Marks Revisited: Beyond Bertin

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http://www.cs.ubc.ca/~tmm/talks.html#mit24

UBC

DESIGNING for PEOPLE

CAIDA

UBC Data Science Institute

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Co-conspirators

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

Marks and channels: Foundational model

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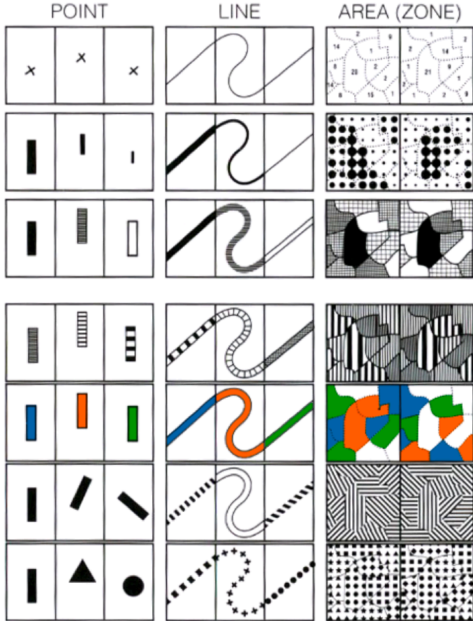   - represent items
  - channels
    - control appearance of marks
    - representing attributes
- widely used
  - Bertin 1967
    - Semiology of Graphics

Marks

→ Points → Lines → Areas
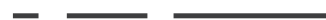
Channels

→ Position → Color

→ Horizontal → Vertical → Both
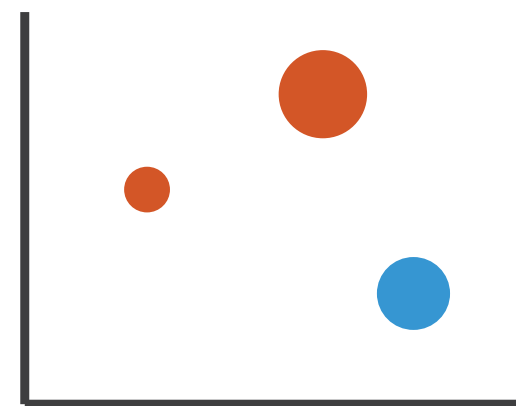
→ Shape → Tilt

→ Size
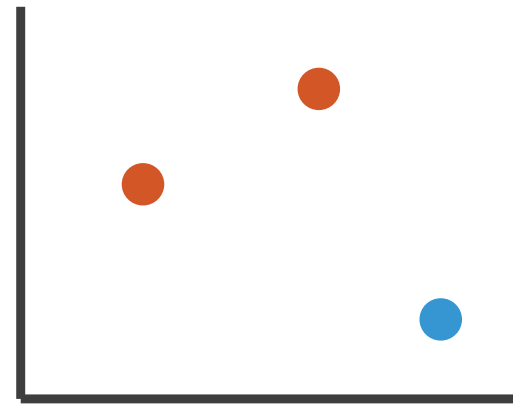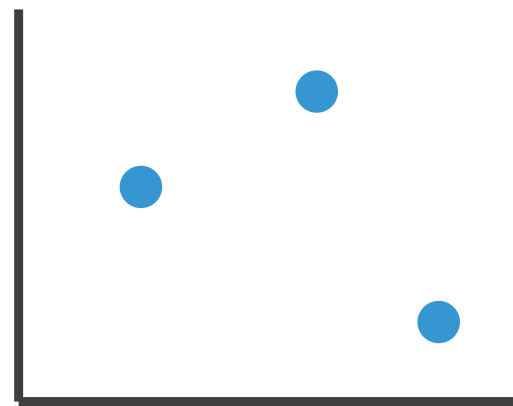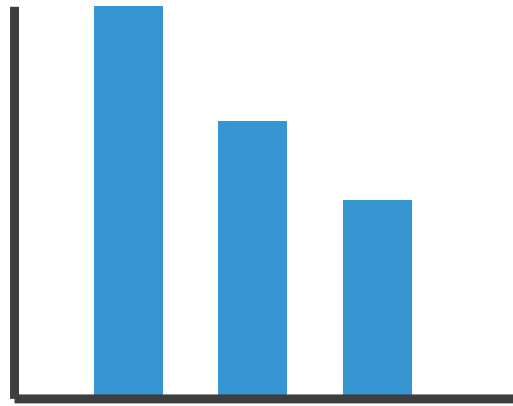
→ Length → Area → Volume

Talk outline

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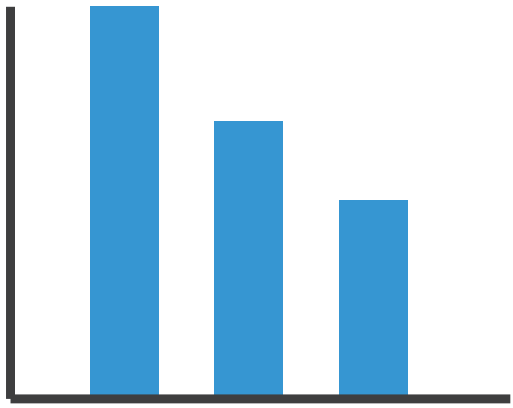- present preliminary ideas towards an alternative model

Visual encoding

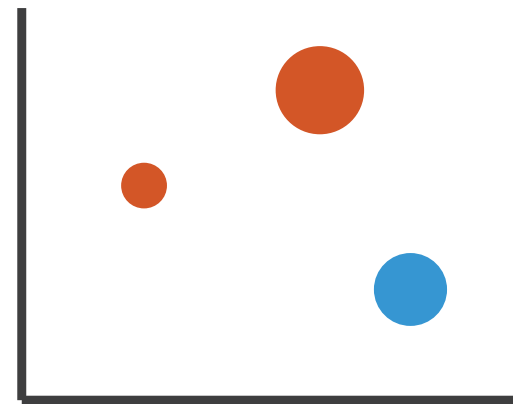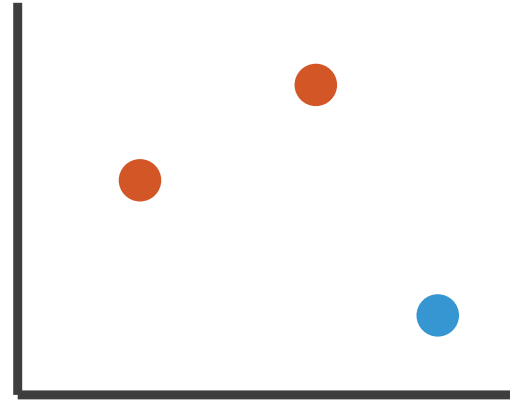- analyze idiom structure as combination of marks and channels

Visual encoding

- analyze idiom structure as combination of marks and channels

idiom: bar chart

1 channel:
vertical position

mark: line

Visual encoding

- analyze idiom structure as combination of marks and channels

idiom: bar chart   idiom: scatterplot

1 channel: 2 channels:
vertical position   vertical position
                          horizontal position

mark: line   mark: point

Visual encoding

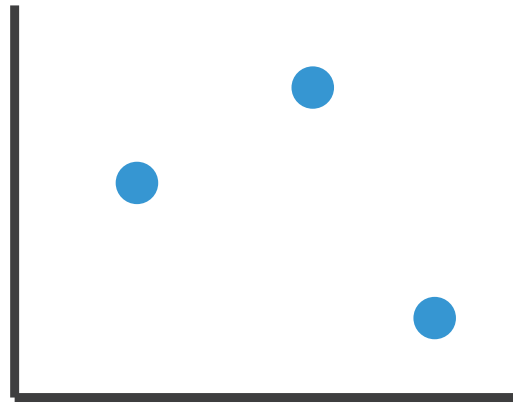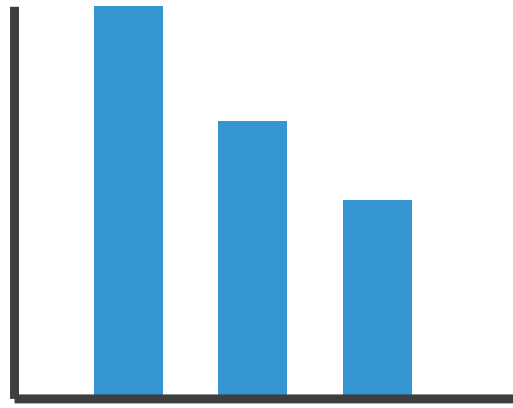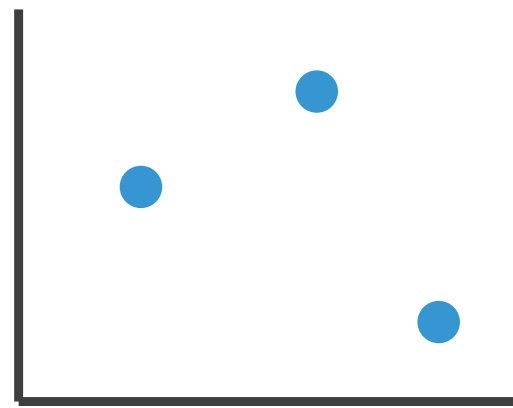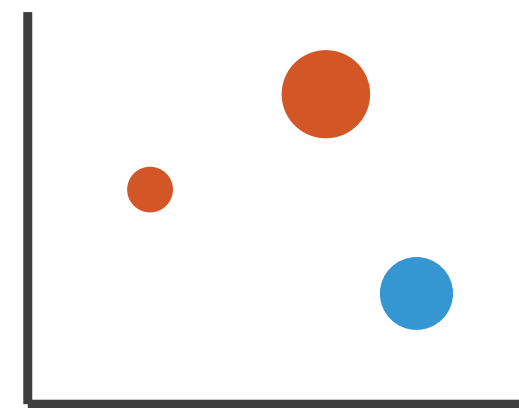- analyze idiom structure as combination of marks and channels

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

- analyze idiom structure as combination of marks and channels

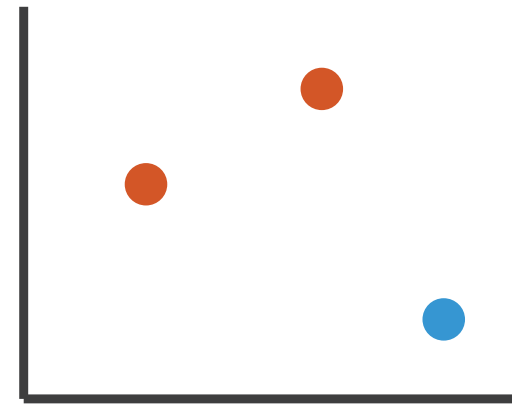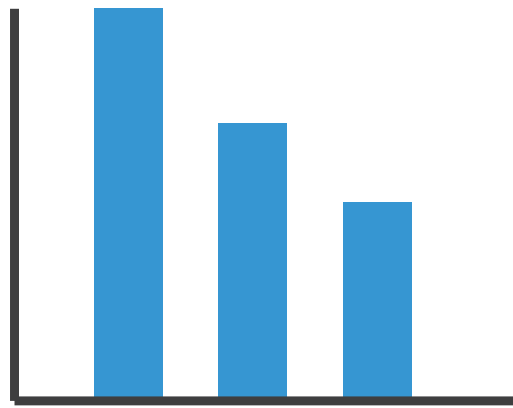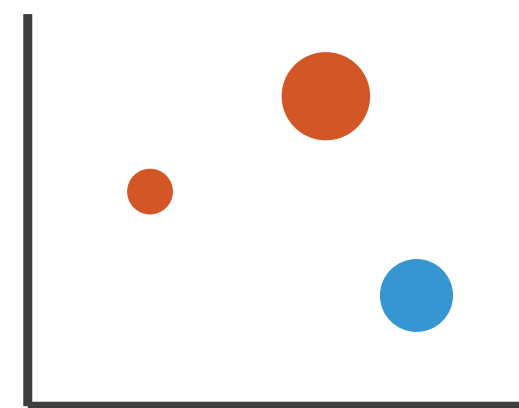idiom: bar chart   idiom: scatterplot

1 channel:
vertical position

2 channels:
vertical position
horizontal position

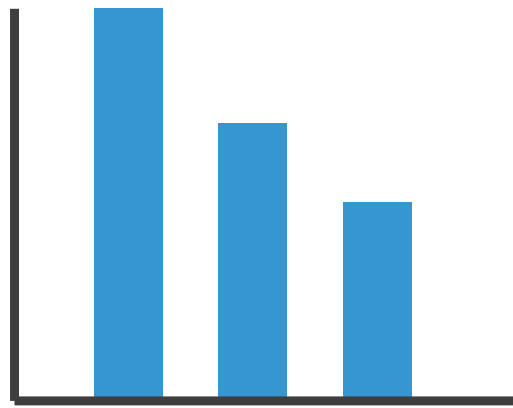3 channels:
vertical position
horizontal position
color hue

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

mark: line   mark: point   mark: point   mark: point

Visual encoding: Spatial data

- marks for given spatial data (boundaries)

idiom: choropleth map

channels:
position
color (saturation)

mark: area

http://bl.ocks.org/mbostock/4060606
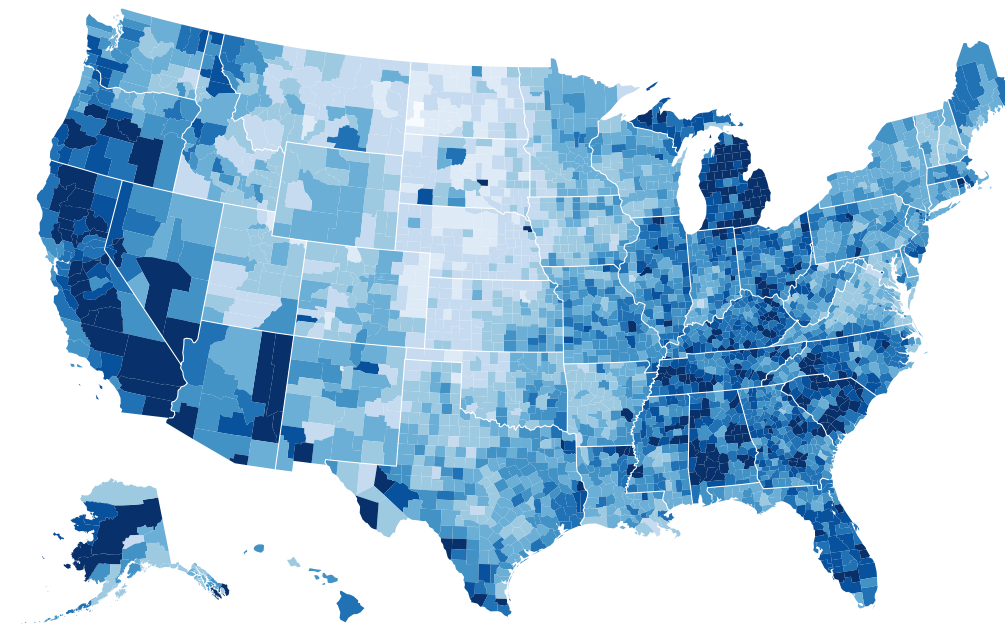
Visual encoding: Network data

- marks for items vs marks for links

→ Tables

→ Networks

Attributes (columns)

Items (rows)

Cell containing value

Link

Node (item)
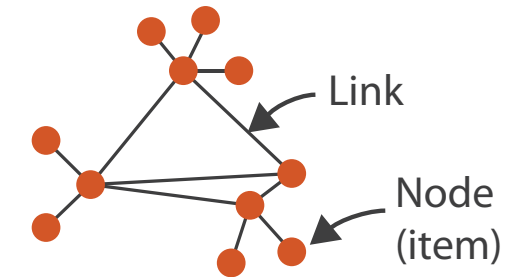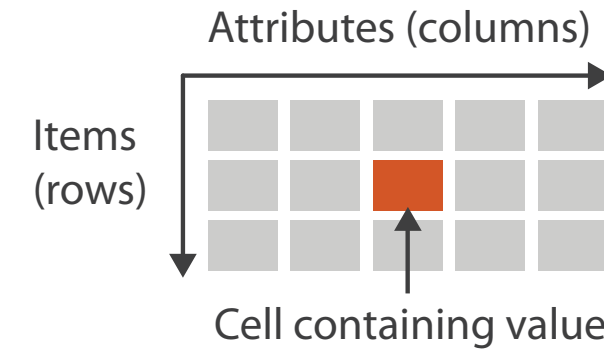
→ **Connection**   → **Containment**
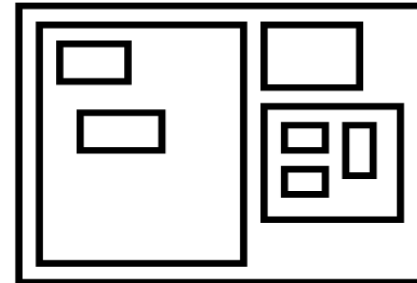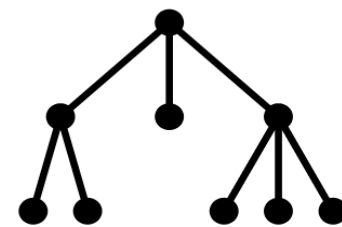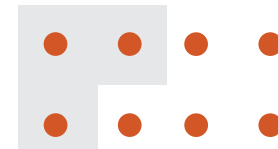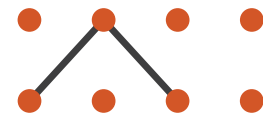
→ *Trees*

idiom: node-link diagram

channel: position

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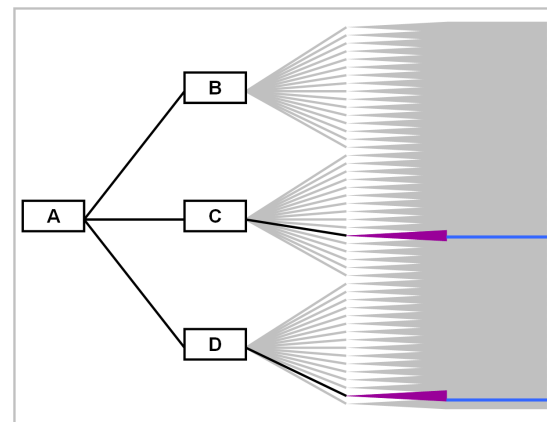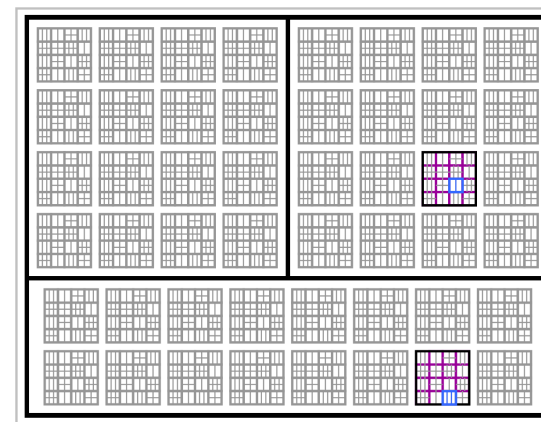
position

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

Node–Link Diagram   **Treemap**

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...
  - 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
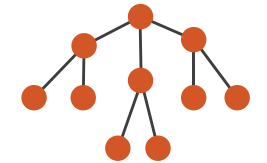   - to support reasoning about design choices
    - capture the key variables at play
    - increase cognitive efficiency & support inferences by grouping similar instances together to facilitate reasoning about classes
      - *[Ralph. Toward Methodological Guidelines for Process Theories & Taxonomies 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

ABSTRA
Research
place wh
been pro
discovere
analyze
the diff
possibilit
informati
series o
designing
designs.

