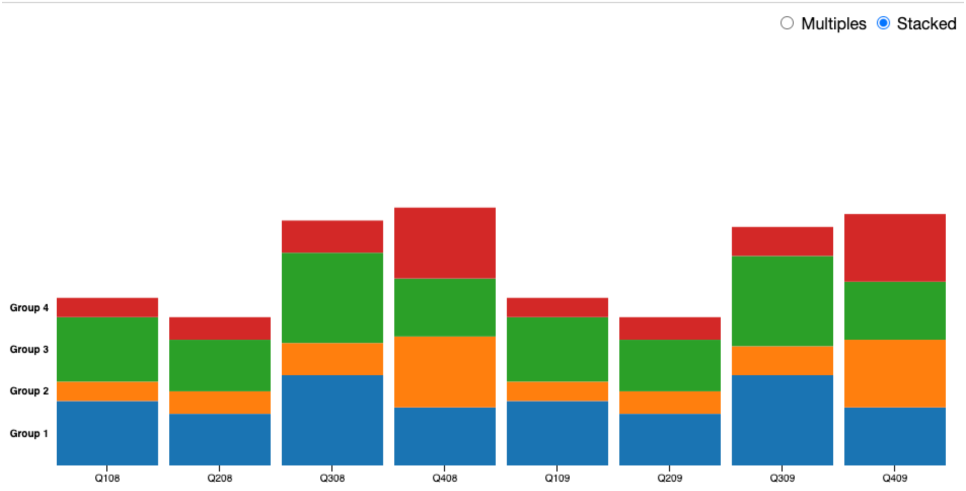


https://observablehq.com/@d3/grouped-bar-chart/2



https://observablehq.com/@d3/stacked-bar-chart/2

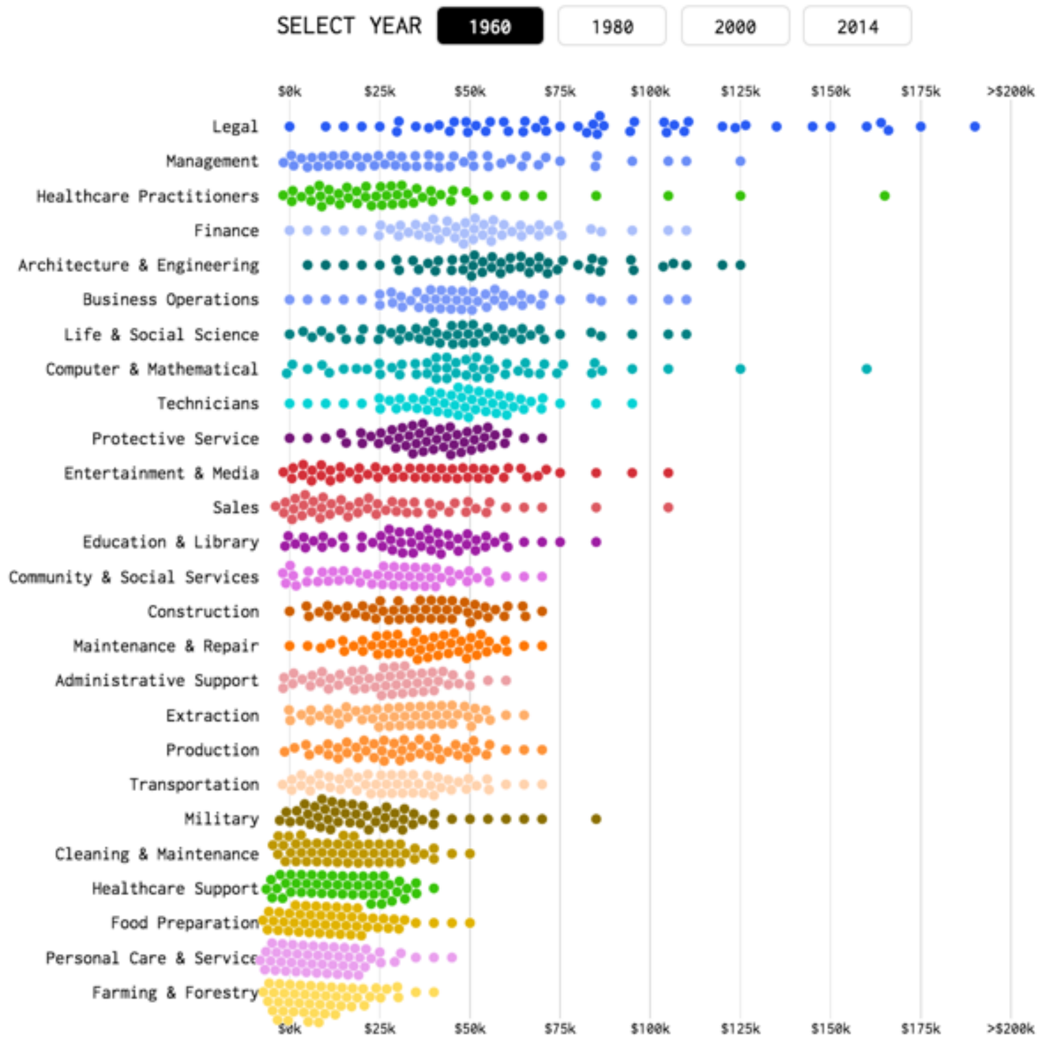




https://blocks.roadtolarissa.com/mbostock/4679202

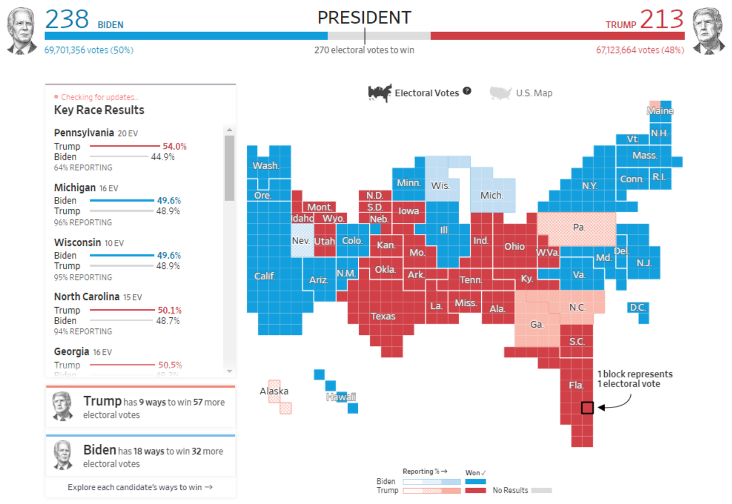
Multi-level analysis required for many cases

- small multiples: juxtaposed views
  - vertical position within row: algorithmic, avoid occlusion
  - vertical position across rows: encodes job type attribute



