Visualization in Practice

Laura Garrison, University of Bergen
laura.garrison@uib.no

ICTP Workshop 2022
2. December 2022

What?

Datasets

Data Types

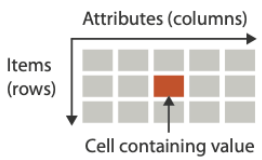
- Items
- Attributes
- Links
- Positions
- Grids

Data and Dataset Types

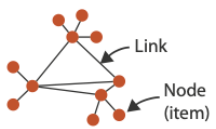
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

Dataset Types

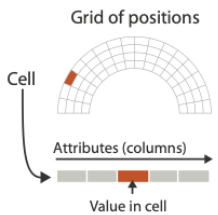
- Tables



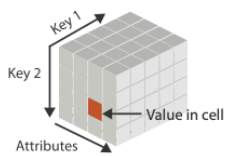
- Networks



- Fields (Continuous)



- *Multidimensional Table*



- *Trees*

- Geometry (Spatial)

Dataset Availability

- Static

- Dynamic

Attributes

Attribute Types

- Categorical

- Ordered
  - *Ordinal*

  - *Quantitative*

Ordering Direction

- Sequential

- Diverging

- Cyclic

What?

Why?

Actions

Analyze

- Consume
  - Discover
  - Present
  - Enjoy
- Produce
  - Annotate
  - Record
  - Derive

Search

	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore

Query

- Identify
- Compare
- Summarize

Targets

All Data

- Trends
- Outliers
- Features

Attributes

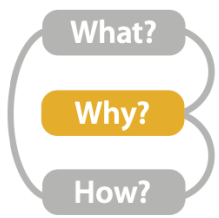
- One
  - Distribution
  - Extremes
- Many
  - Dependency
  - Correlation
  - Similarity

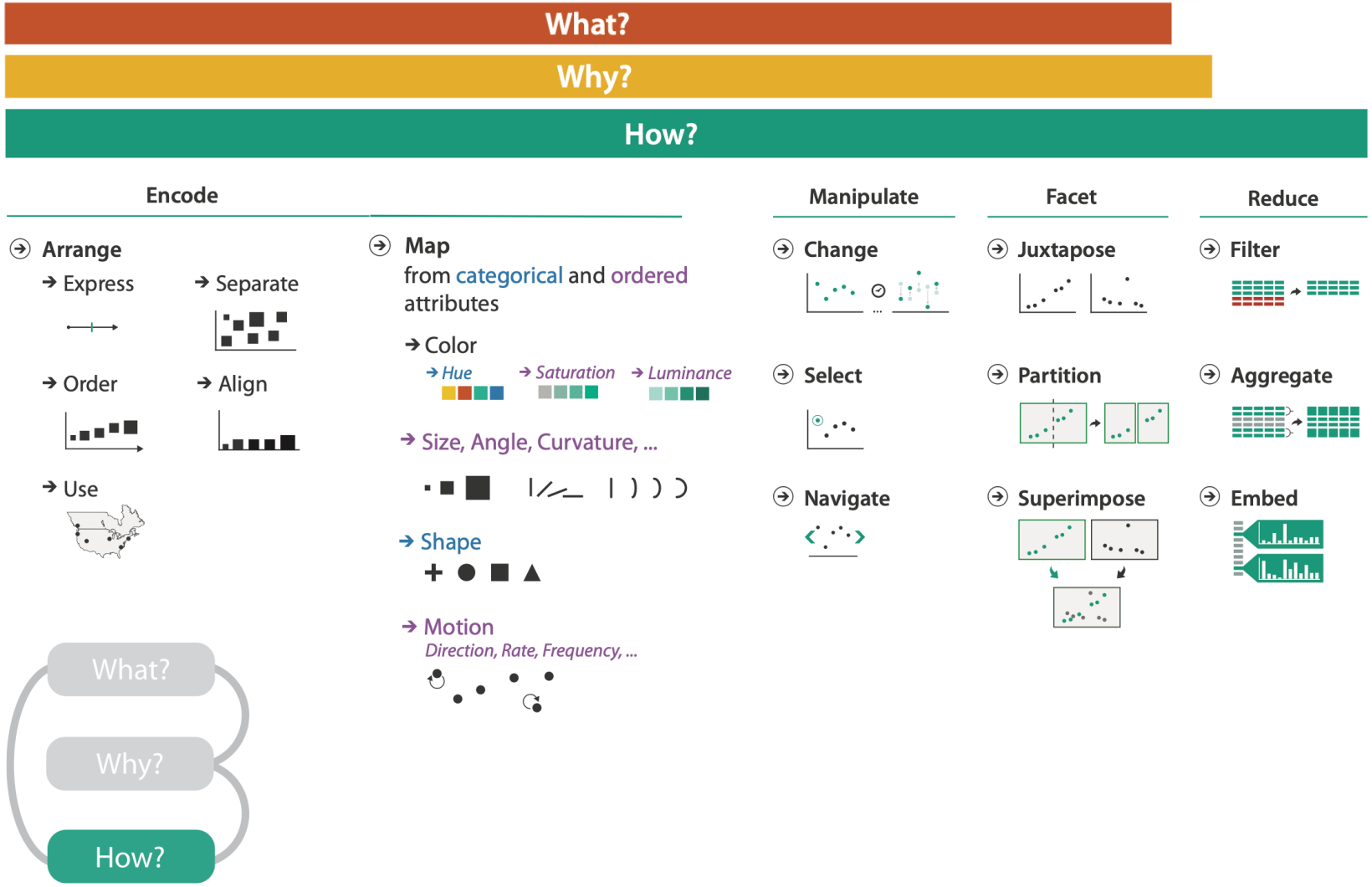
Network Data

- Topology
- Paths

Spatial Data

- Shape





Data abstraction -> Task abstraction -> Visual + Interaction Encoding

Data representation has an impact on interpretation

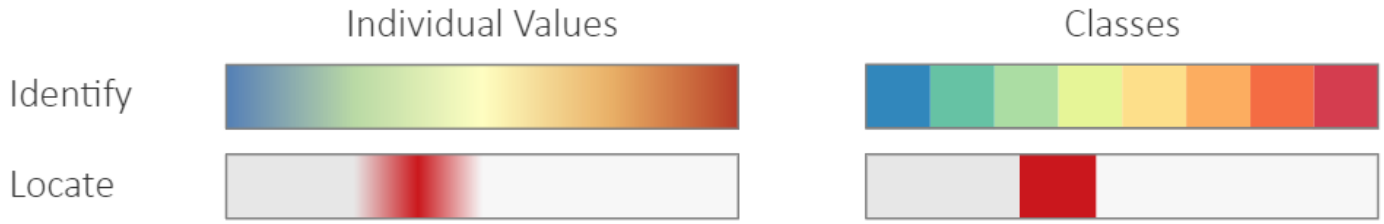
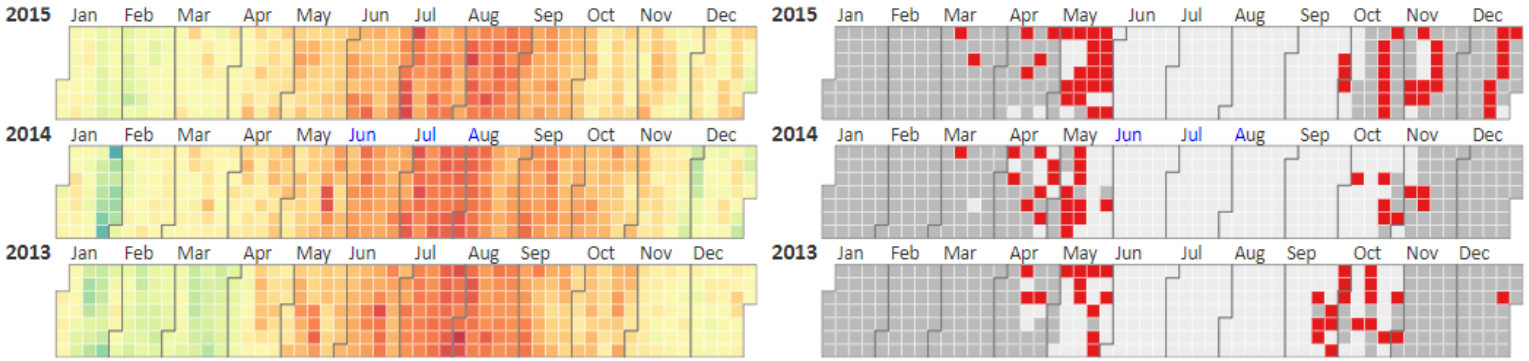