Exploring the Design Space of Composite Visualization

Waqas Javed[*]   Niklas Elmqvist[†]

ABSTRACT
We propose
as a theoreti
tiple views (
visual repres
five such stra
tensive revie
on to show h
of a design s
tions in term
between item
design space

A Design Space of Visualization Tasks

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

Abstr
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Index

A Design Space of Vision Science Methods for Visualization Research

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

Paradigms	Adjustment Types	Response Types	Dependent Measures
What task does the viewer complete?	How is the stimulus level adjusted?	How does the viewer respond to that task?	How do we measure performance?

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.

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13

Teaching design space: analyze visual encoding & map to data

- 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

# Teaching: Bertini in-class exercises, catalyst for questions

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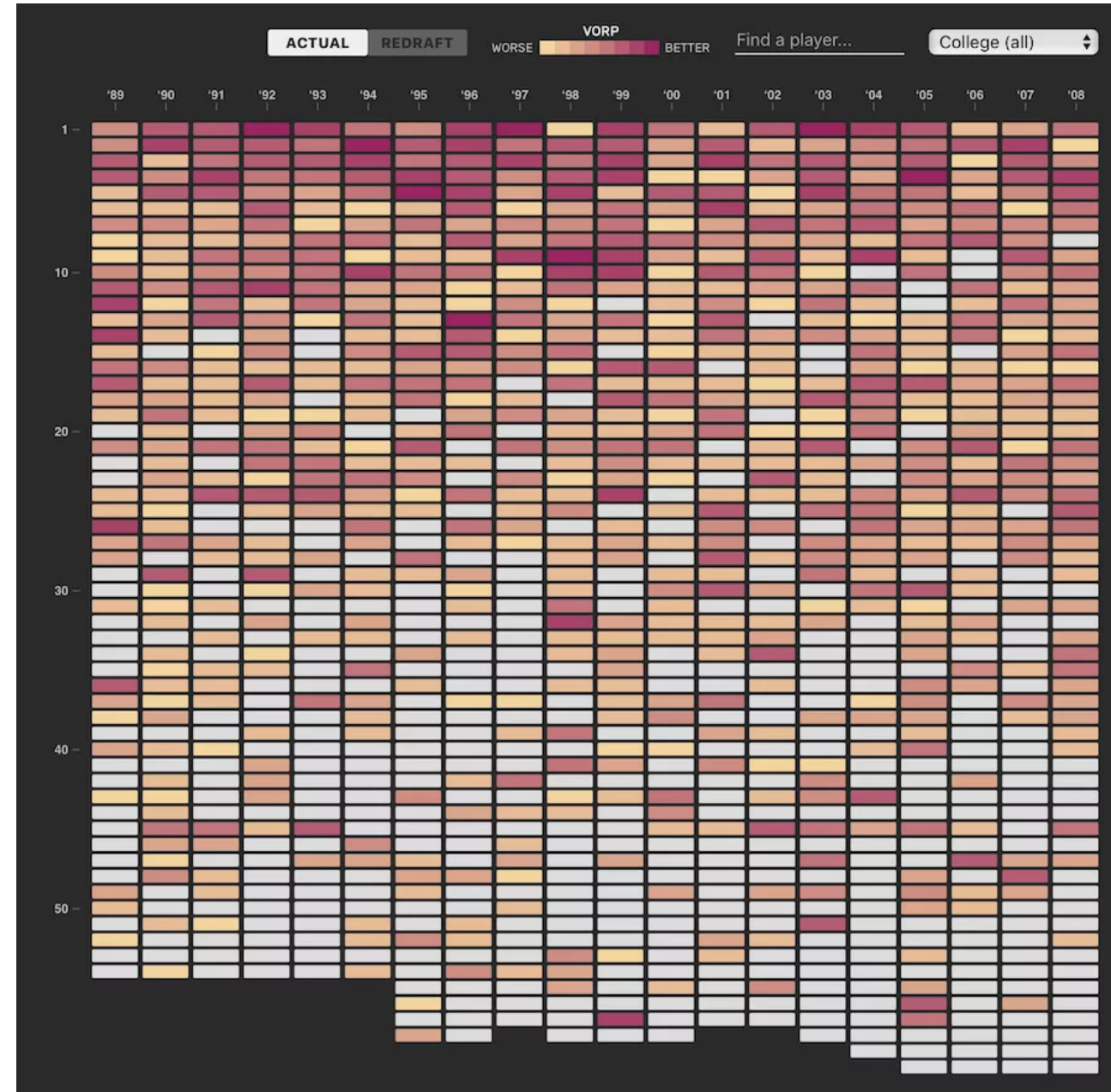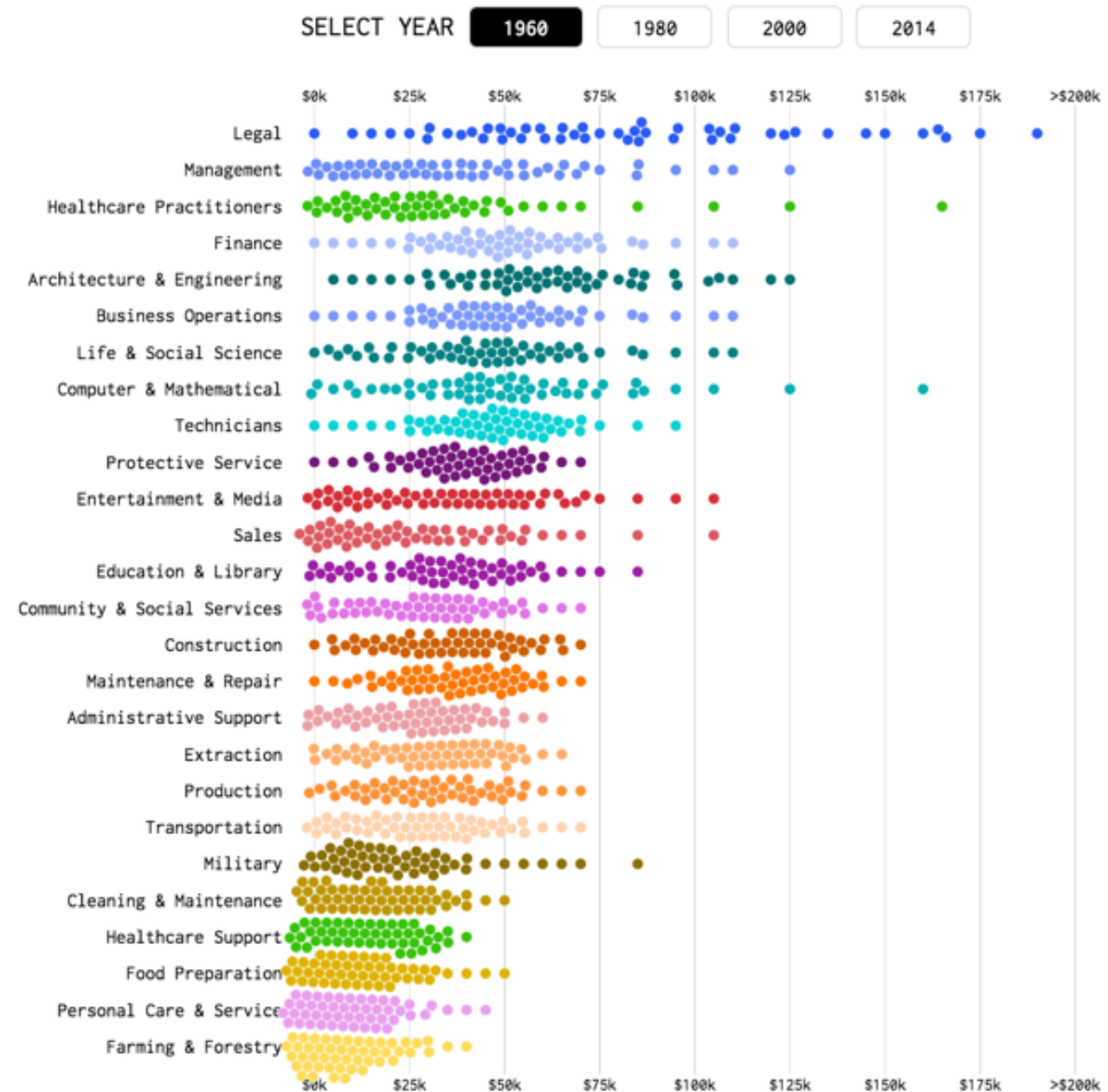
Quiz: Name marks/channels

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

Mass Shootings By Race Of Shooter
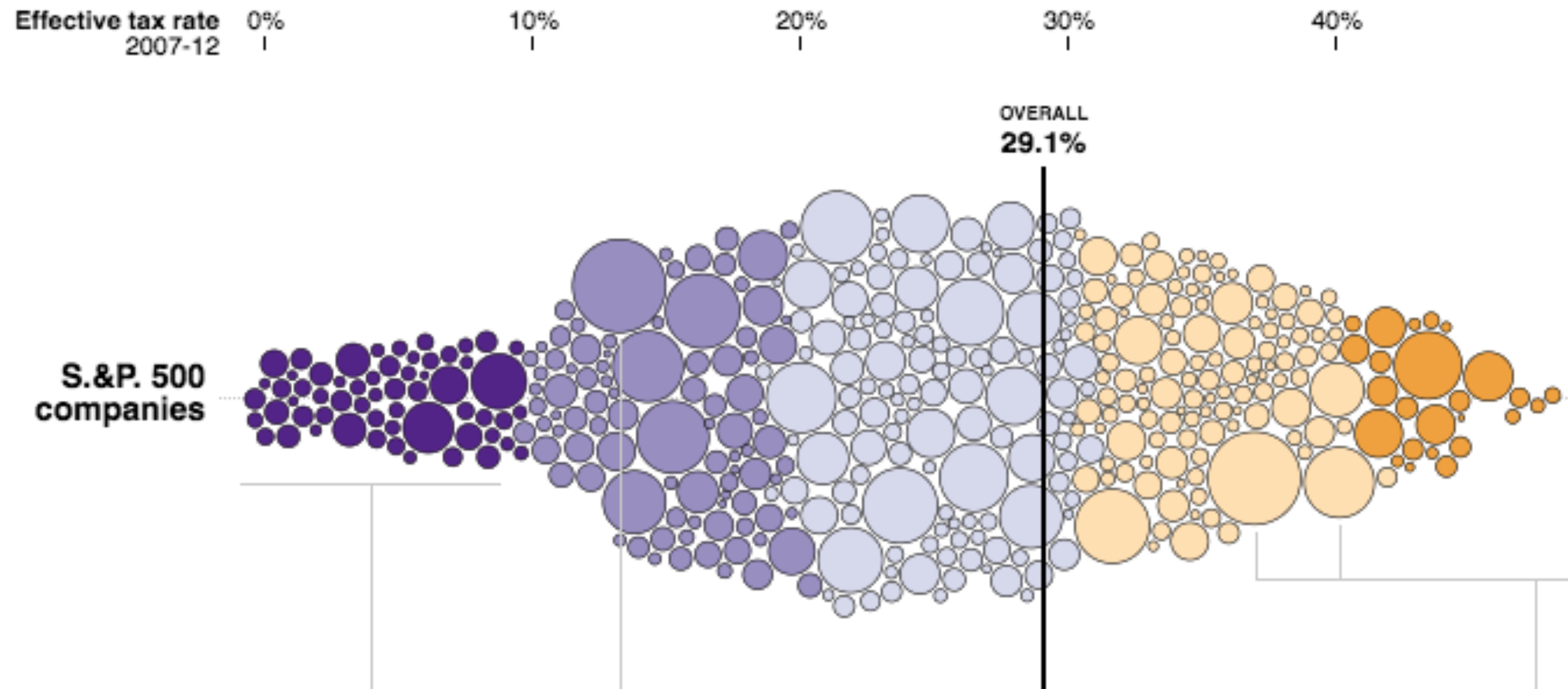
NYTimes Coverage Of Mass Shootings By Race Of Shooter

https://twitter.com/MonaChalabi/status/1158779046693679106?s=20
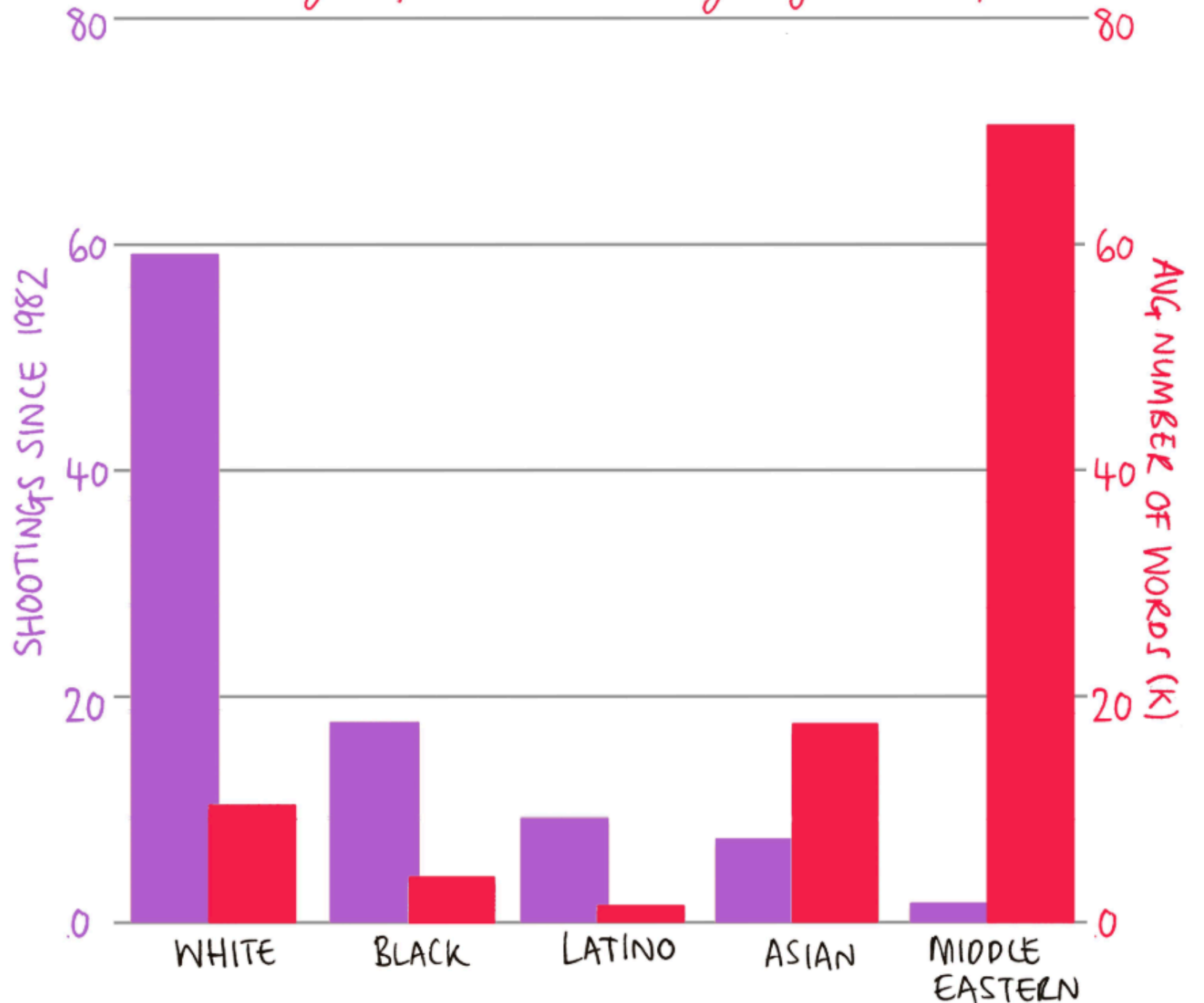
Quiz: Name marks/channels

- Tax Rates

- marks
  - A: points
  - B: lines
  - C: areas

- channels
  - A: position
  - B: color
  - C: motion
  - D: area
  - E: angle

Effective tax rate 2007-12 0% 10% 20% 30% 40%

OVERALL 29.1%

S.&P. 500 companies

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

Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design

Jeffrey Heer and Michael Bostock

Ranking Visualizations of Correlation Using Weber's Law

Lane Harrison, Fumeng Yang, Steven Franconeri, Remco Chang

Measuring the Separability of Shape, Size, and Color in Scatterplots

Stephen Smart
University of Colorado Boulder
Boulder, Colorado
stephen.smart@colorado.edu
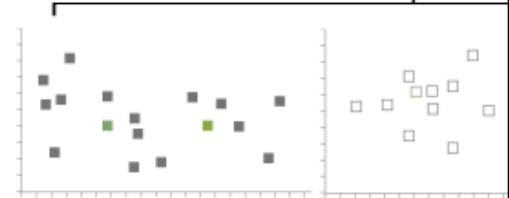
Danielle Albers Szafir

Rethinking the Ranks of Visual Channels

Caitlyn M. McColeman[*], Fumeng Yang[*], Timothy F. Brady, and Steven Franconeri

19

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
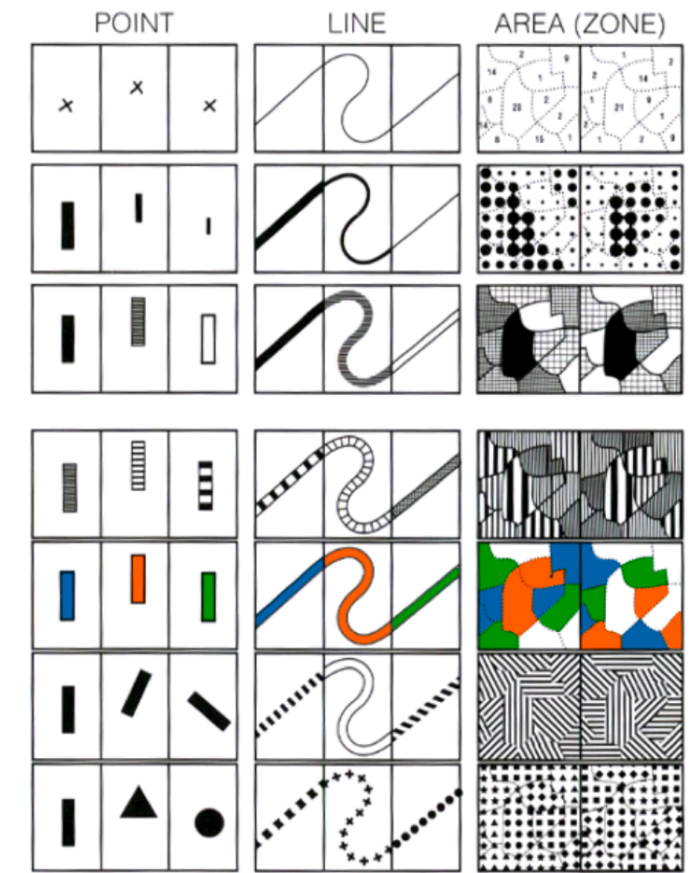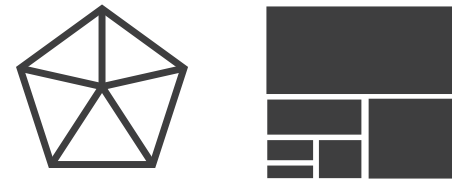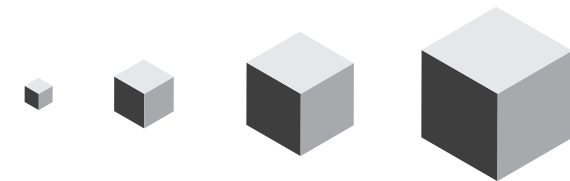
0D   1D   2D   3D

What do marks do?