https://flowingdata.com/2016/06/28/distributions-of-annual-income/

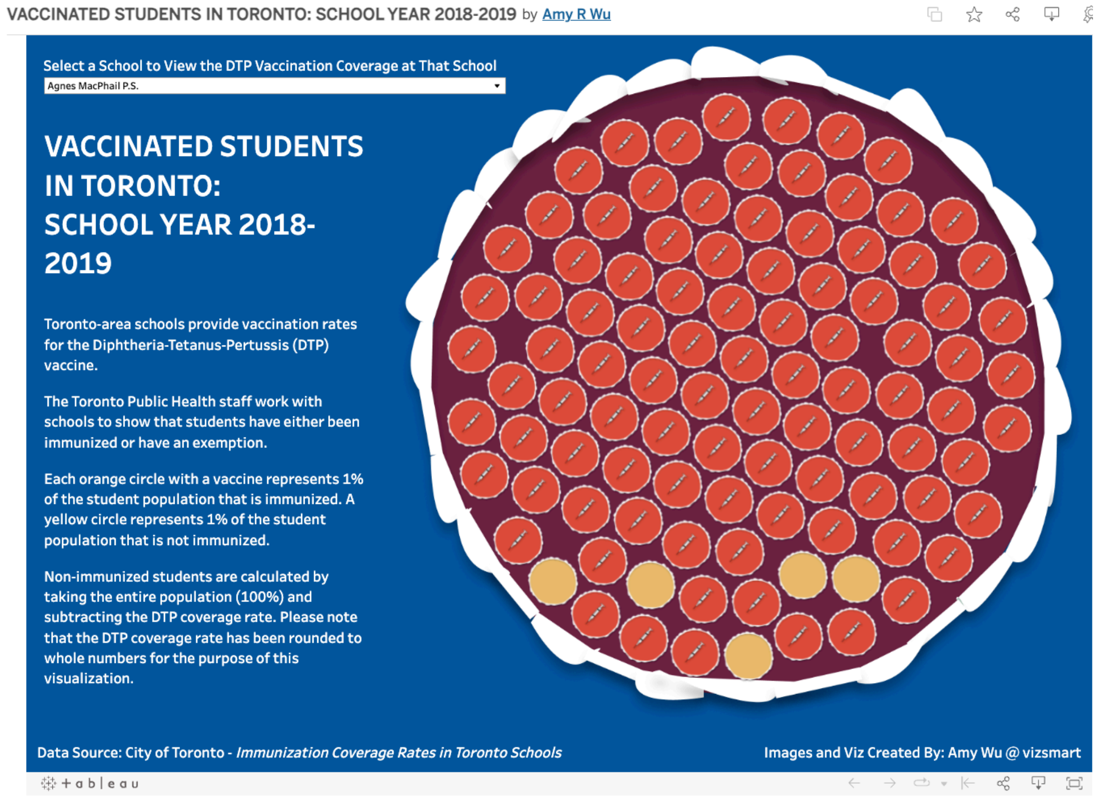
- nesting:
  multi-scale
  views / glyphs