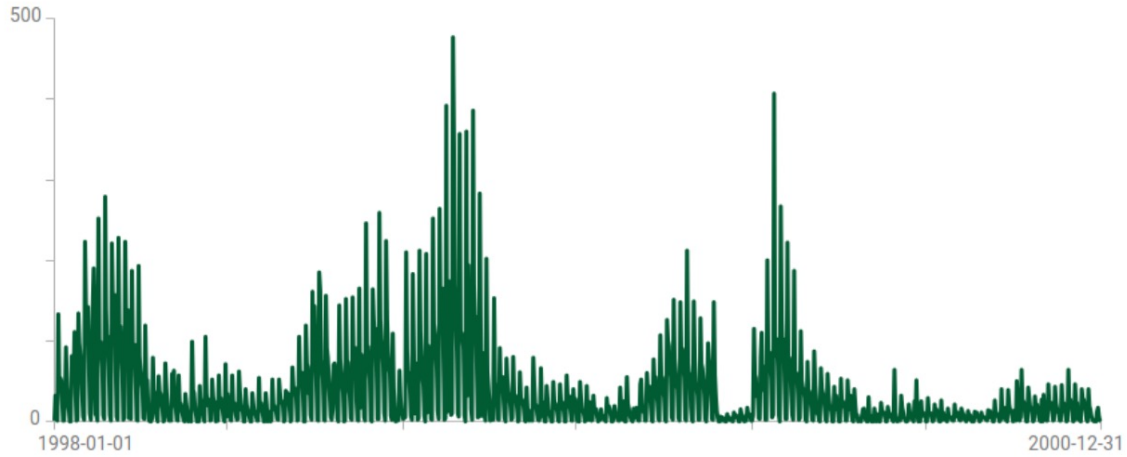
Figure 3.4 Color maps for identifying and locating values and classes.



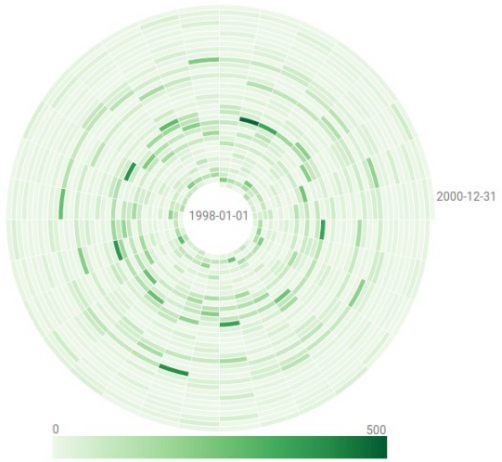
(a) Color coding for identification tasks. (b) Color coding for location tasks.

Figure 3.5 Applying the color maps from Figure 3.4 to temperature data. Adapted from bl.ocks.org/mbostock/4063318.

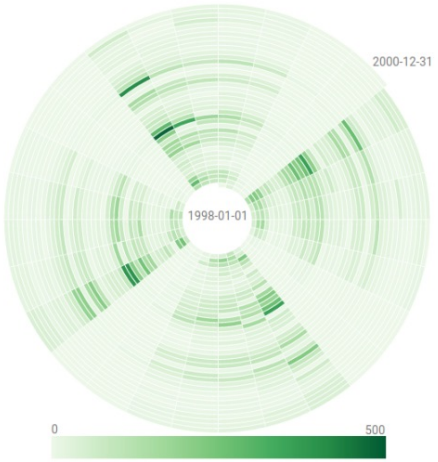
Data representation has an impact on interpretation



(a) Line plot.



(b) Spiral plot (cycle length 32 days).



(c) Spiral plot (cycle length 28 days).

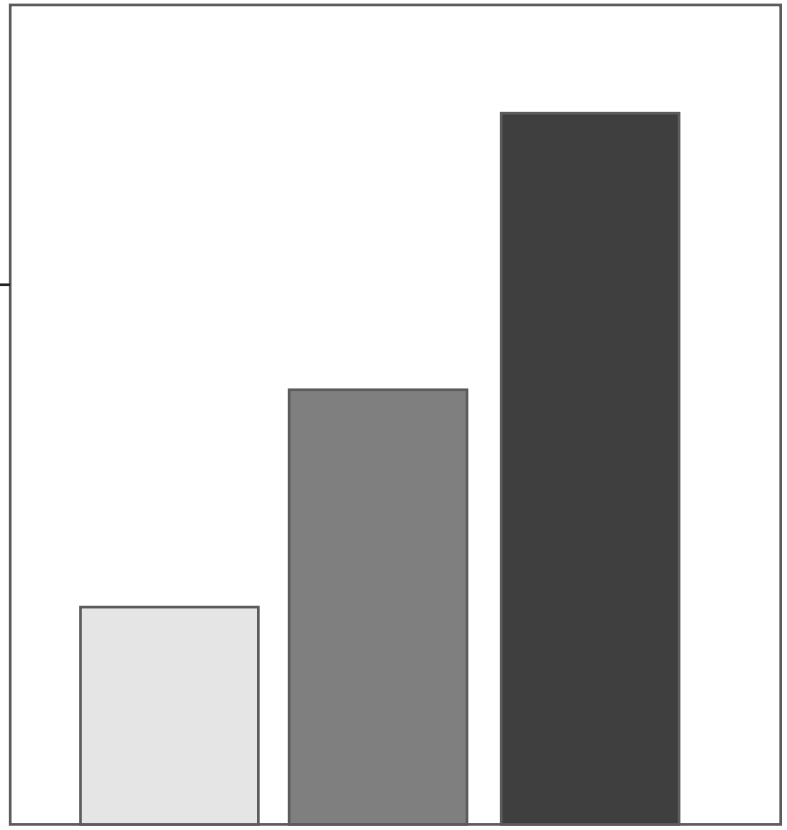
Tominski, T., Schumann, H. (2020). Interactive Visual Data Analysis. AK Peters Visualization Series, CRC Press, Visualization Series. Chp 3.

Tuning visual mappings

Mapping Relations

- 1 : 1
- 1 : n
- n : n

- no n : 1 (meaning of visual representation difficult)



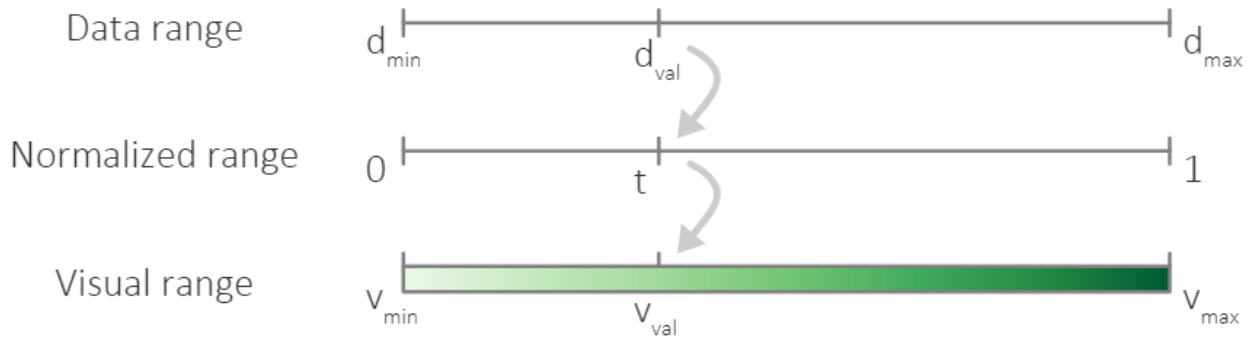
1:n = length + luminance

Sends stronger message but uses up channels

Tominski, T., Schumann, H. (2020). Interactive Visual Data Analysis. AK Peters Visualization Series, CRC Press, Visualization Series. Chp 3.