- idiom: pie chart
  - **area** marks with angle channel: **2D area varies**
    - separated & ordered radially, uniform length
  - accuracy: area less accurate than rectilinear aligned line length
  - task: part-to-whole judgements

- idiom: coxcomb chart
  - marks with length channel: **1D length varies**
    - separated & ordered radially, uniform width
  - direct analog to radial bar charts
  - 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
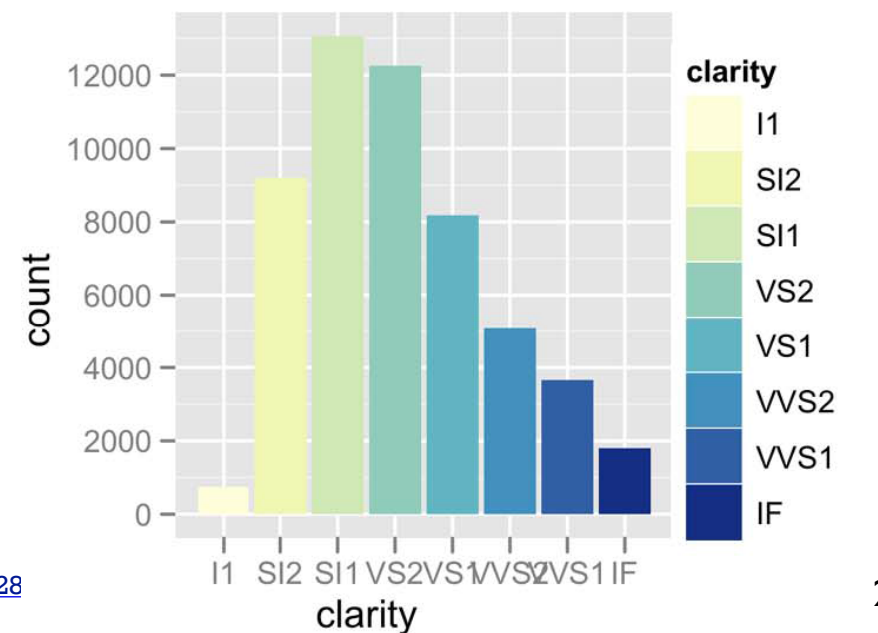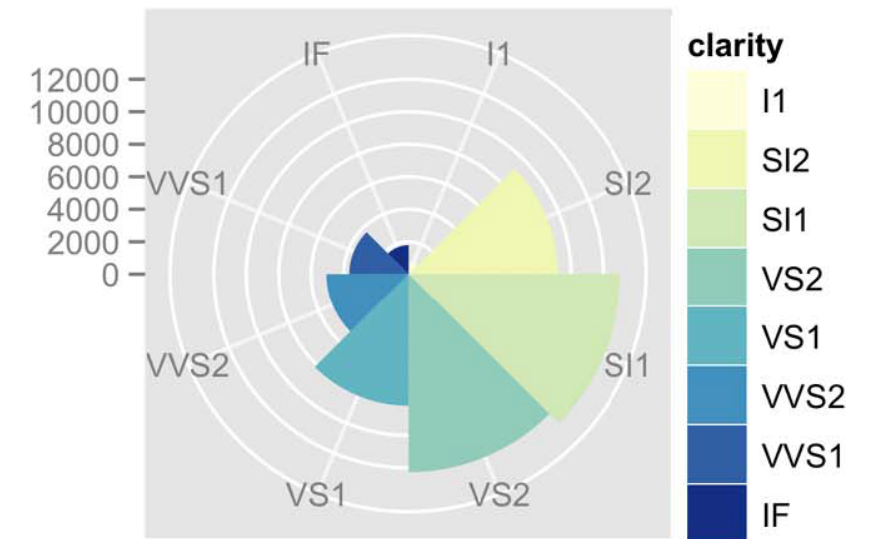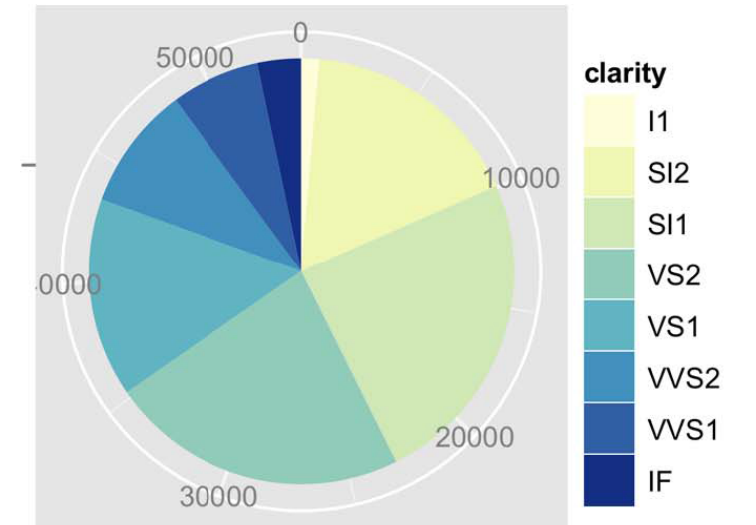
Coxcomb channel analysis

- 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

- mark type: encode or decode?

  – infer designer intent

  – predict viewer response: if channels differ, which "wins"?

nonuniform width as length increases

uniform width as length increases

radial & rectilinear bars: uniform width as length increases
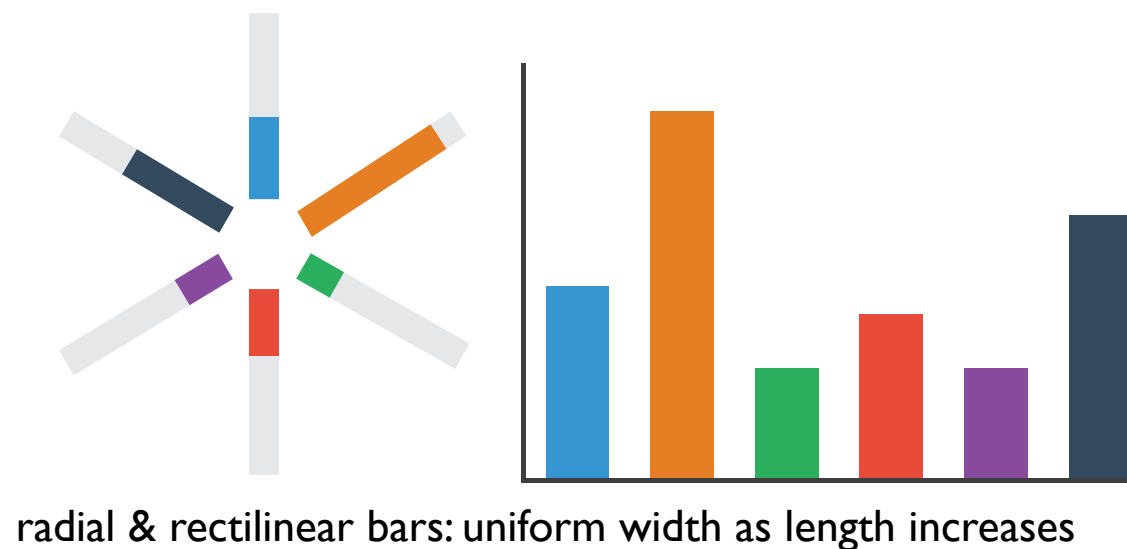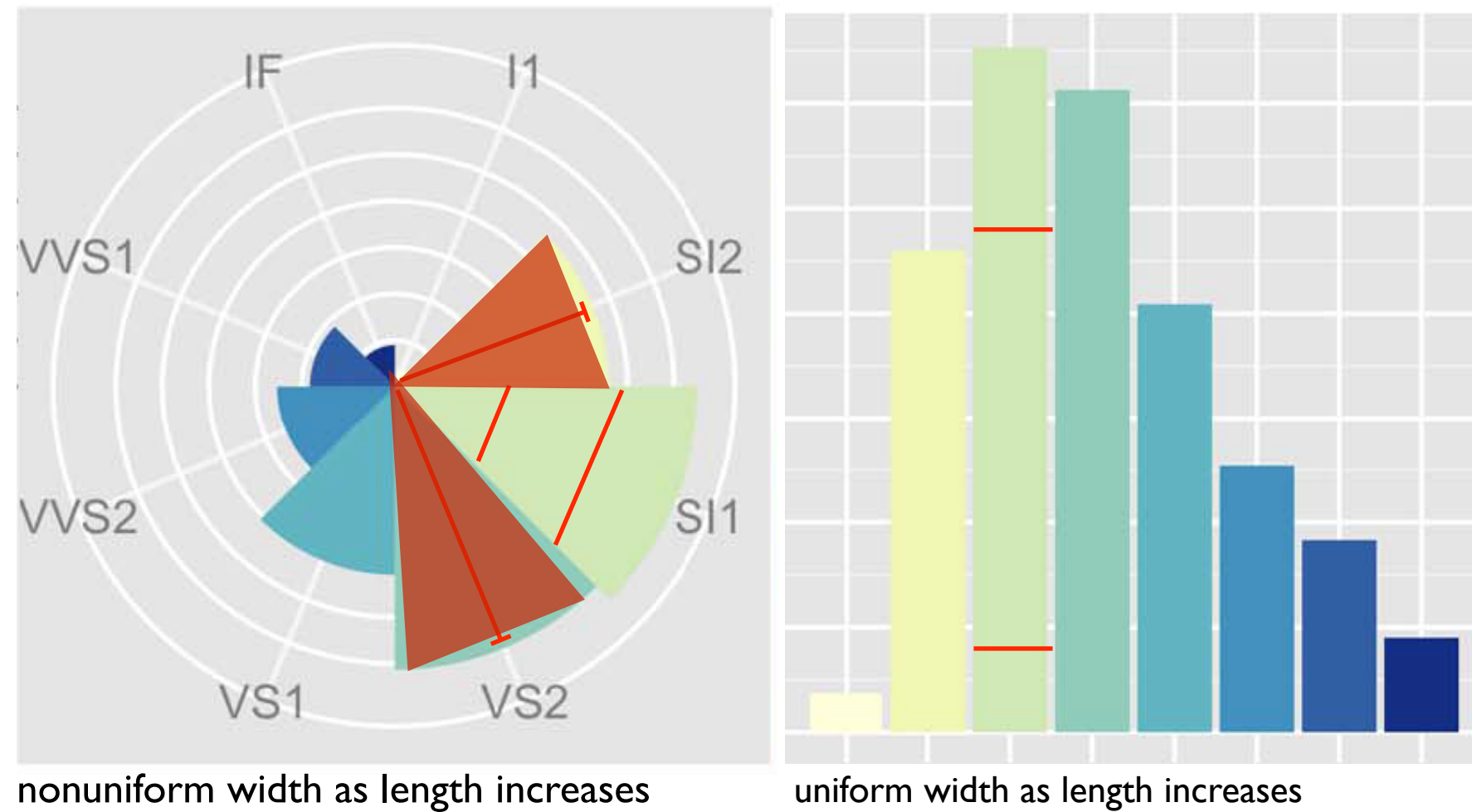
Channels used: what does it mean?

- Does channel size encode attribute?
  - yes: sizes differ
    - according to dog name (alphabetical order)
  - no: size differences not meaningful
    - just emerges from choice of layout, radial vs rectilinear
    - not a "real" attribute

- Can we use size channel to encode another attribute?
  - no!
  - it's "taken" already, would change meaning

Q5 Marks & Channels: Why Does My Dog [4 pts]
Credit: https://public.tableau.com/app/profile/wjsutton/viz/WhyDoesMyDog___IronQuest/DesktopVersion

Why does my Great Dane shed so much?

Great Danes, and other large breeds, shed so much due to the sheer size of their body, there's just so much hair that can fall out!

However, a simple brush once or twice per week is all you really need to do to keep the shedding under control.

Why does my Chow Chow sound like a pig?

A grunting or oinking sound is actually a reverse sneeze. Reverse sneezing is when a dog's throat muscles spasm and soft palate are irritated.

The dog will breathe in too much air through his nose and make pig-like noises. Despite the oddness, most of the time, the dog is okay.

Akita
Bernese Mountain Dog
Boxer
Cane Corso
Chow Chow
Doberman
German Shepherd
Great Dane
Great Pyrenees
Greyhound
Malamute
Mastiff
Golden Retriever
Labrador
Rottweiler
St. Bernard
Weimaraner

Large Dogs

Why does my St Bernard sit on me?

Many large dogs, like St Bernards, lay, lean and even sit on us! Despite the discomfort, this can be seen as a form of affection - the dogs want to be close to you.

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

Channel availability

- channels as constraints
  - 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
  - Unavailable: which channels unavailable / precluded / taken?
    - general dependencies between channels
    - specifics of idiom/algorithm design
  - Free: which channels free to encode another attribute?
    - without changing usability of existing encoding

General dependencies: Position

- need fine-grained ability to specify for adequate descriptive power
  - rectilinear (horizontal and/or vertical)
    - high precision
      - depth (3D position): very low precision
  - radial (angular position and/or radial distance)
    - lower precision
- 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
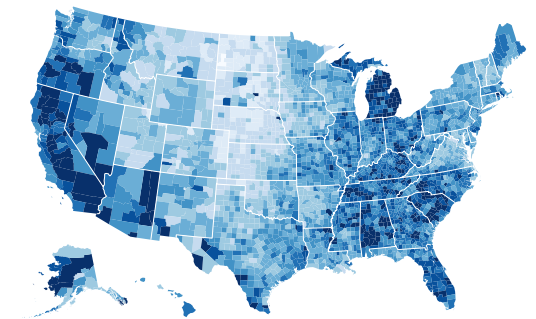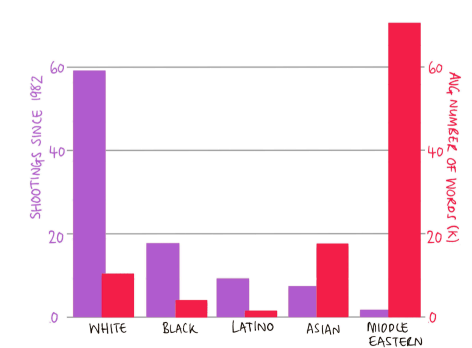
Q5 Marks & Channels: Why Does My Dog *[4 pts]*
Credit: https://public.tableau.com/app/profile/wjsutton/viz/WhyDoesMyDog___IronQuest/DesktopVersion

General dependencies: Size
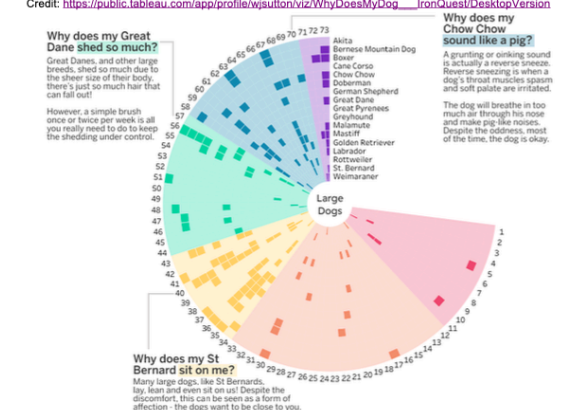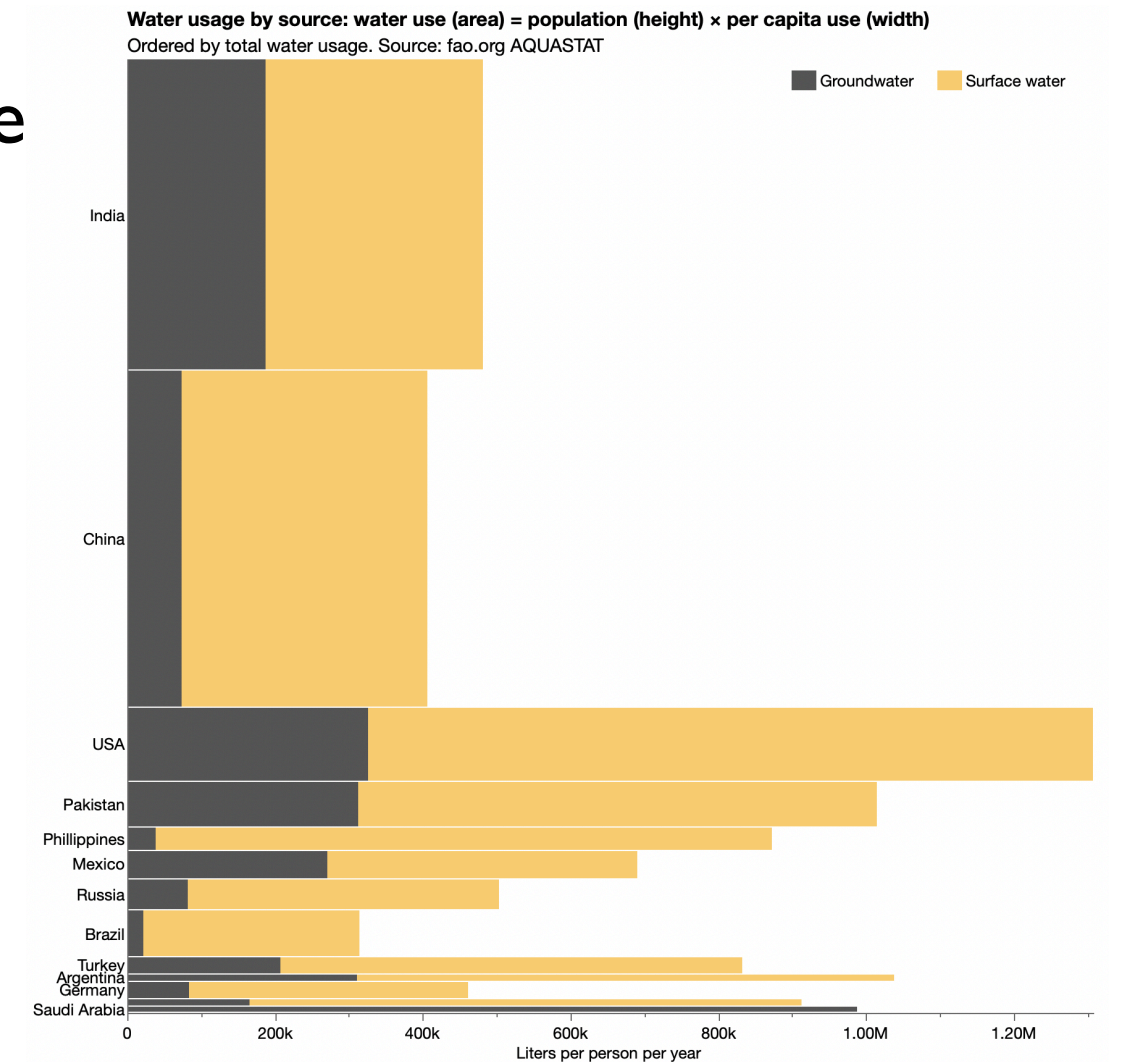
- 1D (length) << 2D (area) << 3D (volume)