https://www.anychart.com/blog/2020/11/06/election-maps-us-vote-live-results/

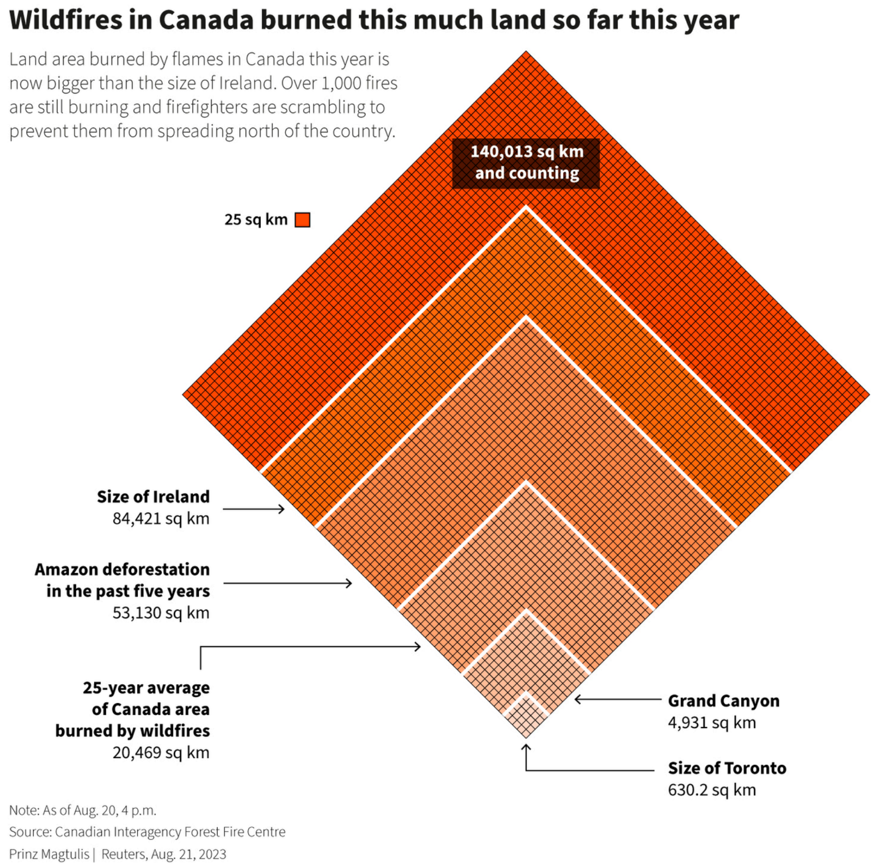
Unit encodings

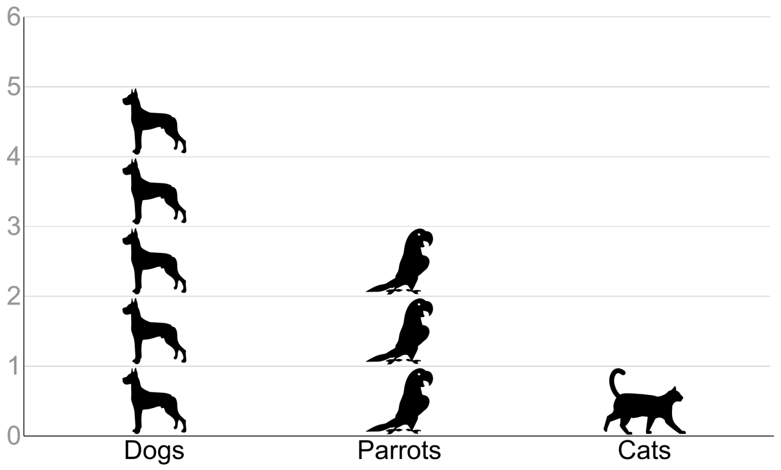
- point marks
  - general case: quantity only!
  - position channel not necessarily in use
- often constrained by idiom
  - then need **multi-level interpretation**
    - top level: interlocking mark
      - rectilinear: support counting width & height separately
    - bottom level: unit point marks
      - can be independently color-coded (or interactively highlighted)



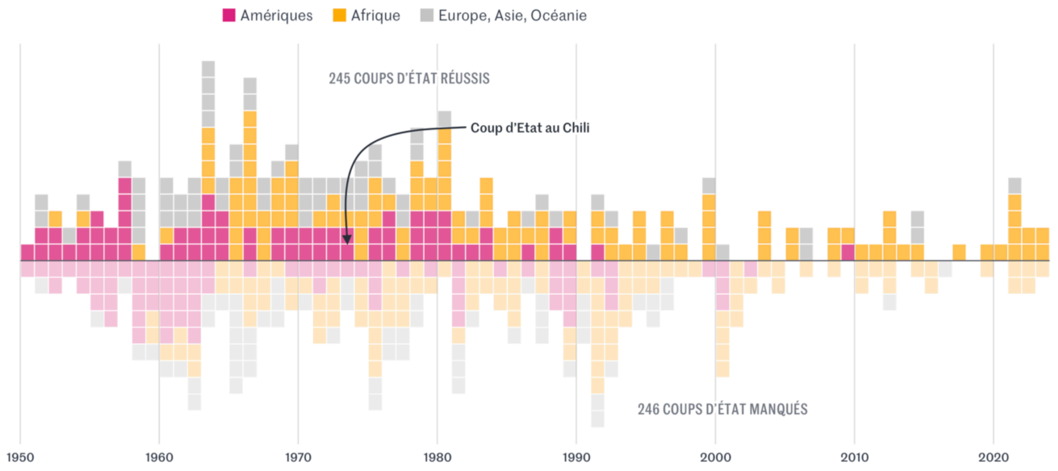
https://www.informationisbeautifulawards.com/showcase/6163-vaccinated-students-in-toronto-school-year-2018-2019

https://public.tableau.com/app/profile/amy.r.wu/viz/DTP_16715915193810/DTPDashboard





http://steveharoz.com/research/isotype/



https://www.lemonde.fr/les-decodeurs/article/2023/09/11/depuis-1950-pres-de-cinq-cents-coups-d-etat-tentes-ou-reussis-surtout-en-amerique-latine-et-en-afrique_6188906_4355770.html

https://twitter.com/prinzmagtulis/status/1693684342818574675

Conclusion: Preliminary steps towards answers?

- Old marks/channels models
  - marks, based on Bertin's geometry: 0D points, 1D lines, 2D areas, 3D volumes
  - channel rankings by accuracy, based on Cleveland& McGill two-value ratio task
- Alternative marks/channels proto-models
  - channel-based constraint analysis, channel availability: Encoded, Free, Unavailable
  - mark types model, mark-based constraints
    - Unconstrained / Singleton, for single items (points & simple line segments)
    - Paths, for multiple items (complex lines)
    - Filled & Interlocking, with boundary & interiors (areas)
  - channel dependency proto-model
    - distinguish coordinate frame positions as shared, vs size & orientation as local
  - multi-level mark type analysis
- do these help think and reason about design space of visual encodings?