Mapping Mechanics

- Linear mapping $t = \frac{d_{val} - d_{min}}{d_{max} - d_{min}}$
  - standard approacn – min-max value of data mapped to the entire spectrum of a channel



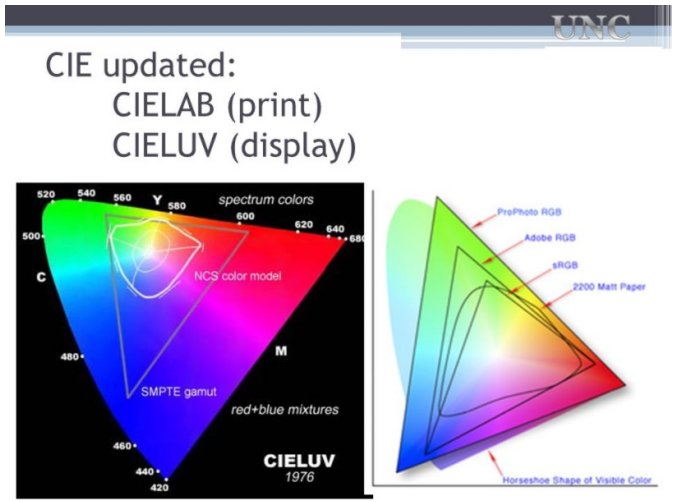
- Log mapping $t = \frac{\log(d_{val} - d_{min})}{\log(d_{max} - d_{min})}$
  - stretches out smaller values
- Individual vs aggregate values

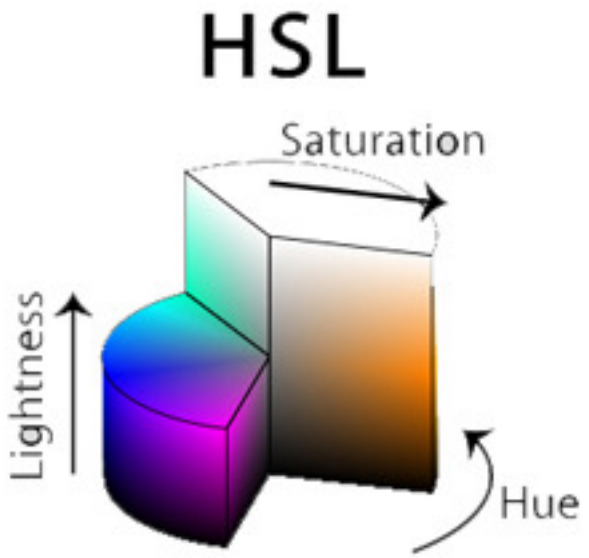
About color...

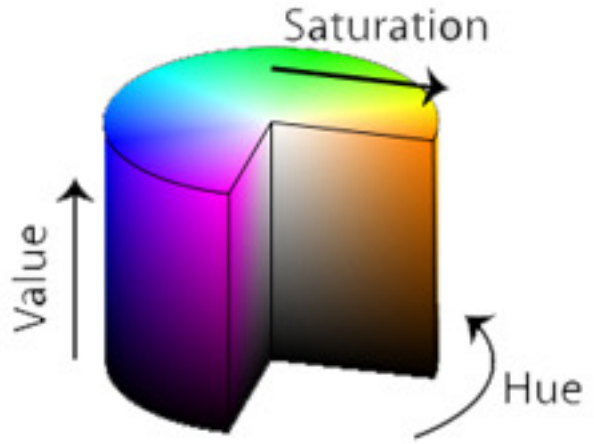
- Different color systems

CMYK - Subtractive Color

RGB - Additive Color

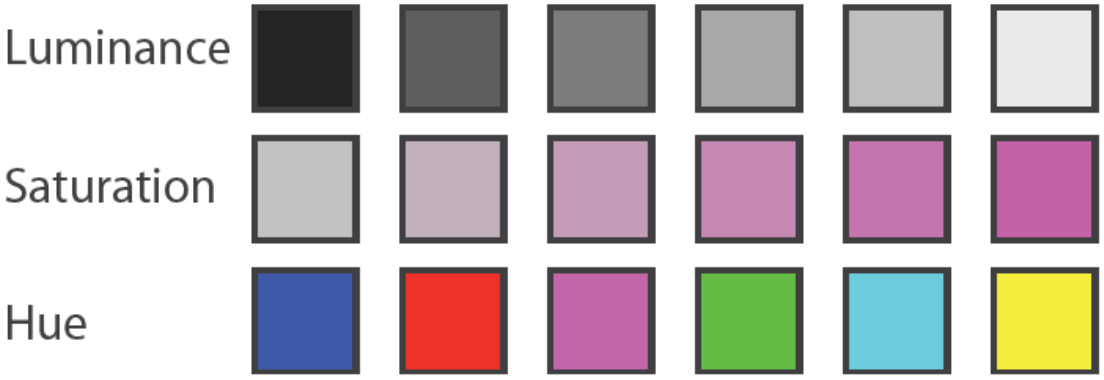






About color...

Decomposed into three channels:



Ordered → Magnitude

Ordered → Magnitude

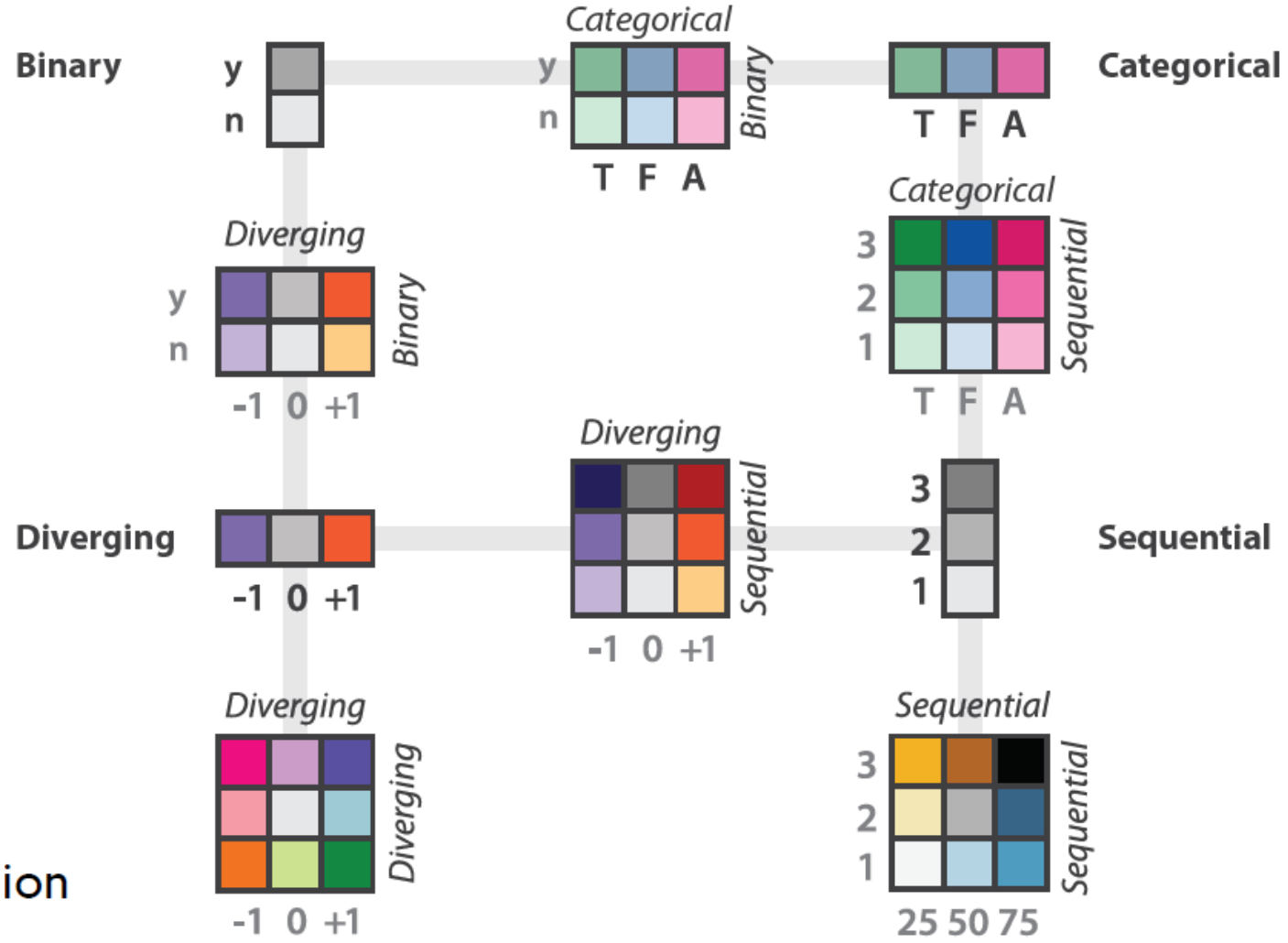
Categorical → Identity

About color...

- Categorical

- Ordered
  - *Sequential*
  - *Diverging*

- Bivariate



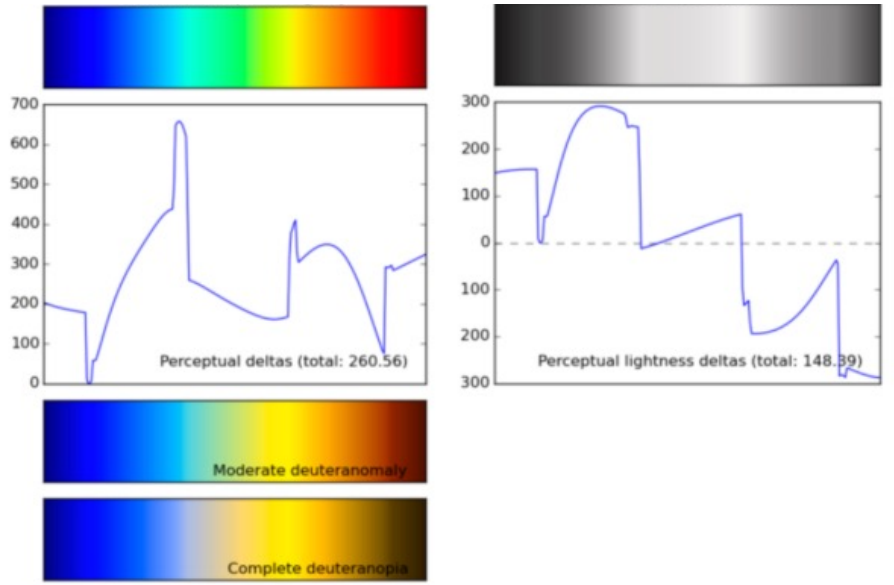
Color scheme options available with Altair (Python version of Vega-Lite):
https://vega.github.io/vega/docs/schemes/

after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

About color...

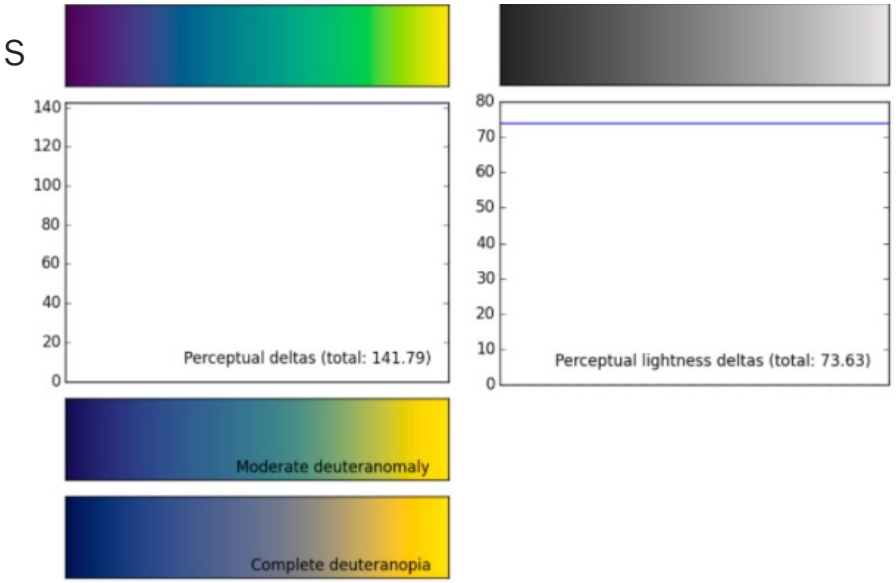
- Perceptual uniformity and ordering
  - Rainbow map introduces artificial structures ☹
- Monotonically increasing luminance

Rainbow



non-uniform perceptual changes between colors in rainbow (jet) map.

Viridis



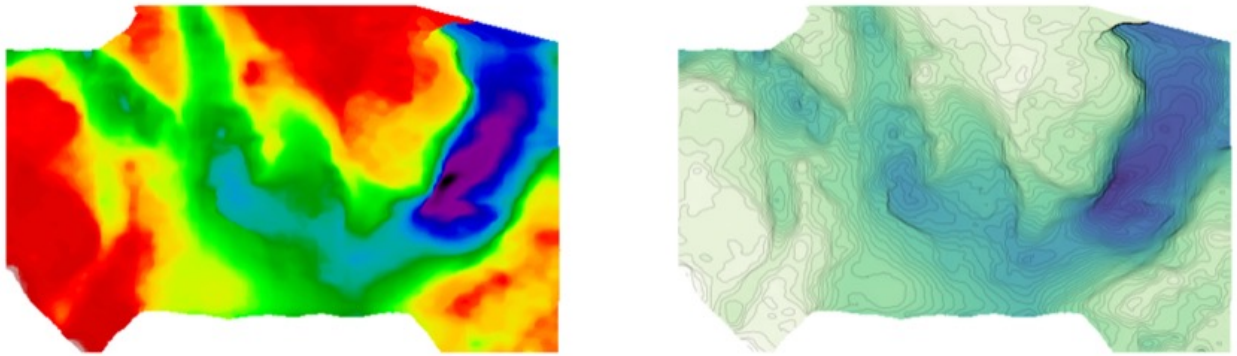
If you really want the Rainbow, consider using **Turbo**.

More info: https://ai.googleblog.com/2019/08/turbo-improved-rainbow-colormap-for.html

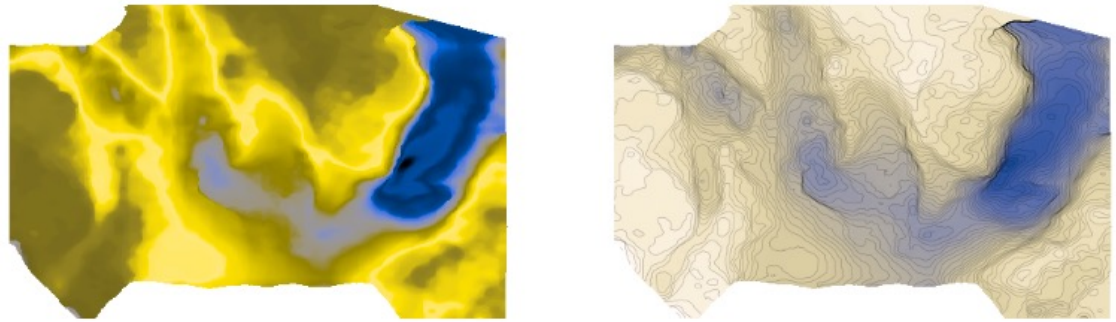
https://gorelik.net/2020/08/17/what-is-the-biggest-problem-of-the-jet-and-rainbow-color-maps-and-why-is-it-not-as-evil-as-i-thought/

About color...