- 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

Water usage by source: water use (area) = population (height) × per capita use (width)
Ordered by total water usage. Source: fao.org AQUASTAT

Groundwater · Surface water

https://www.forthgo.com/blog/2019/12/18/bar-mekko-chart-study/ 26

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
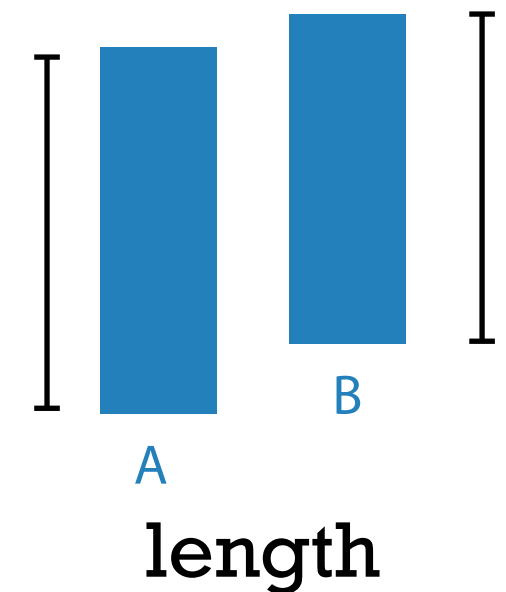 - but not vice versa: can have length without position
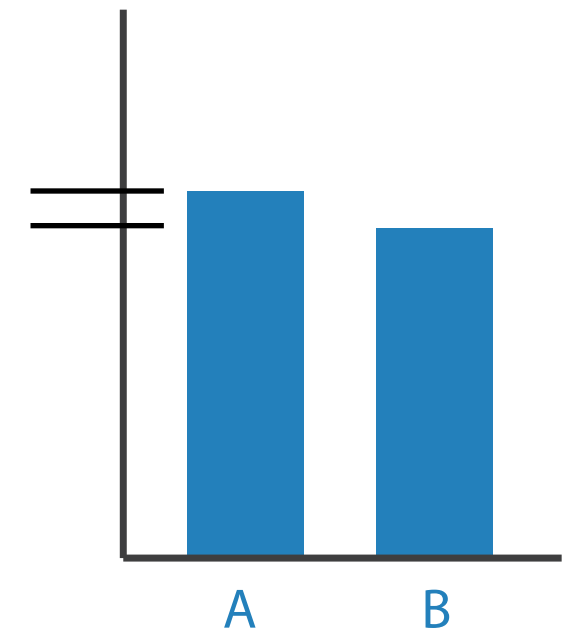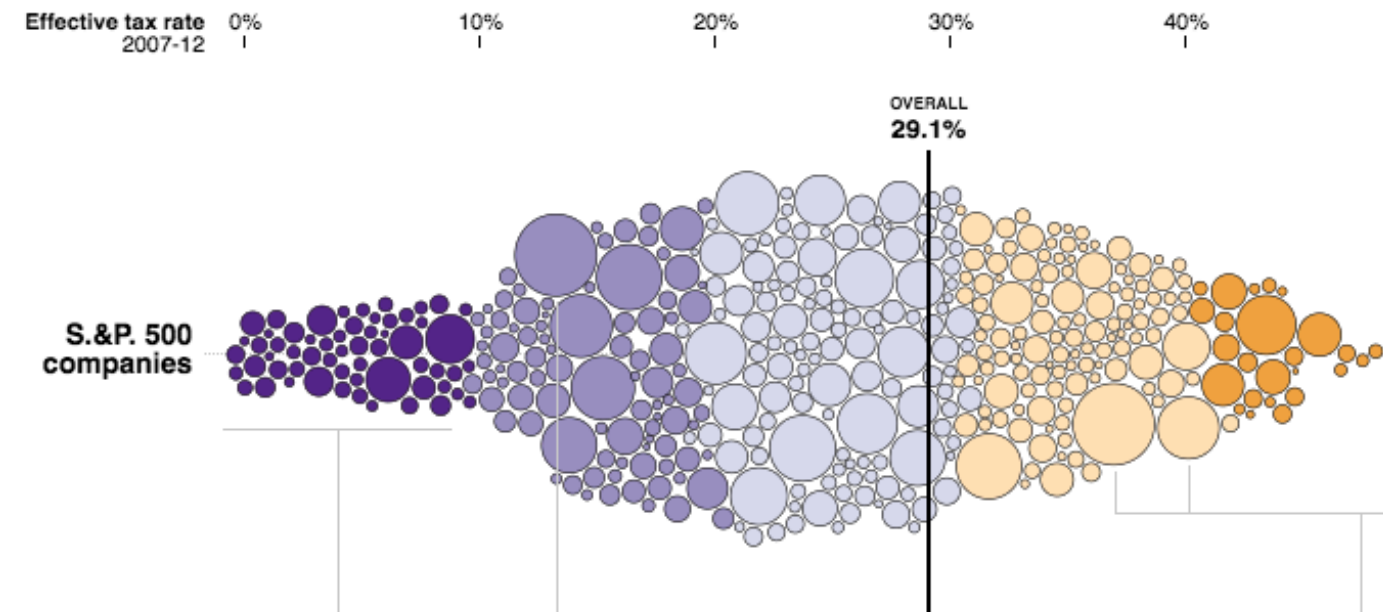

position along aligned scale
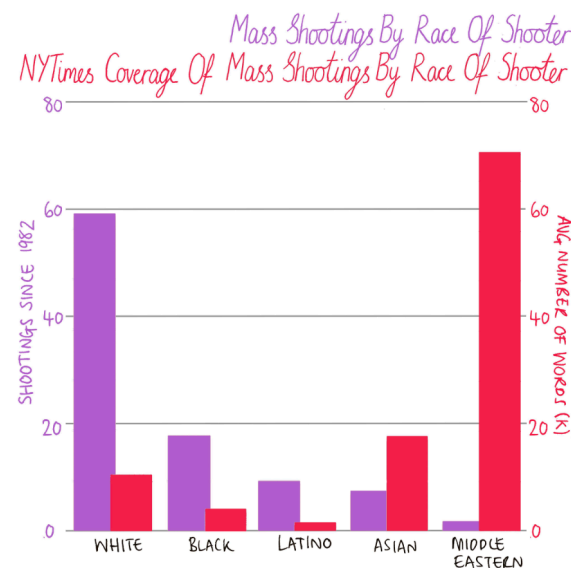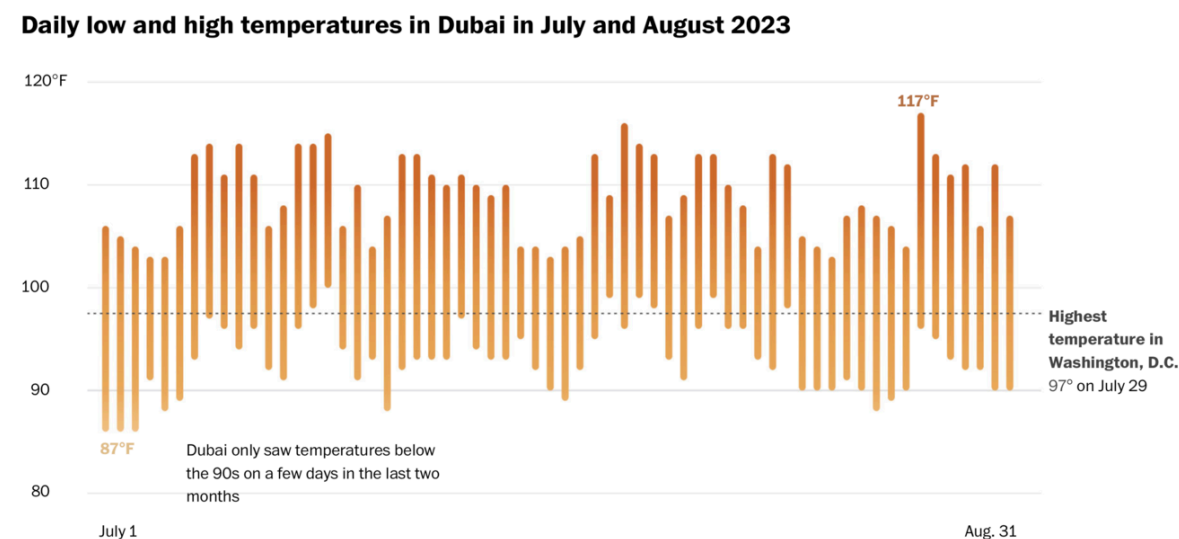
length

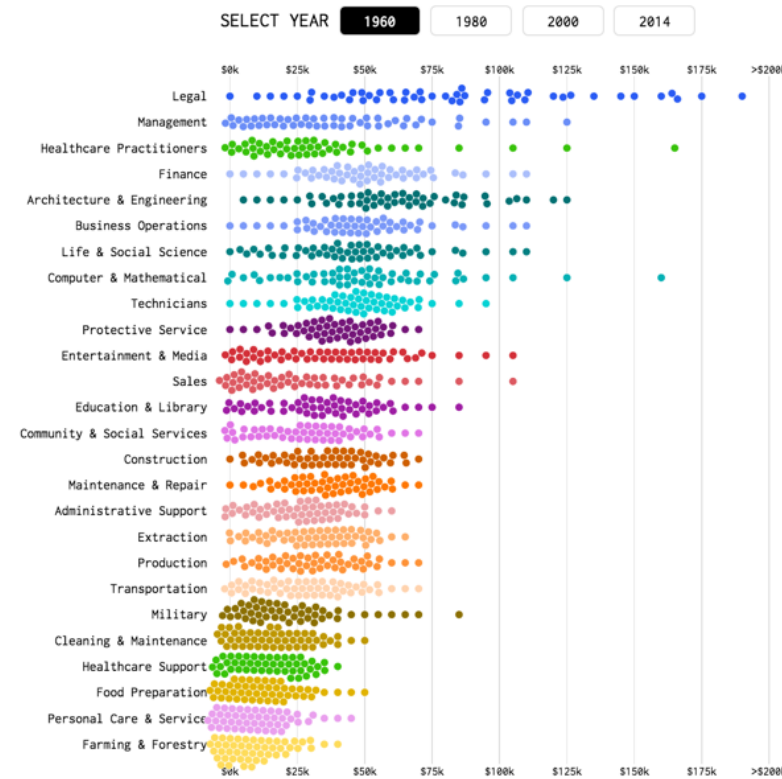# Channel availability analysis: Circle packings

- customized circle packing
  - Encoded channels
    - horizontal position: encodes tax rate
    - color: rate, redundant with horizontal position
    - size: market cap
  - Unavailable channels
    - vertical position: used by algorithm to avoid overlap
    - radial positions (angular, distance): precluded by horizontal position channel use
  - Free channels
    - motion
  - unclear
    - shape? orientation?

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

Channel availability analysis: Circle packings

- customized circle packings are special case
  - beeswarm plots

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

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

- general circle packing
  - algorithmic constraint: no overlaps, minimal gaps
    - Unavailable: position used by algorithm
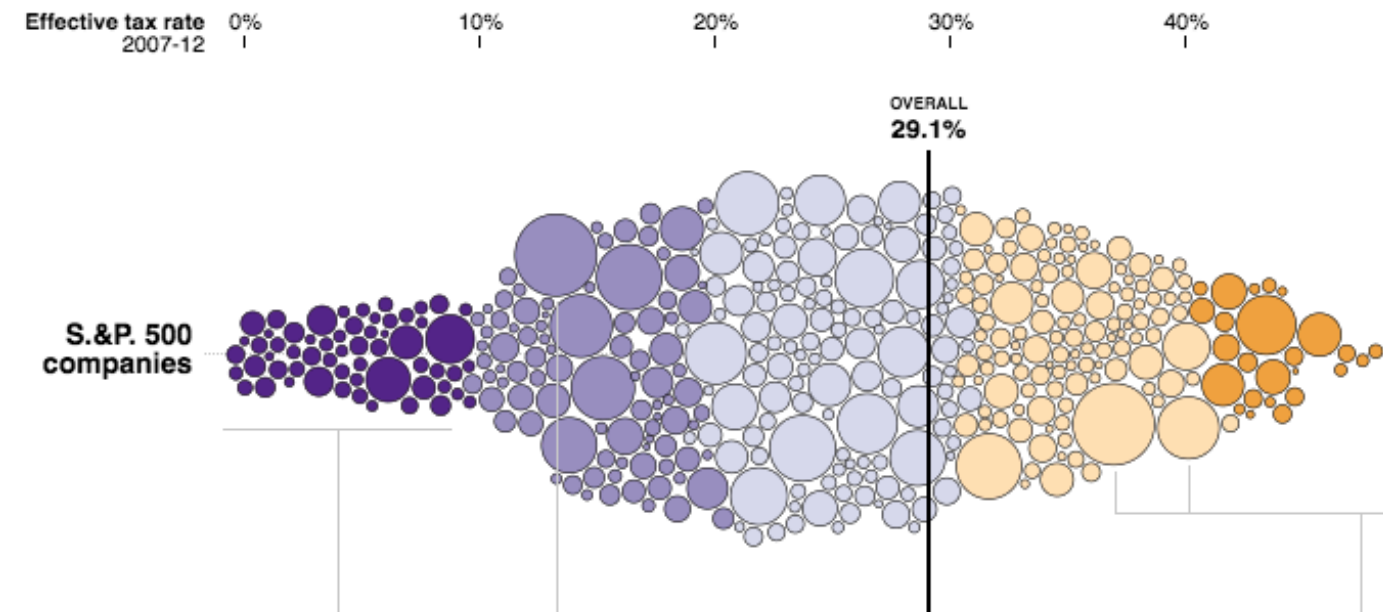
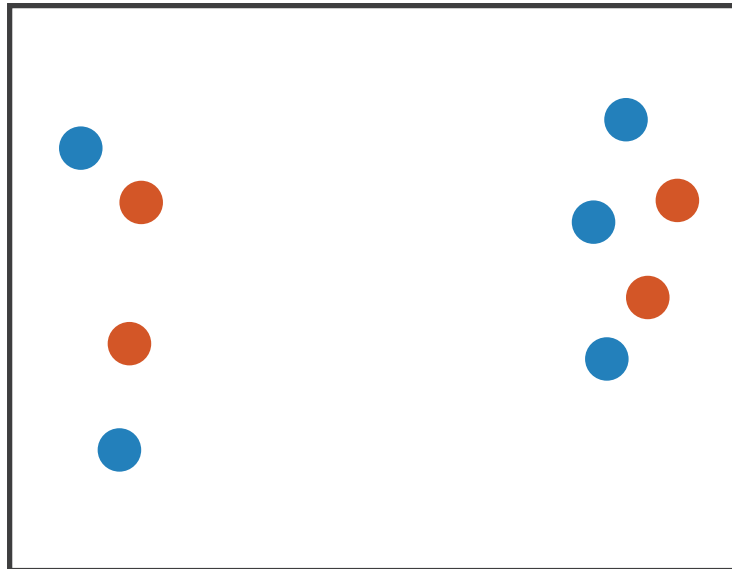# Channel availability analysis: Grouped bar charts