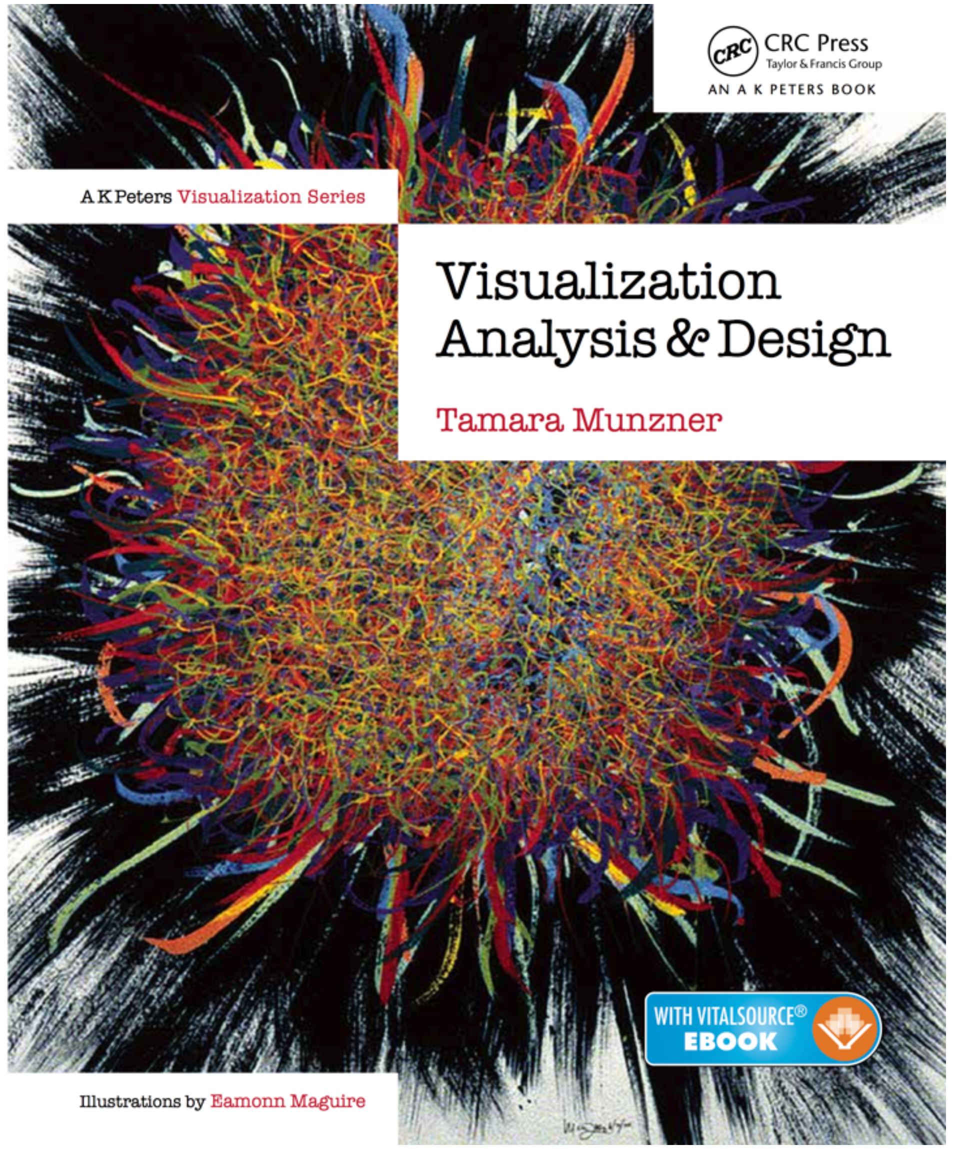
More stuff

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#northeastern24

  –more questions? thoughts on answers??

- book
  http://www.cs.ubc.ca/~tmm/vadbook

- full courses, papers, videos, software, talks
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm



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CRC Press, AK Peters Visualization Series, 2014.

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