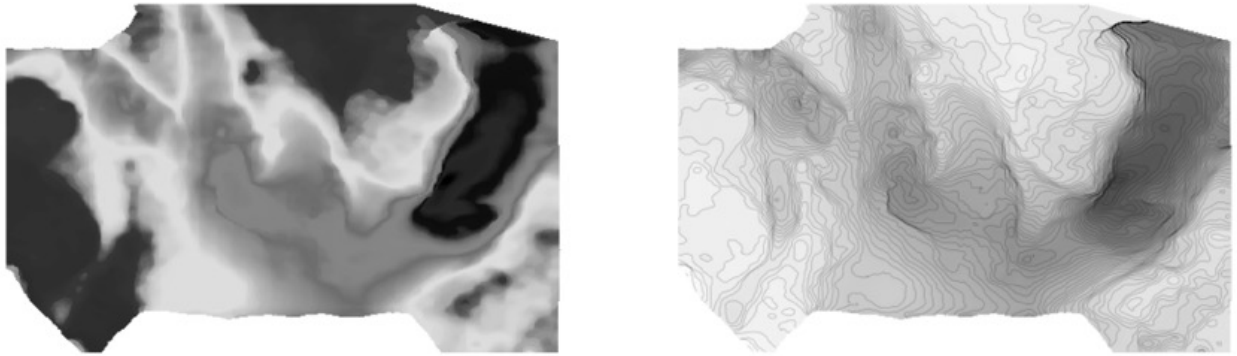
- Let's look at this with real data...
- Nova Scotia seafloor depth
  - rainbow (left) vs YIGnBu (right)



Let's check that it is indeed colourblind-safe and grey-safe:



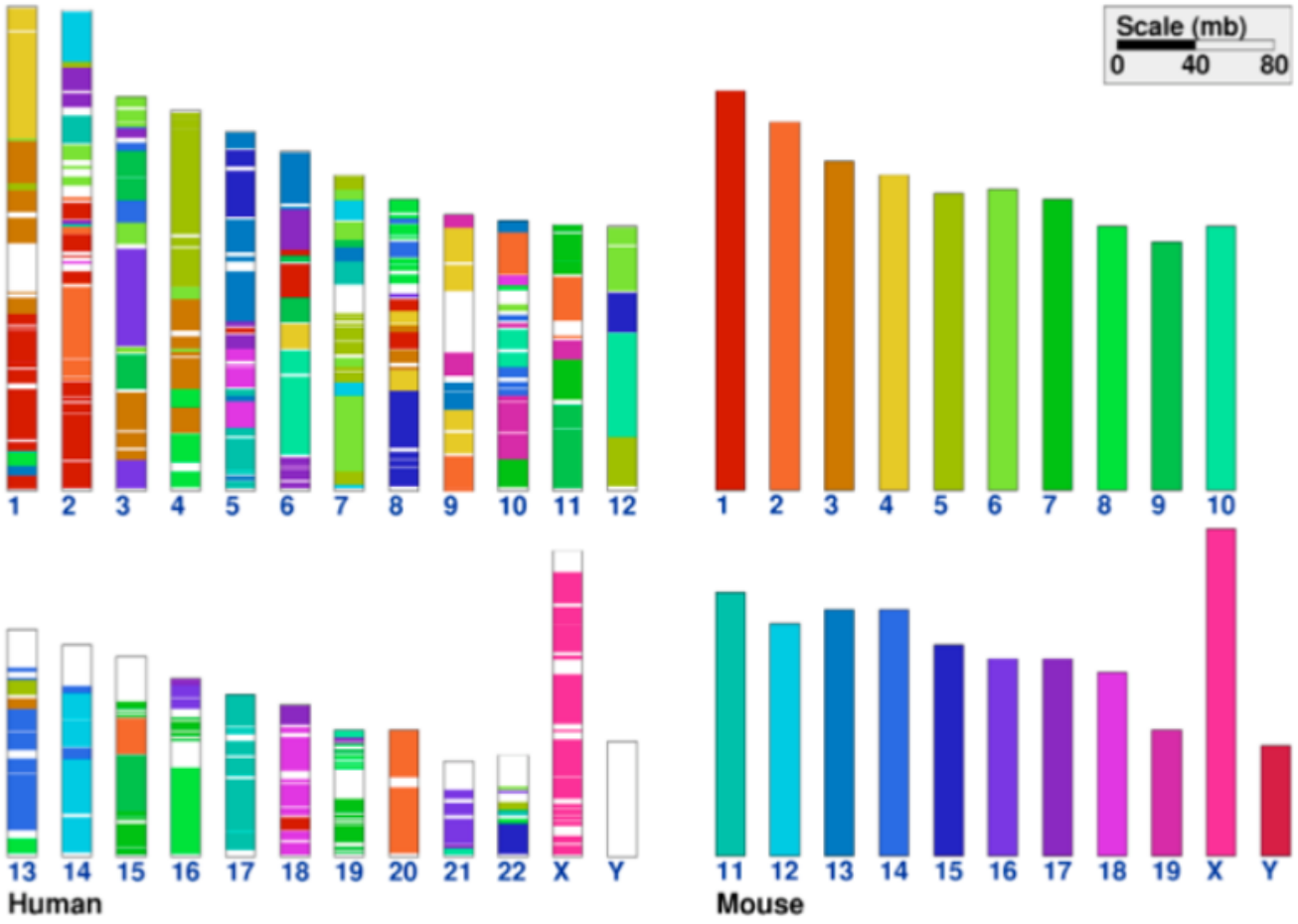
Is this a pit? What? →



https://agilescientific.com/blog/2017/12/14/no-more-rainbows

About color...