- 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 same as 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
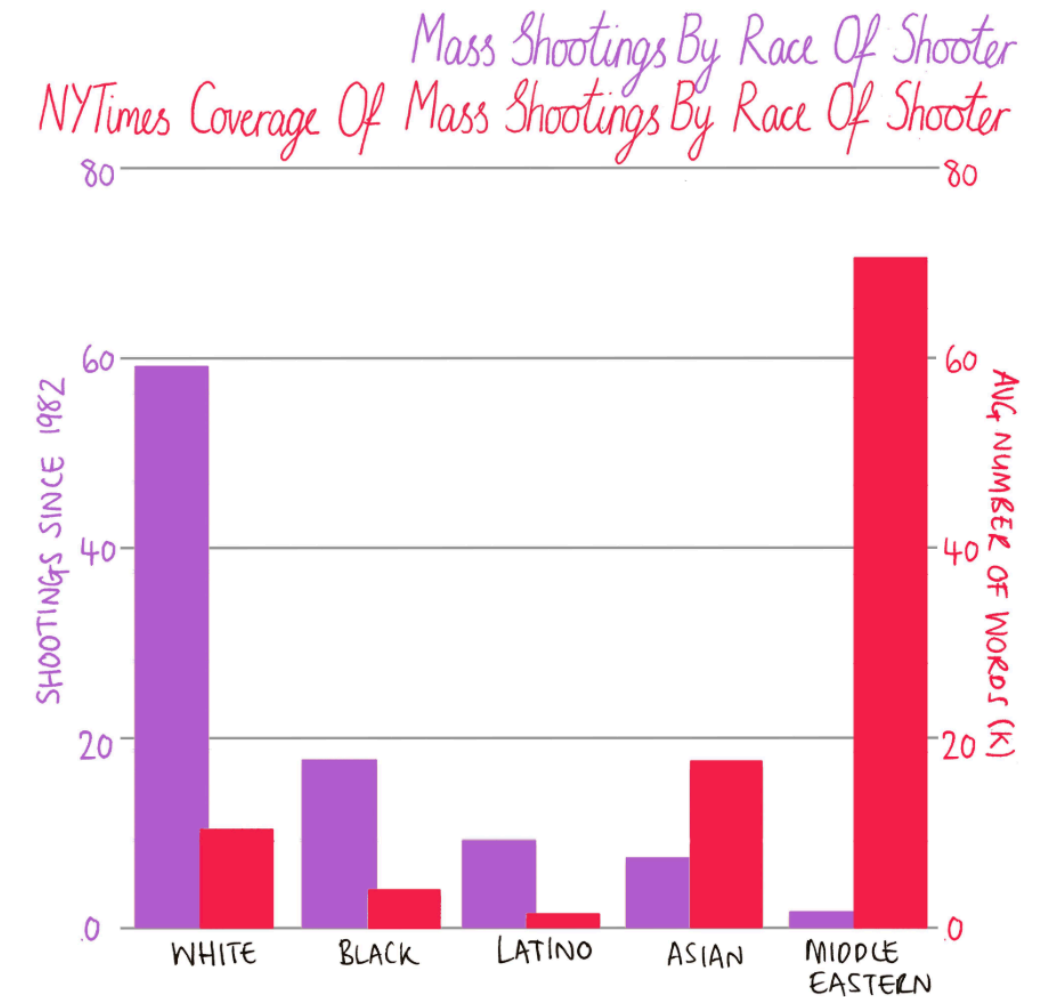
Separability vs integrality: Existing framework

Position
+ Hue (Color)

Size
+ Hue (Color)

Width
+ Height

Red
+ Green

Fully separable
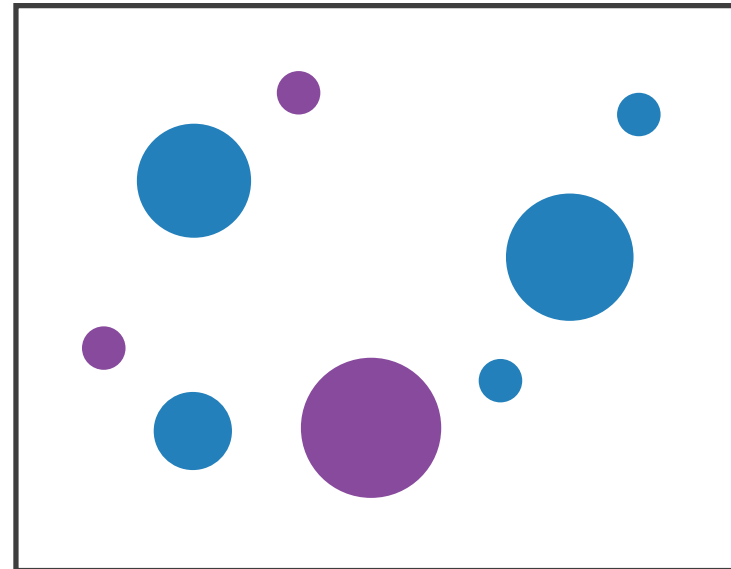
Some interference

Some/significant interference

Major interference

2 groups each

2 groups each

3 groups total: integral area
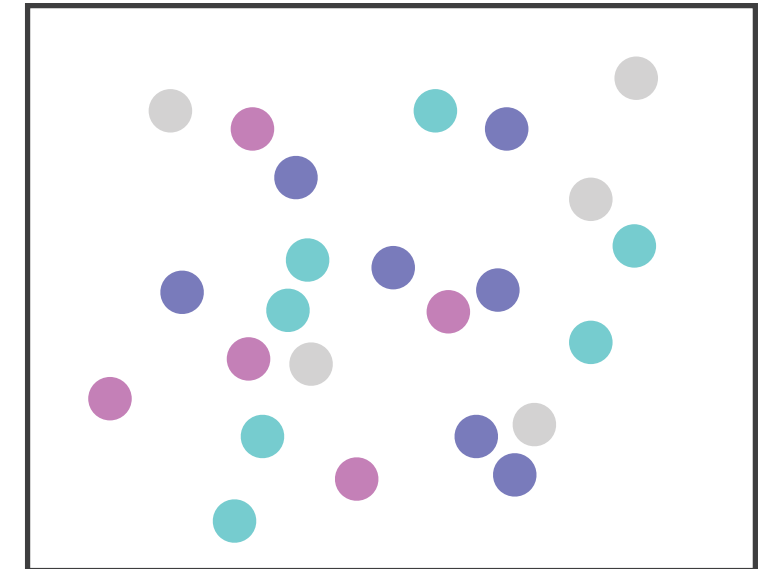
4 groups total: integral hue

Channel availability model augments, not replaces

# Channel availability model

- Channel availability
  - Encoded
    - clear meaning
  - Unavailable: which channels unavailable / taken?
    - general dependencies
    - idiom/algorithm design
  - Free: which channels free to encode another attribute?
    - without changing usability of existing encoding

- how does this idea relate to mark types?

Area marks: Rethinking

- area marks is a terrible name
  - other marks all have graphical area too
    - allowing us to encode with color
  - 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
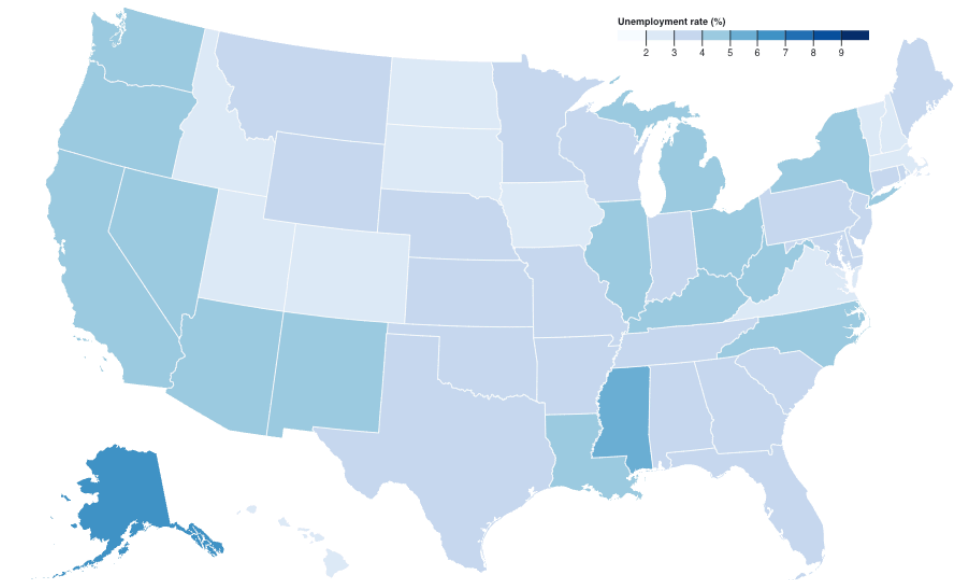
Interlocking (area) marks

- many channels locked down with interlocking marks
  - boundary encodes meaning
  - cannot change size, shape, position, orientation
  - mark type as a constraint
- 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/
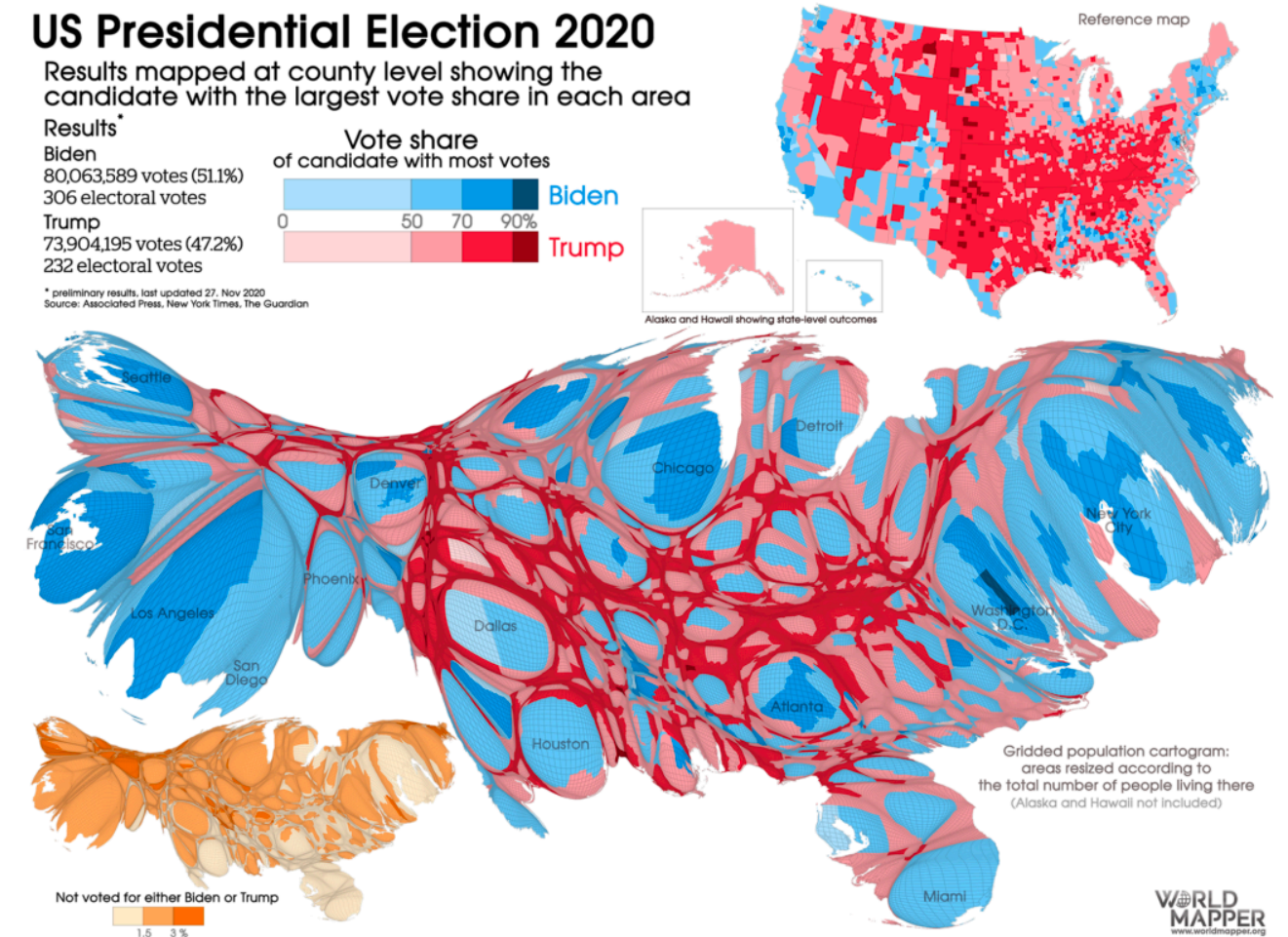
Interlocking marks: Non-spatial

- 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
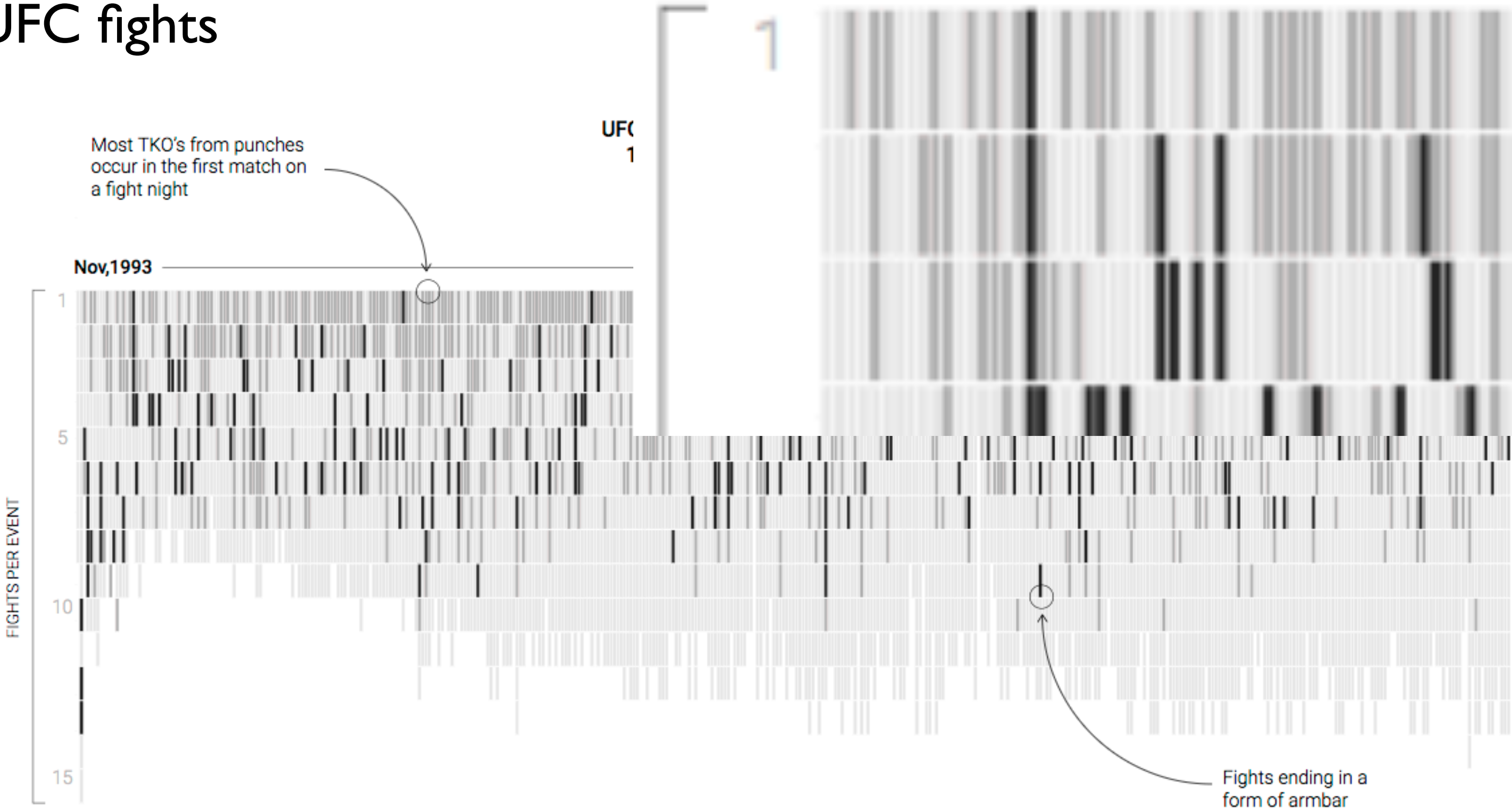   - individual mark boundaries have no intrinsic meaning
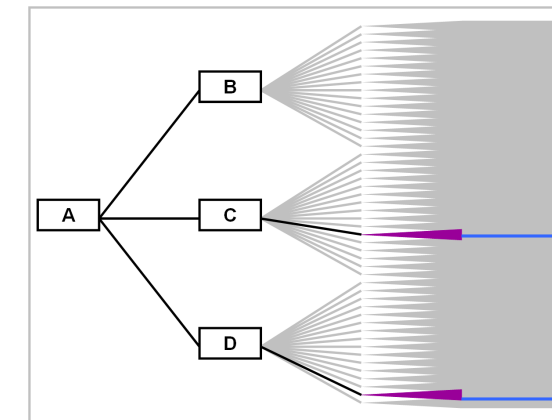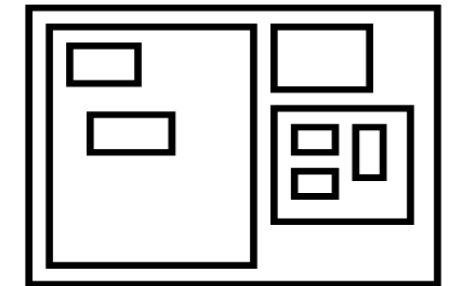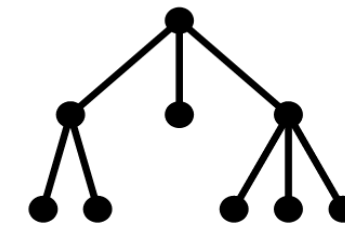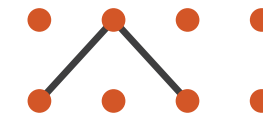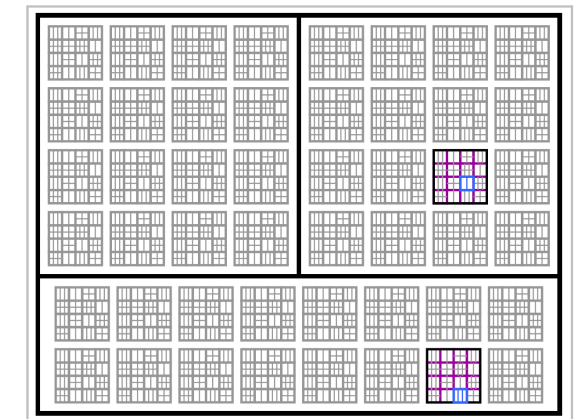
Node–Link Diagram   **Treemap**