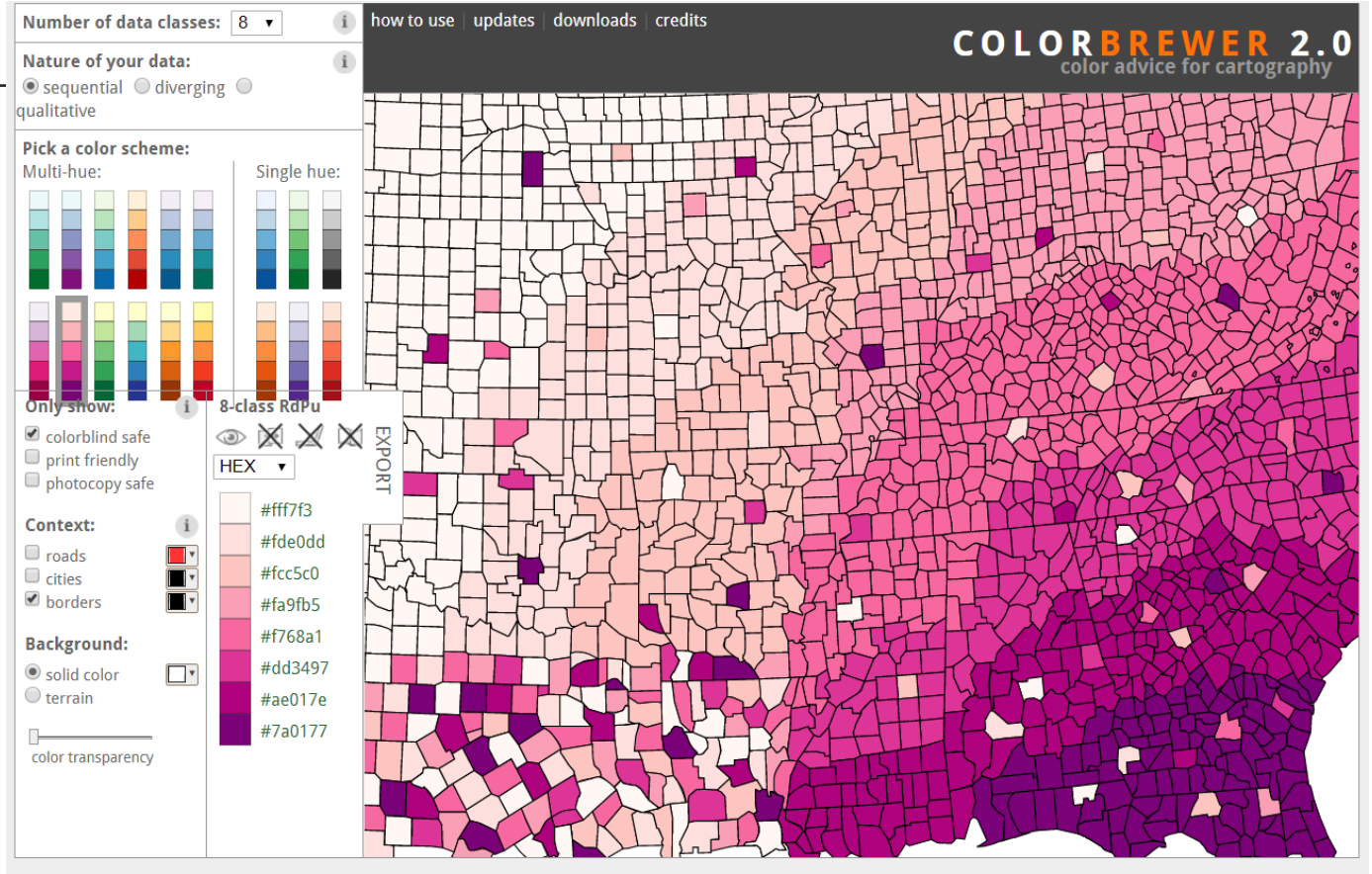
- Categorical color
  - There's a limit to number of colors that are discriminable
  - More than 5-10 bins becomes difficult



[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

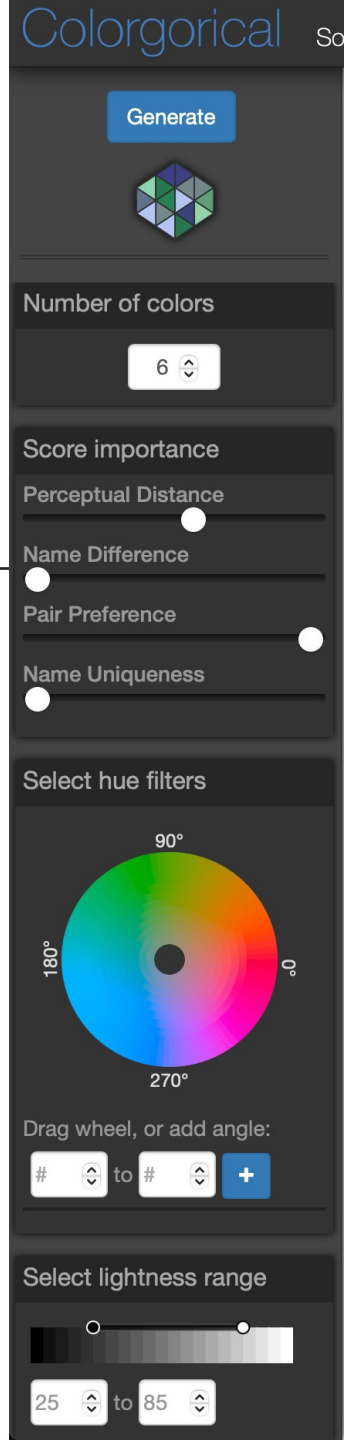
Color Tools

- ColorBrewer
  - http://colorbrewer2.org/
- Colorgorical
  - http://vrl.cs.brown.edu/color
- Sequential Color Scheme Generator
  - http://eyetracking.upol.cz/color/
- Colorpicker for Data
  - http://tristen.ca/hcl-picker/



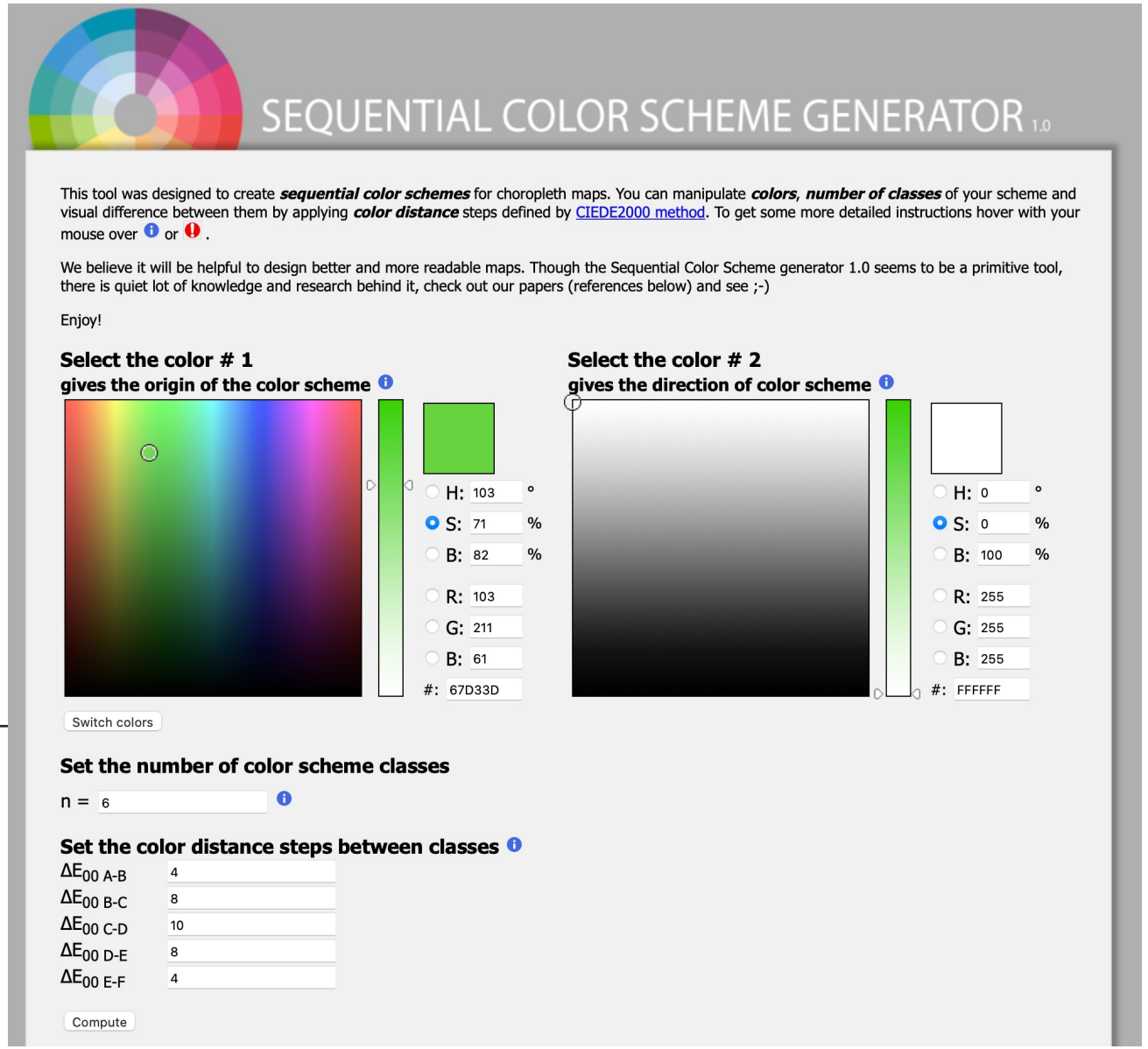
Color Tools

- ColorBrewer
  - http://colorbrewer2.org/
- Colorgorical
  - http://vrl.cs.brown.edu/color
- Sequential Color Scheme Generator
  - http://eyetracking.upol.cz/color/
- Colorpicker for Data
  - http://tristen.ca/hcl-picker/