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

Quiz: Name that mark

- C: UFC fights

Most TKO's from punches occur in the first match on a fight night

Fights ending in a form of armbar
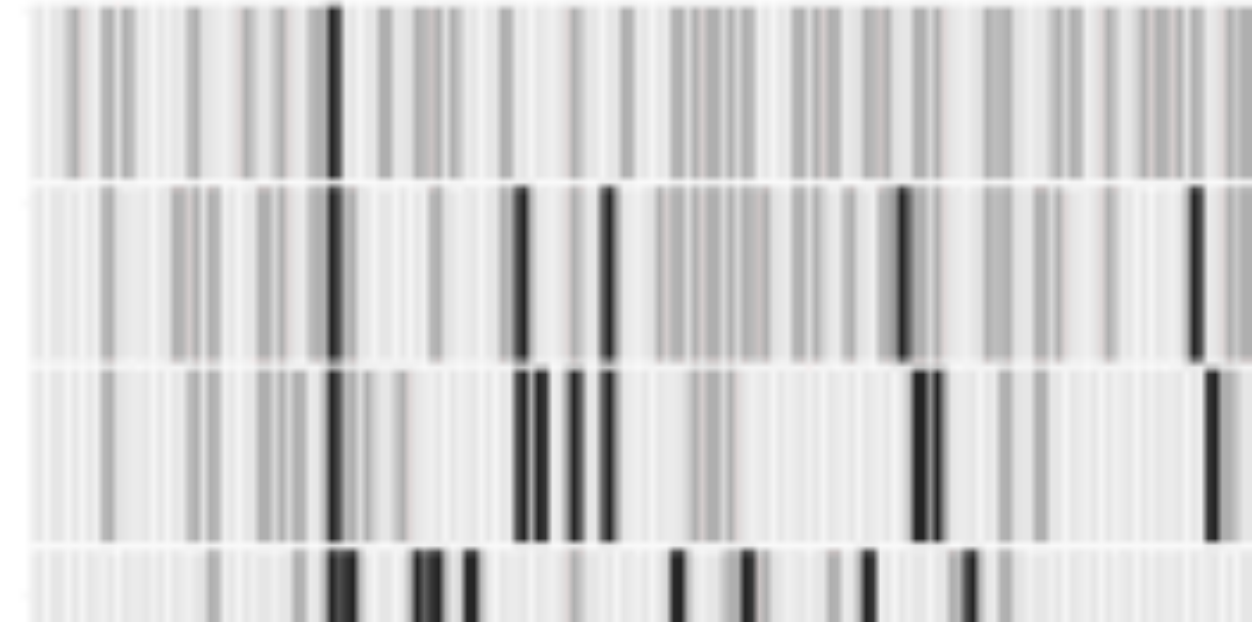
FIGHTS PER EVENT

Nov,1993

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

Nov,1993

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

Interlocking marks: Tile heatmaps

Correlation: Variables in Clustered Order

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

- 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
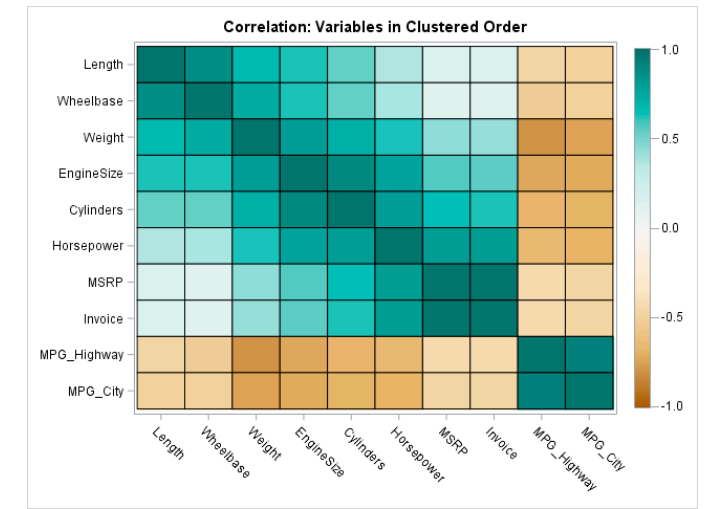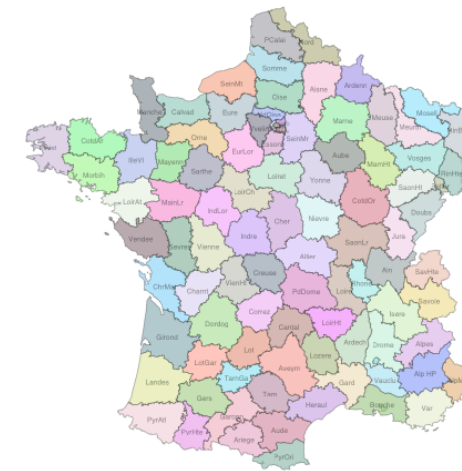
Spatially ordered treemaps.
Wood and Dykes.
IEEE TVCG (Proc. InfoVis) 14(6):1348-1355, 2008.
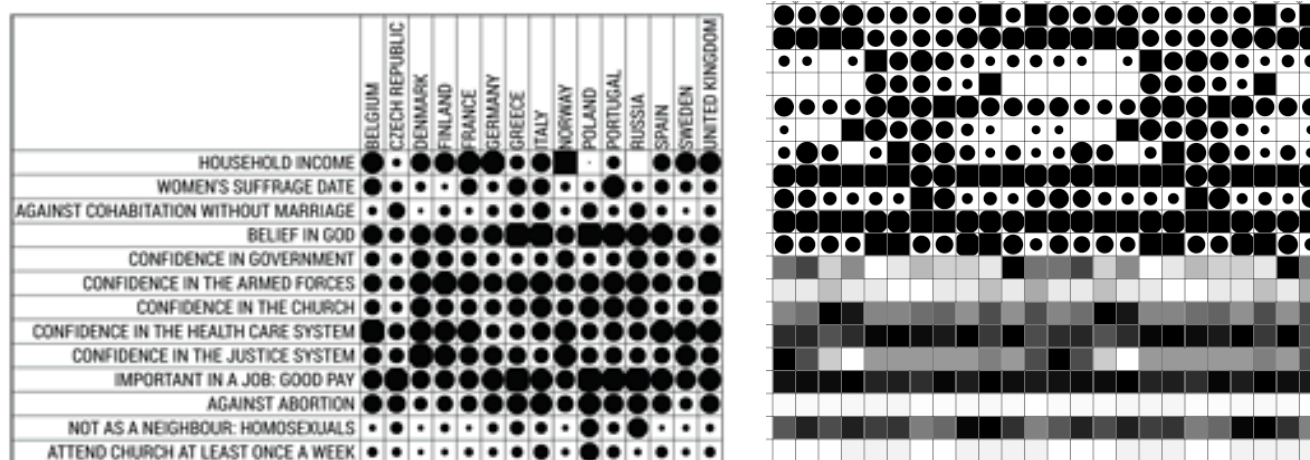
Bertifier. Charles Perin, Pierre Dragicevic, Jean-Daniel Fekete (2014).
Revisiting Bertin's Matrices: New Interactions for Crafting Tabular Visualizations. TVCG, VIS' 2014.

Interlocking marks: Circle packings

- interlocking marks
  - not size-coded point marks (with circle shape)
  - shape / position / orientation: equal & unavailable
 - more like treemap than scatterplot

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

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

https://www.arcgis.com/apps/StorytellingTextLegend/index.html?appid=b686a7679cb747e9825d1d1bb6b26046
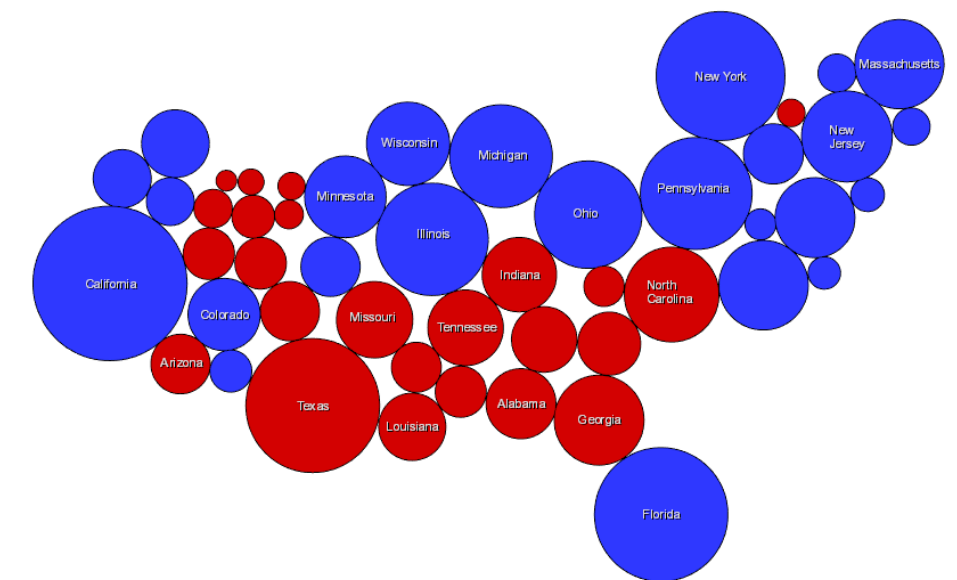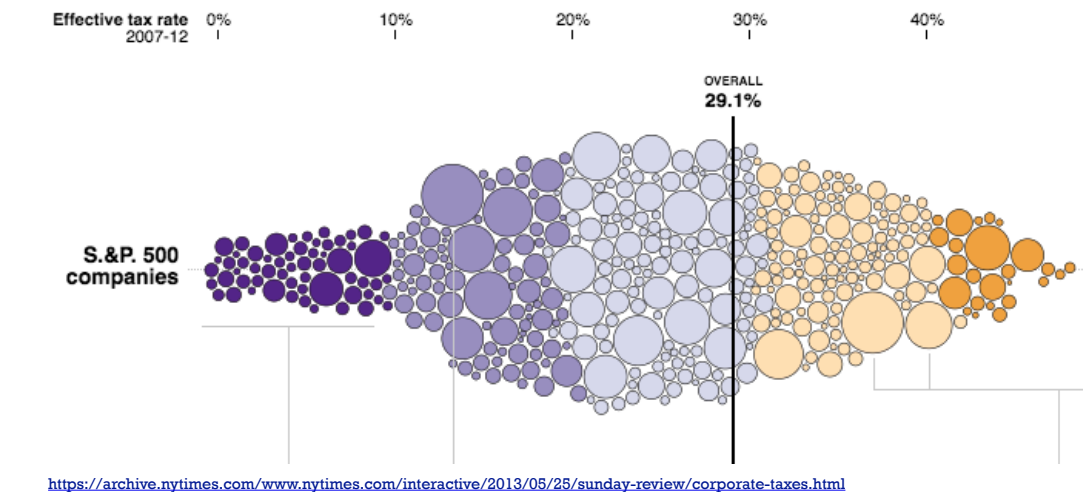
Interlocking? Election maps roundup

- yes interlocking
  - A: already covered
  - B/C: equal-area alg algorithm simplifies shape
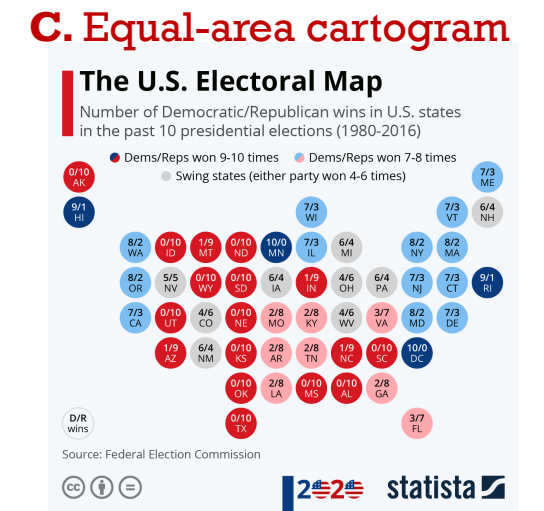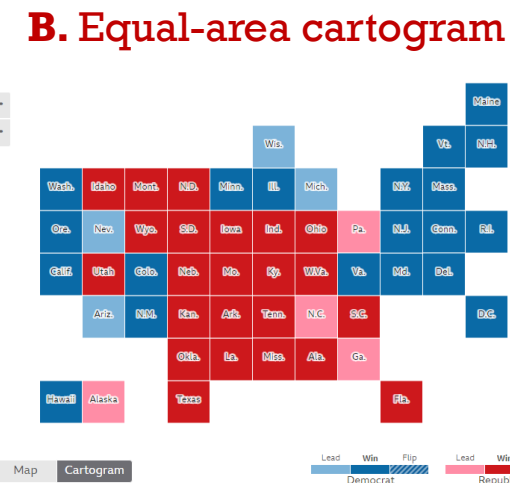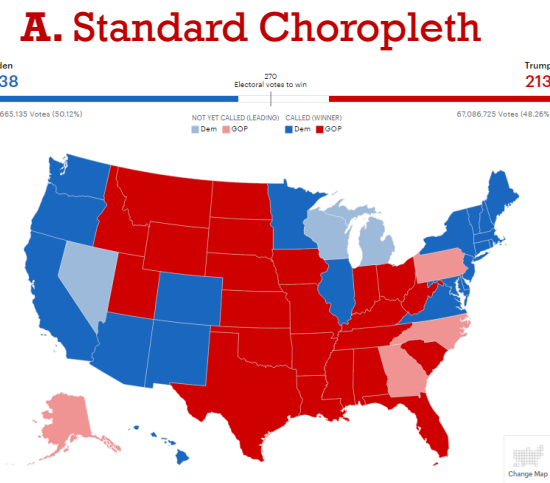
- yes interlocking
  - E/F multi-level
  - top level: interlocking marks
  - bottom level: square units
    - E/F: countability for votes
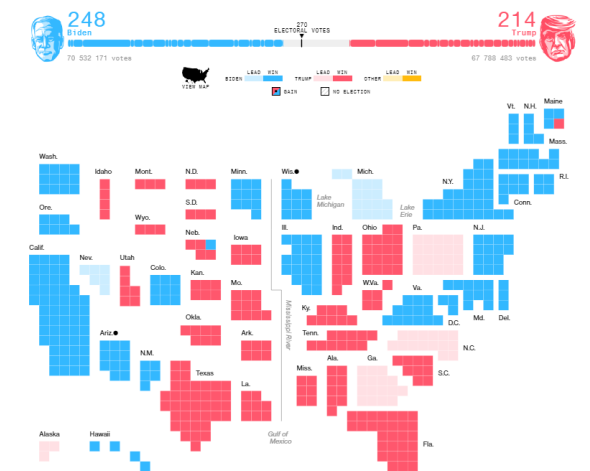   - F whitespace: population density

- no, point marks
  - size coded by area

A. Standard Choropleth

B. Equal-area cartogram

C. Equal-area cartogram

D. Area-proportional continuous cartogram

E. Units assembled into state-like shapes
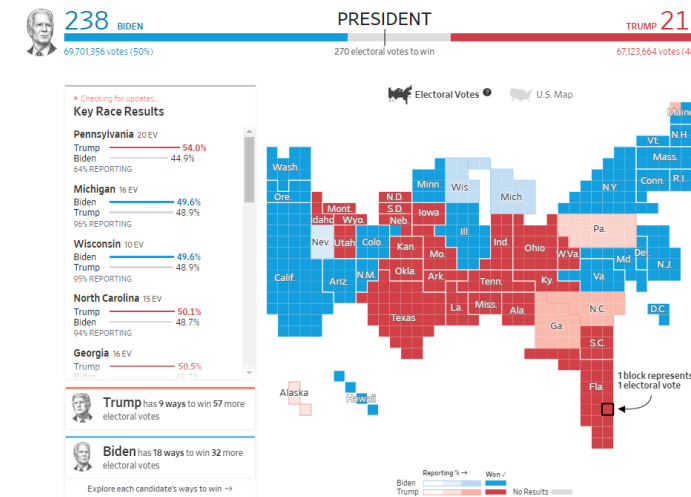
F. Units in state-like shapes spaced apart

E. Map with bubbles

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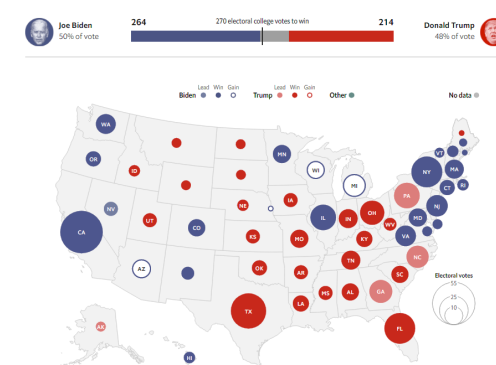
Unit encodings

- point marks
  - general case: quantity only!
  - position channel not necessarily in use
- often constrained by idiom
  - 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)
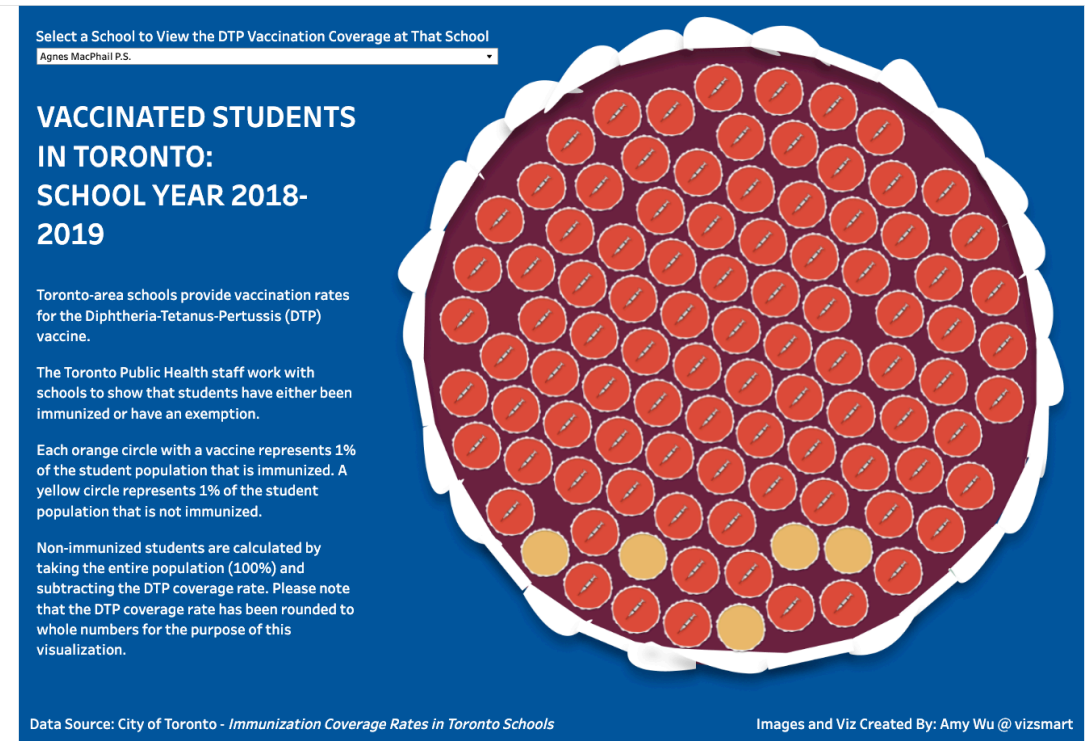
Wildfires in Canada burned this much land so far this year
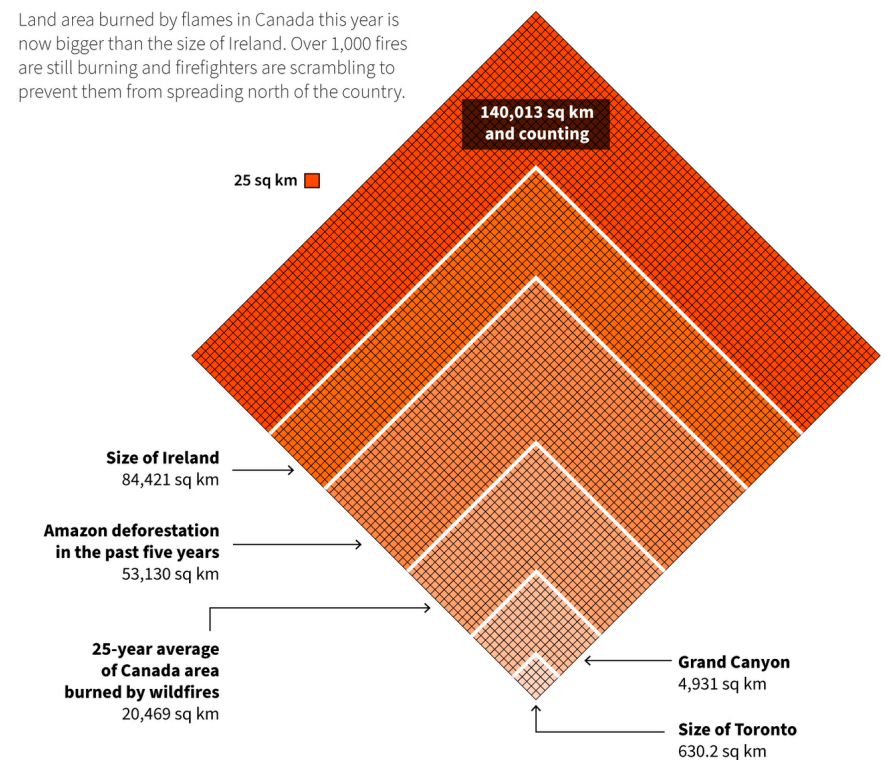
Distinguishing marks through constraints

- 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?
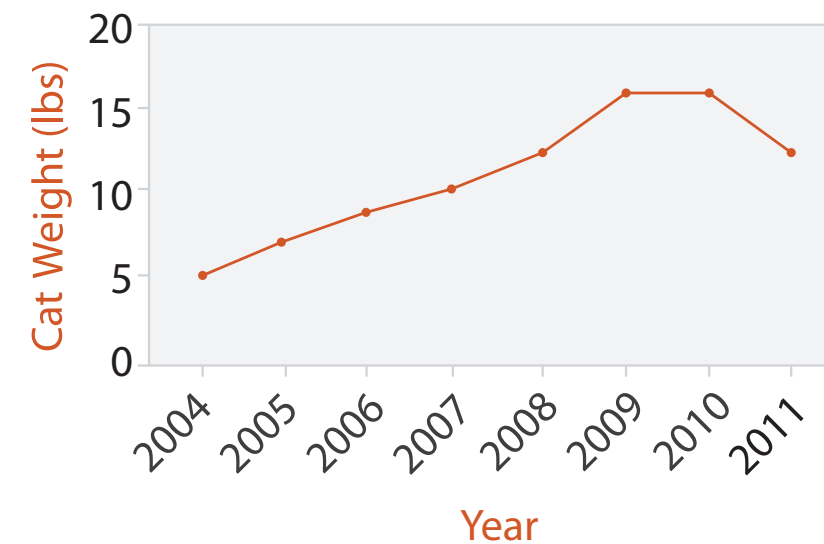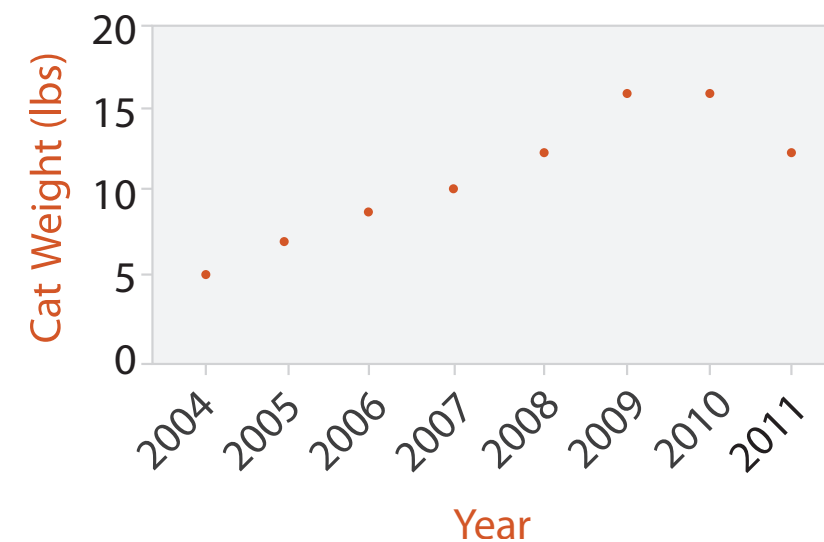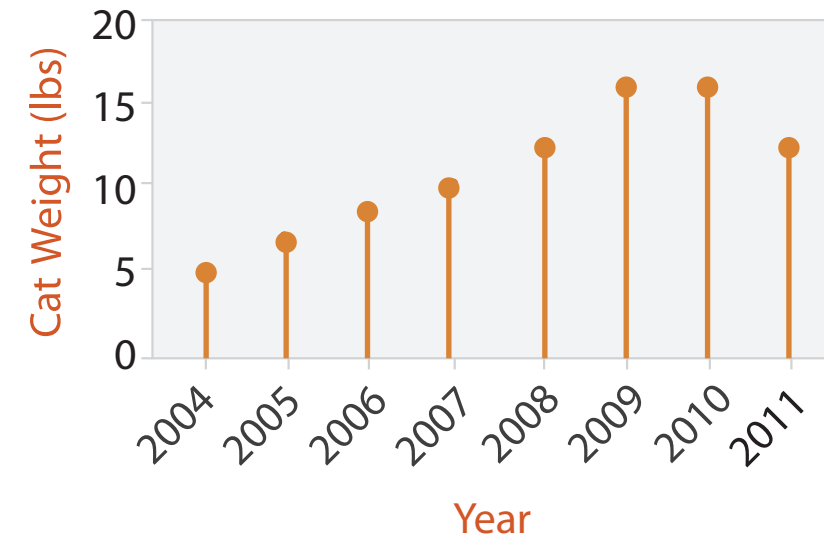
- so... what about line marks?
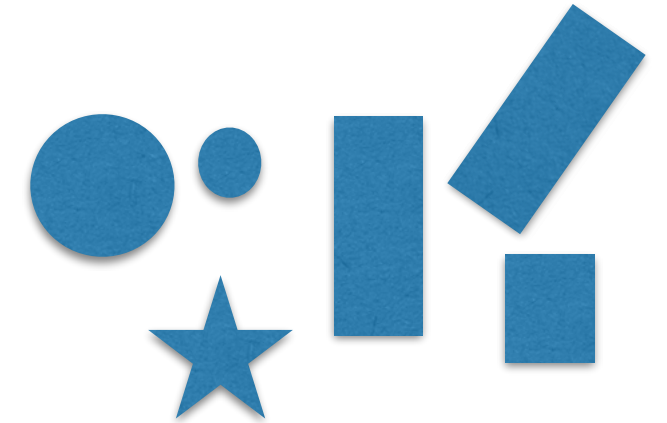
Line marks: Also confusing

- curved lines are not line marks!
  - model: one mark represents one item of data
  - line mark: express single quantitative attribute for one item with length

- also misnamed?
 - proposal: call them "segment" marks instead!
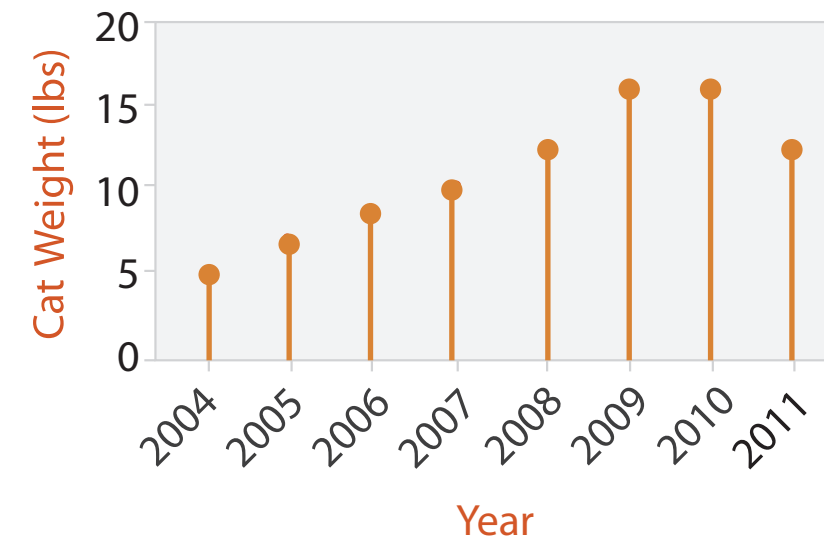
Line marks: Also confusing

- do line charts use line marks?
  - no
    - at least, not exactly like bar charts do
  - connection line segments between points
    - trend task: emphasize relationships between items
  - line chart encodes many items, not just one
    - with many piecewise-linear segments
    - or smoothed into curve
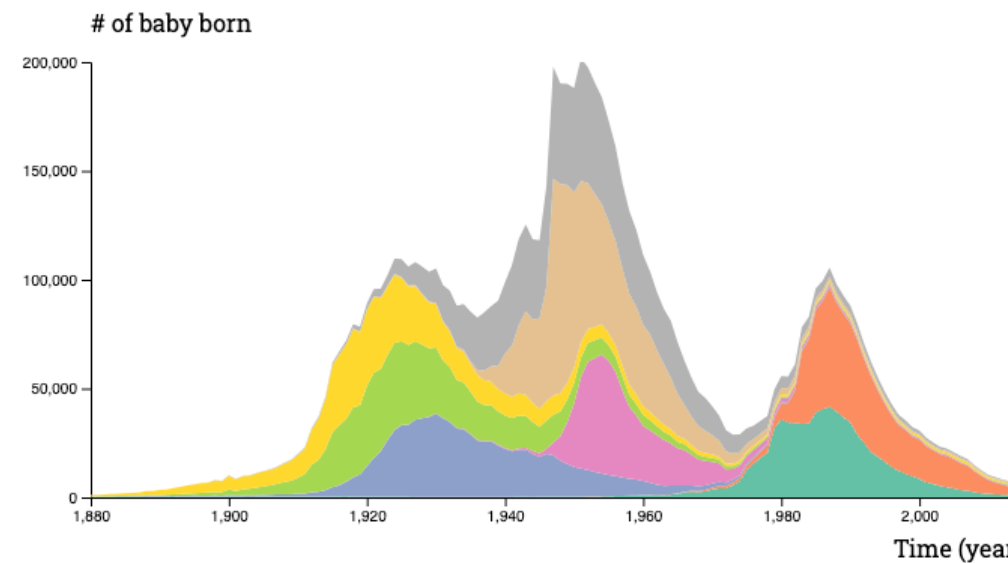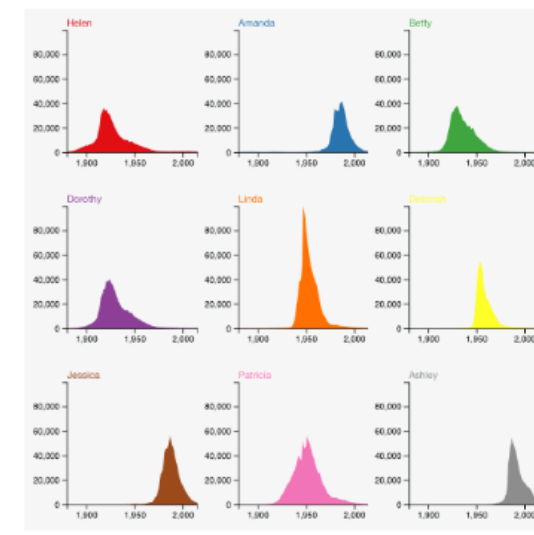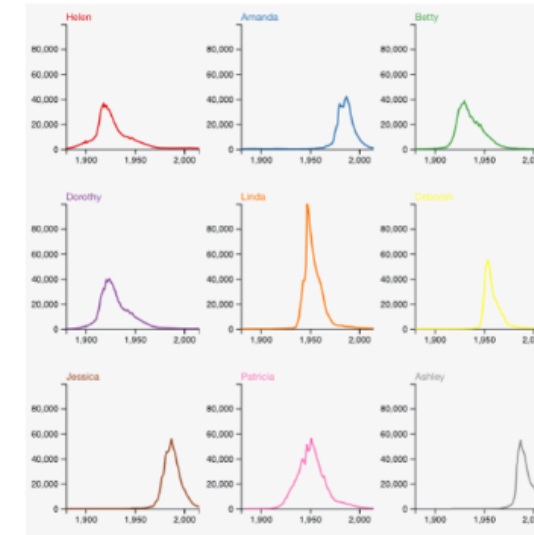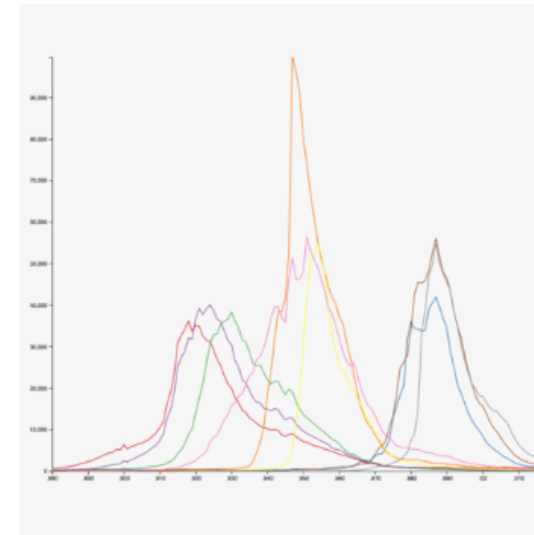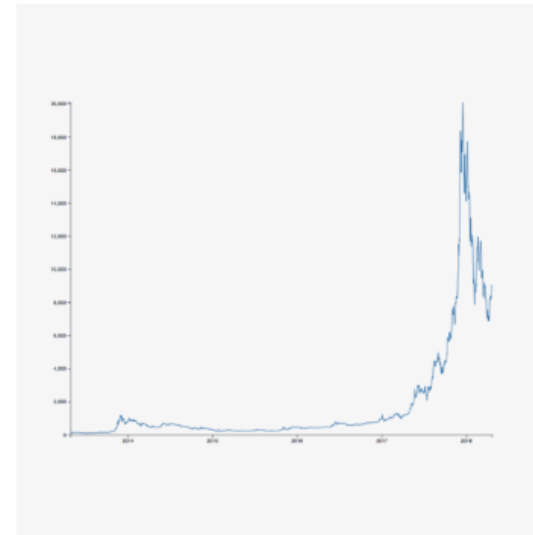
Line marks: Also confusing