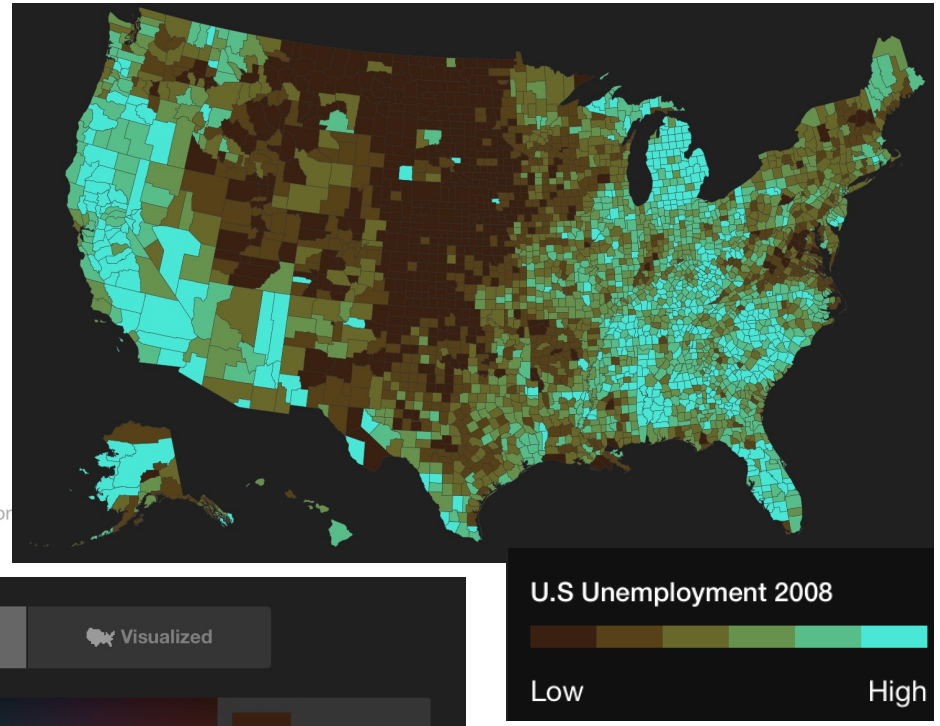
Color Tools

- ColorBrewer
  - http://colorbrewer2.org/
- Colorgorical
  - http://vrl.cs.brown.edu/color
- Sequential Color Scheme Generator
  - http://eyetracking.upol.cz/color/
- Colorpicker for Data
  - http://tristen.ca/hcl-picker/



Color Tools

- ColorBrewer
  - http://colorbrewer2.org/
- Colorgorical
  - http://vrl.cs.brown.edu/color
- Sequential Color Scheme Generator
  - http://eyetracking.upol.cz/color/
- Colorpicker for Data
  - http://tristen.ca/hcl-picker/



Visualization Idioms

- Tabular data
- Spatial data
- Network & tree data

If you'd like to follow along...

- day_05 on ICTP 2022 GitLab
- Install modules
  - From inside repo, run:

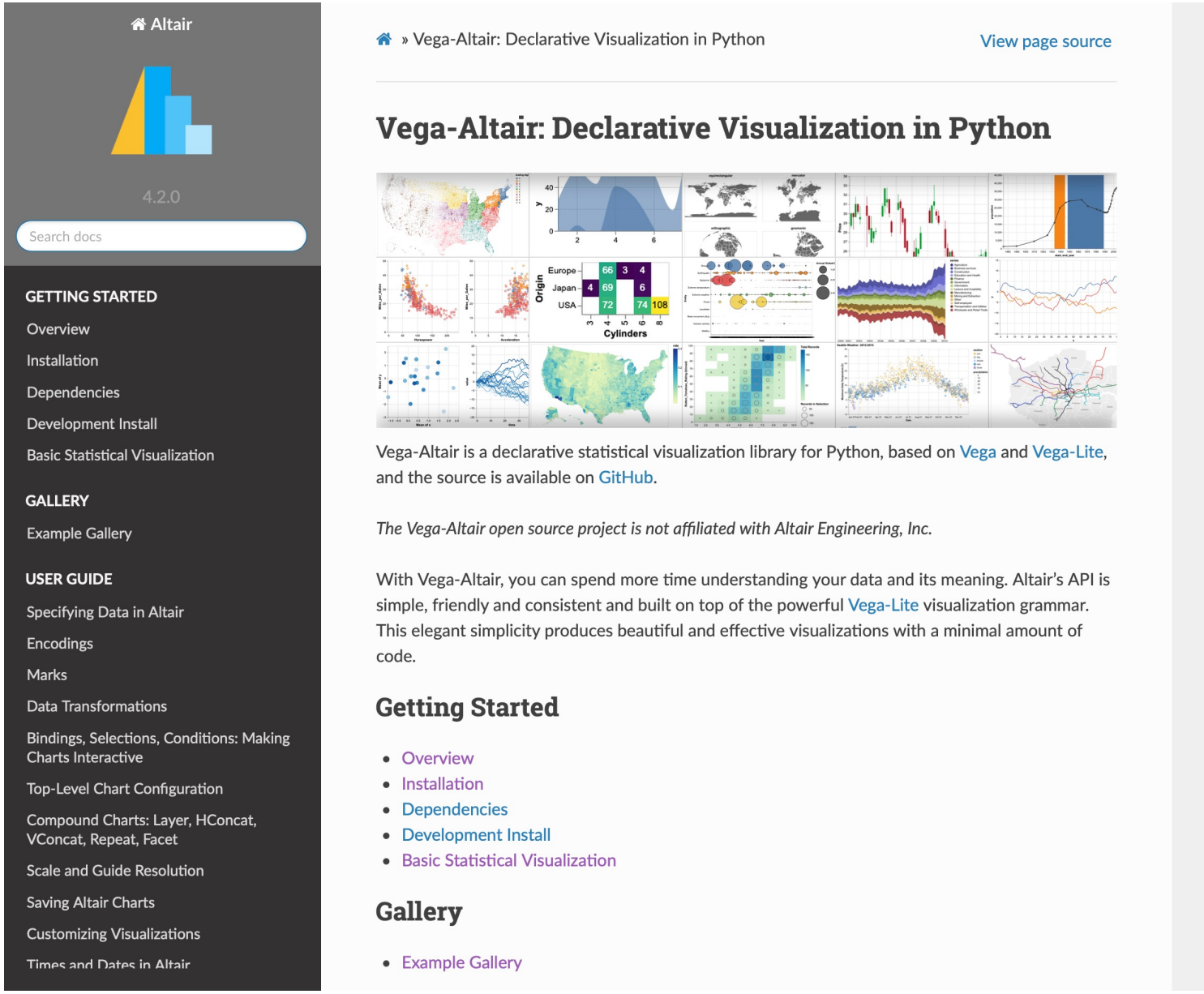
  pip install -r requirements.txt
- Sample visualizations
  - ./basic_charts/
  - ./basic_charts_html_output/

```python
import altair as alt
import pandas as pd

penguins_data = pd.read_json('./basic_charts_data/penguins.json')
print(penguins_data.head())


# how many of each species of penguin are there?
penguin_species_bar = alt.Chart(penguins_data).mark_bar().encode(
    alt.Y('Species:N', sort='x'),
    x = 'count()',
    color = 'Species'
).properties(
    title='Number of Penguins by Species'
)

penguin_species_bar.configure_title(
    fontSize=20,
    anchor='start'
).save('./basic_charts_html_output/bar.html')
```

./basic_charts/bar.py

Vega-Altair

- Declarative statistical visualization library for Python
- Built on top of Vega-Lite (https://vega.github.io/vega-lite/)
- Directly applies marks and channels in construction of a visualization
- Output as json spec embedded in html file – no plugins/other installations required to view/interact



https://altair-viz.github.io/index.html

Vega Ingredients

- Data → DataFrame to visualize upon
- Mark → Notations for each row observation (line, bar, tick, point)
- Encoding → Data representation Channel (X Position, Y Position, color, size)
- Transform → Data Transformation before applying visualization (calculate, filter, aggregate,fold)
- Scale → Function which inputs data and renders it on the screen.
- Guide → Visual aids on charts (legends), ticks on x and y axis.