- when does region inside curved "line" boundary act like an area mark?
  - can encode information within its boundary
    - color, even text
  - only if it's wide enough?
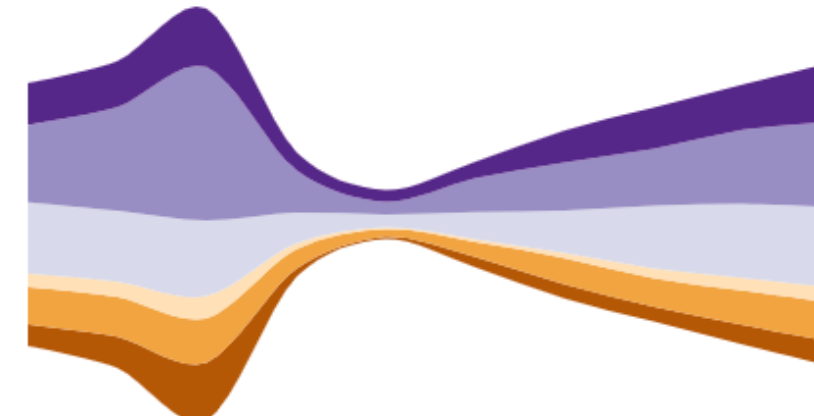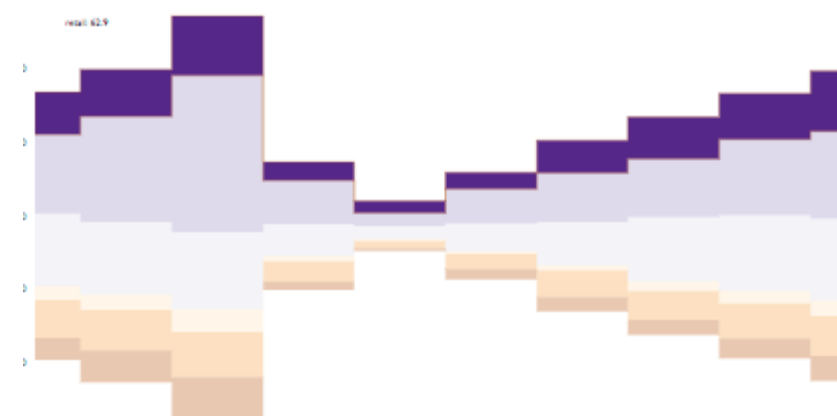 - or always!?
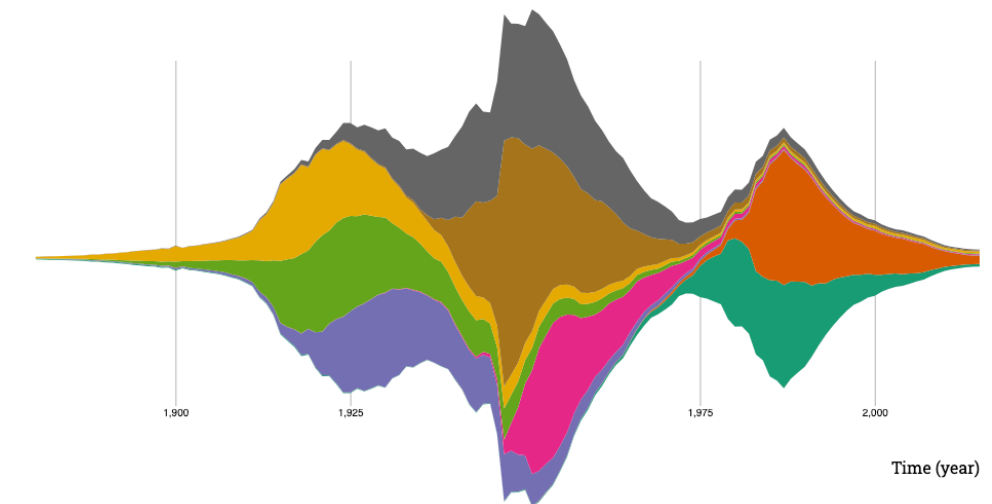- what about the region below it?...
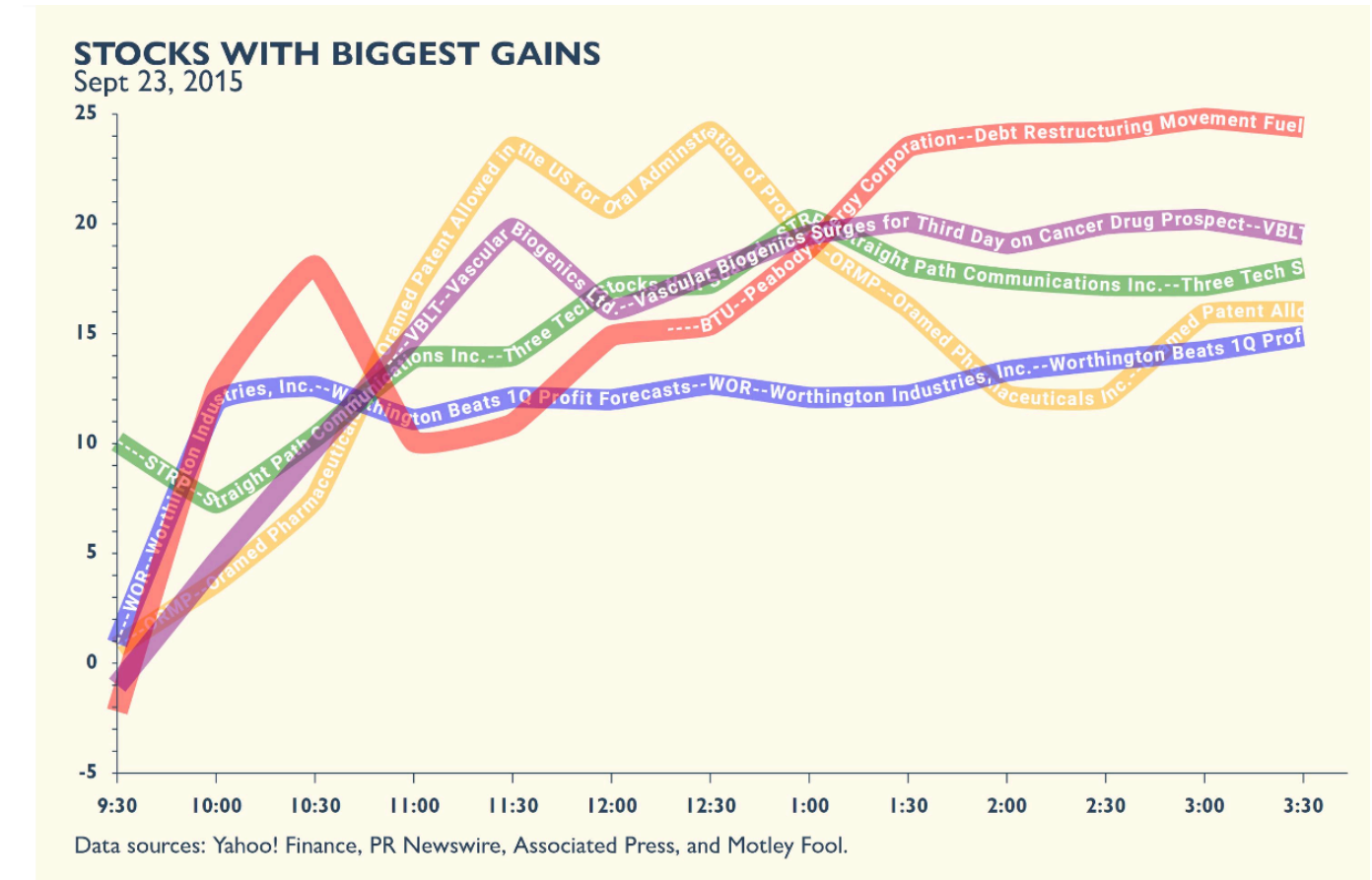
Brath. Visualizing with Text (Fig 7.14). CRC Press, 2020.

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).]
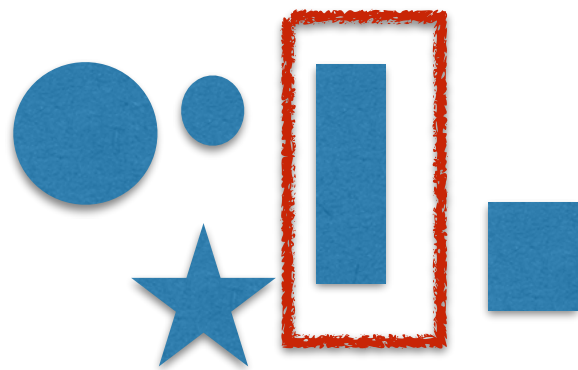
Line marks: what good are they?

- are line/segment marks an unnecessary construct?
  - how does segment differ from "length-coded point mark"?

  - is segment just two point marks in a trenchcoat???
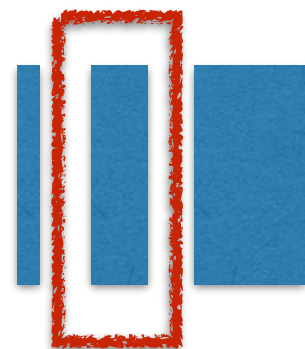   - two position-coded point marks, connected by segment
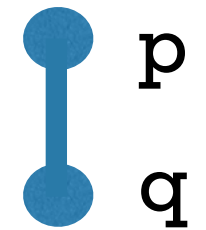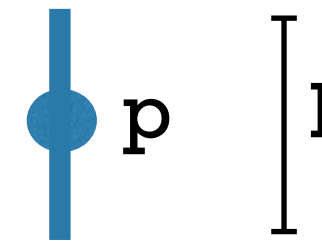
- radical proposal: eliminate line marks as a separate mark type!
  - merge lines and points together, into "unconstrained" marks

➔ Points

➔ Lines
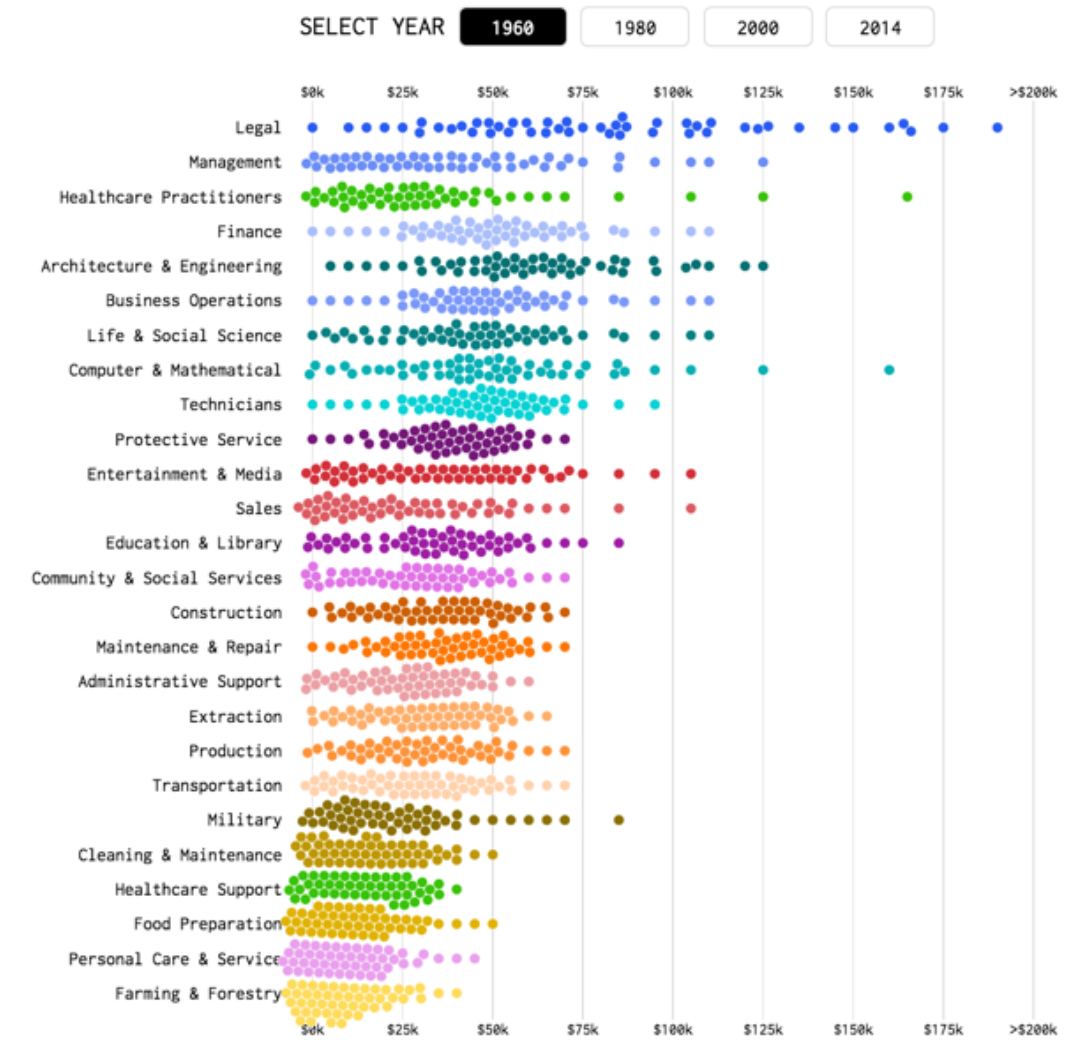
Many, many questions

- including
  - Size-coded point marks vs area marks?
  - Area marks vs area channel?
  - What kind of marks are in
    - a tile heatmap?
    - a circle packing?
    - a cartogram?
    - a multi-level thingie with units?
  - Line mark: line segment vs curved path?
    - Do line charts use line marks?
  - Line chart boundaries vs filled area charts interiors?
  - Length-coded point marks vs line marks?

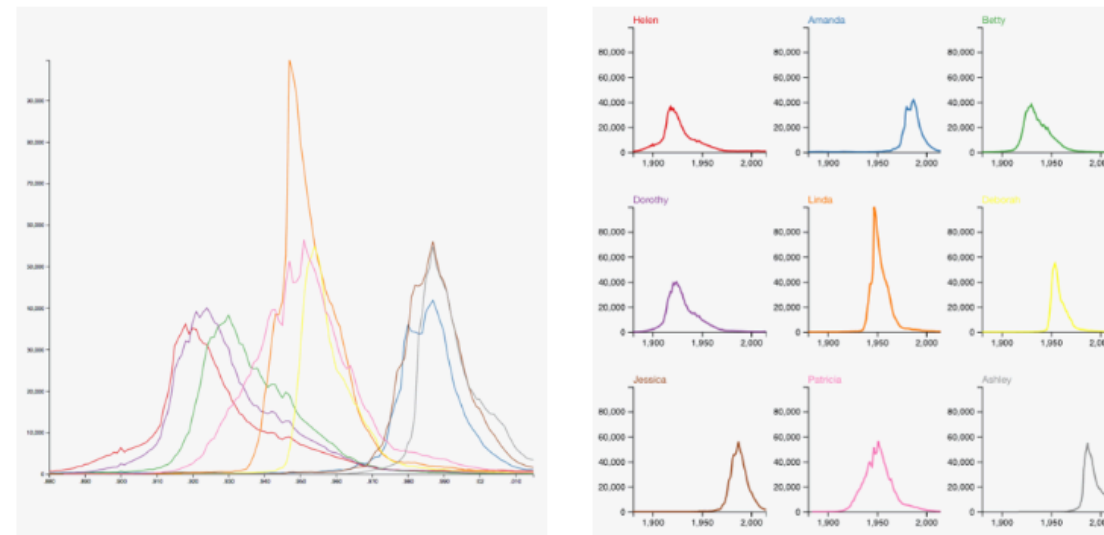# Alternative models: preliminary steps towards answers?

- Old mark/channel model: geometry-based marks
  - 0D points, 1D lines, 2D areas, 3D volumes
- Alternative mark/channel model
  - channel-based analysis: channel availability model
    - Encoded, Unavailable, Free
  - mark-based analysis: mark constraint model
    - Unconstrained (points), Interlocking (areas)

- what best helps us think and reason about design space of visual encoding?
  - combination of both? just one?
  - another alternative?
    - are there other interesting emergent properties arising from bottom-up channel analysis?
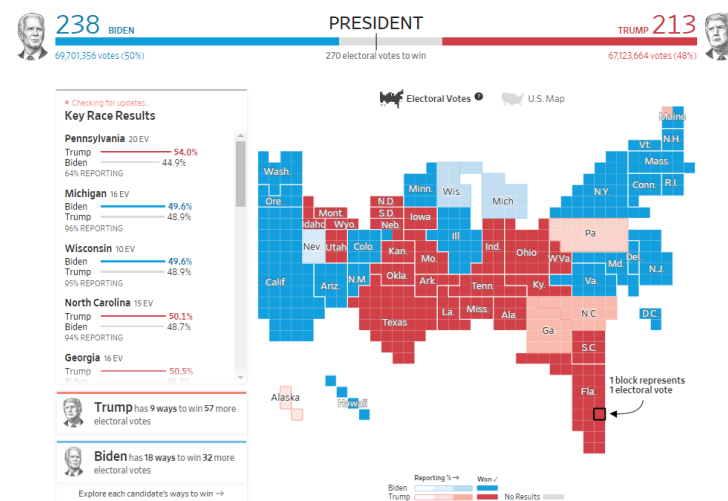
Beyond marks and channels

- multi-level analysis requires larger design space

  - small multiples: juxtaposed views

    - vertical position within row: algorithmic, avoid occlusion

    - vertical position across rows: encodes job type attribute

  - superposition:
    layered views

  - nesting:
    multi-scale
    views / glyphs

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

https://d3-graph-gallery.com/line.html

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

Rethinking book design space: Visualization Analysis & Design 2e
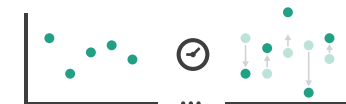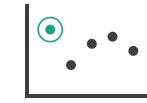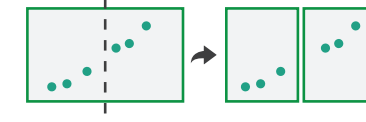
More stuff

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#mit24
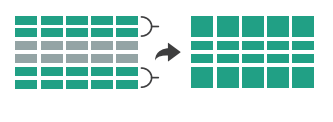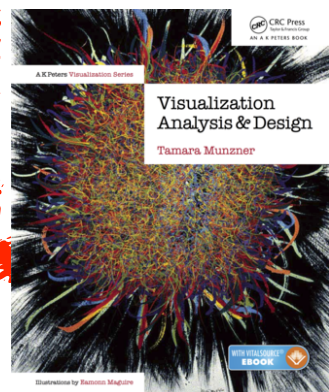
  – more questions? thoughts on answers??

- 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
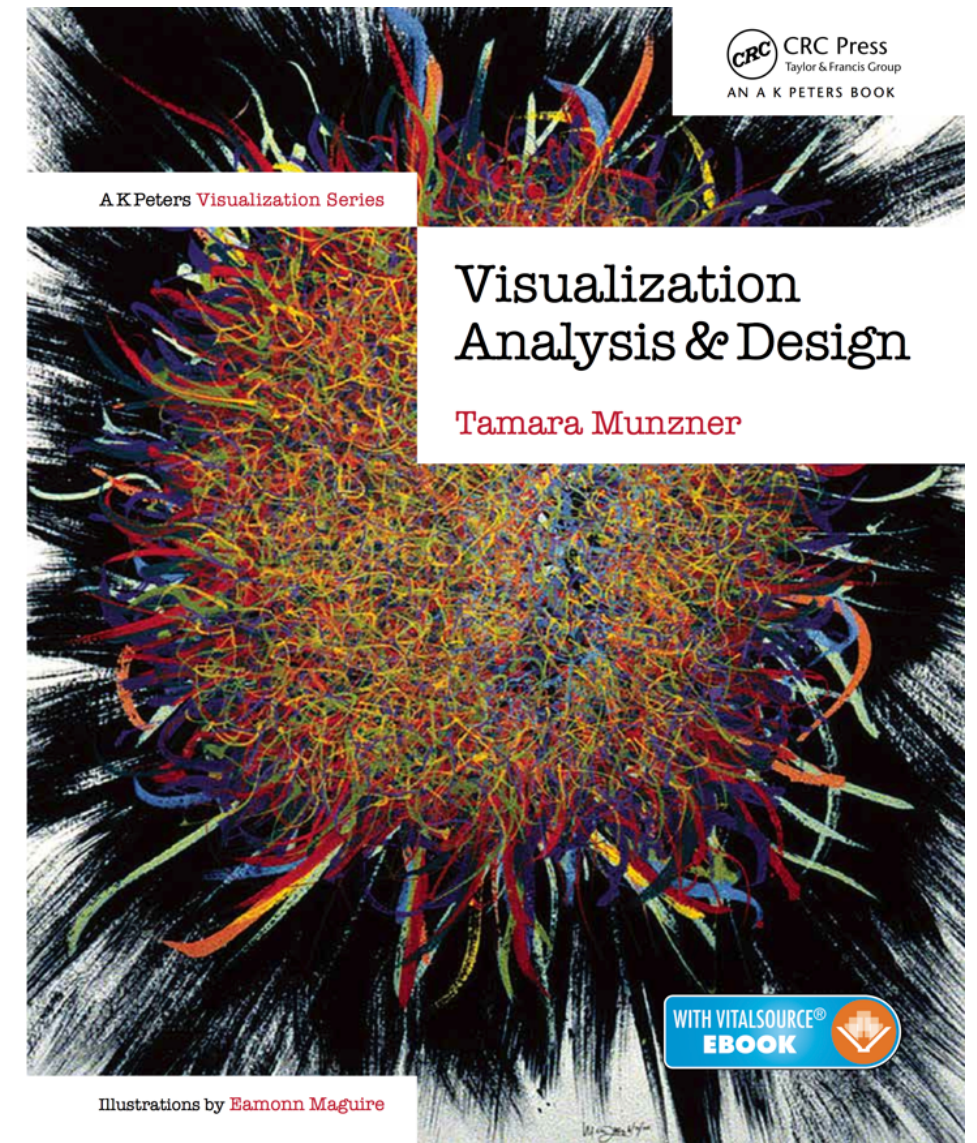
Visualization Analysis and Design. Munzner.
CRC Press, AK Peters Visualization Series, 2014.

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@tamaramunzner