Arrange, Map

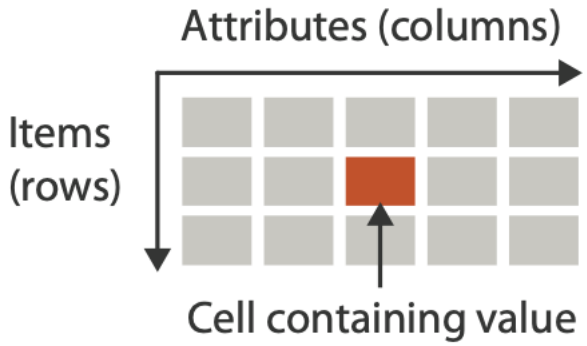
Encode

- **Arrange**
  - Express
  - Separate
  - Order
  - Align
  - Use

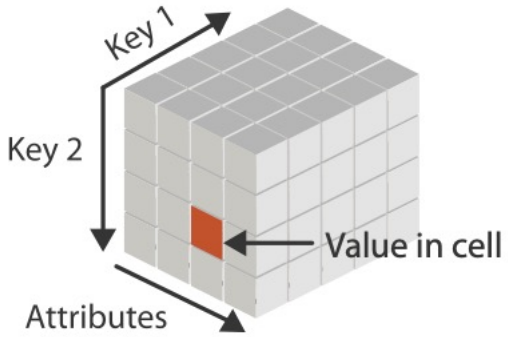
- **Map**
  from categorical and ordered attributes
  - Color
    - *Hue*
    - *Saturation*
    - *Luminance*
  - Size, Angle, Curvature, ...
  - Shape
  - Motion
    Direction, Rate, Frequency, ...

Tabular Data

- (Key, Value)
  - key = independent attribute
    - unique index for item lookup
  - can have multiple keys in multidimensional tables
  - value = dependent attribute
    - cell value
- Classify arrangement by keys used (0, 1, 2, ...)



➔ *Multidimensional Table*



➔ *0 Keys*

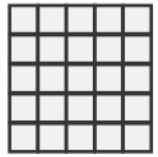
➔ **Express Values**

➔ *1 Key*

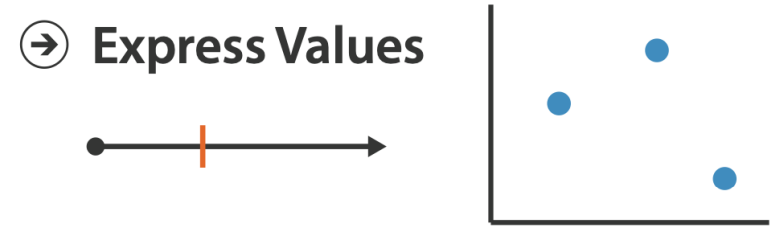
List

➔ *2 Keys*

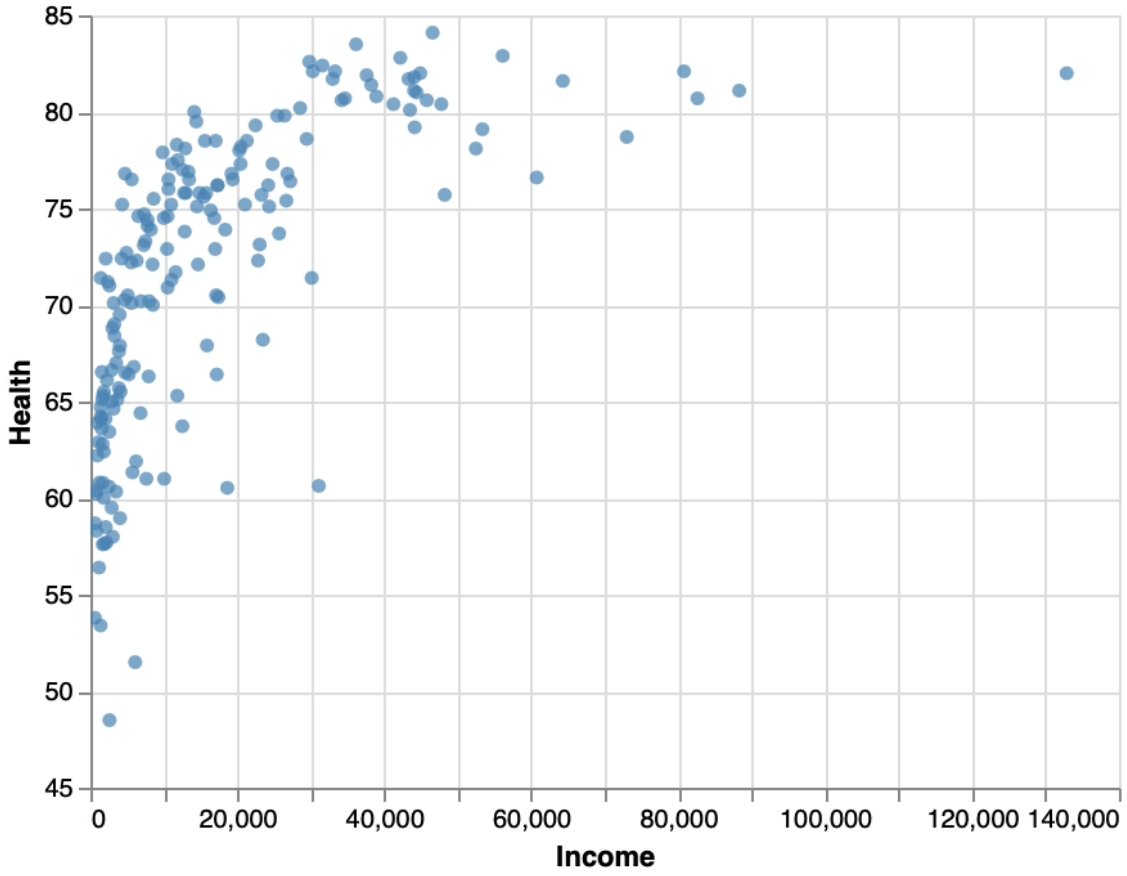
Matrix



Scatterplot

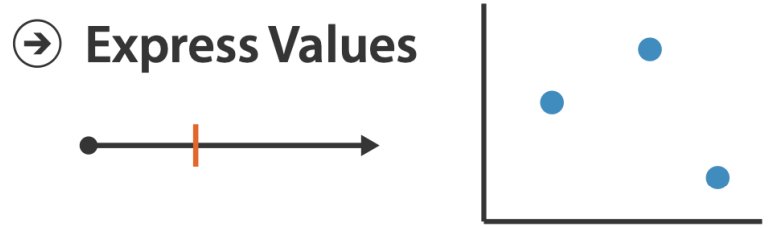


- no keys, only values
  - 2 quantitative attributes
- mark: points
- channels
  - horizontal + vertical position
- tasks
  - find trends, outliers, distribution, correlation, clusters
- scalability
  - hundreds of items

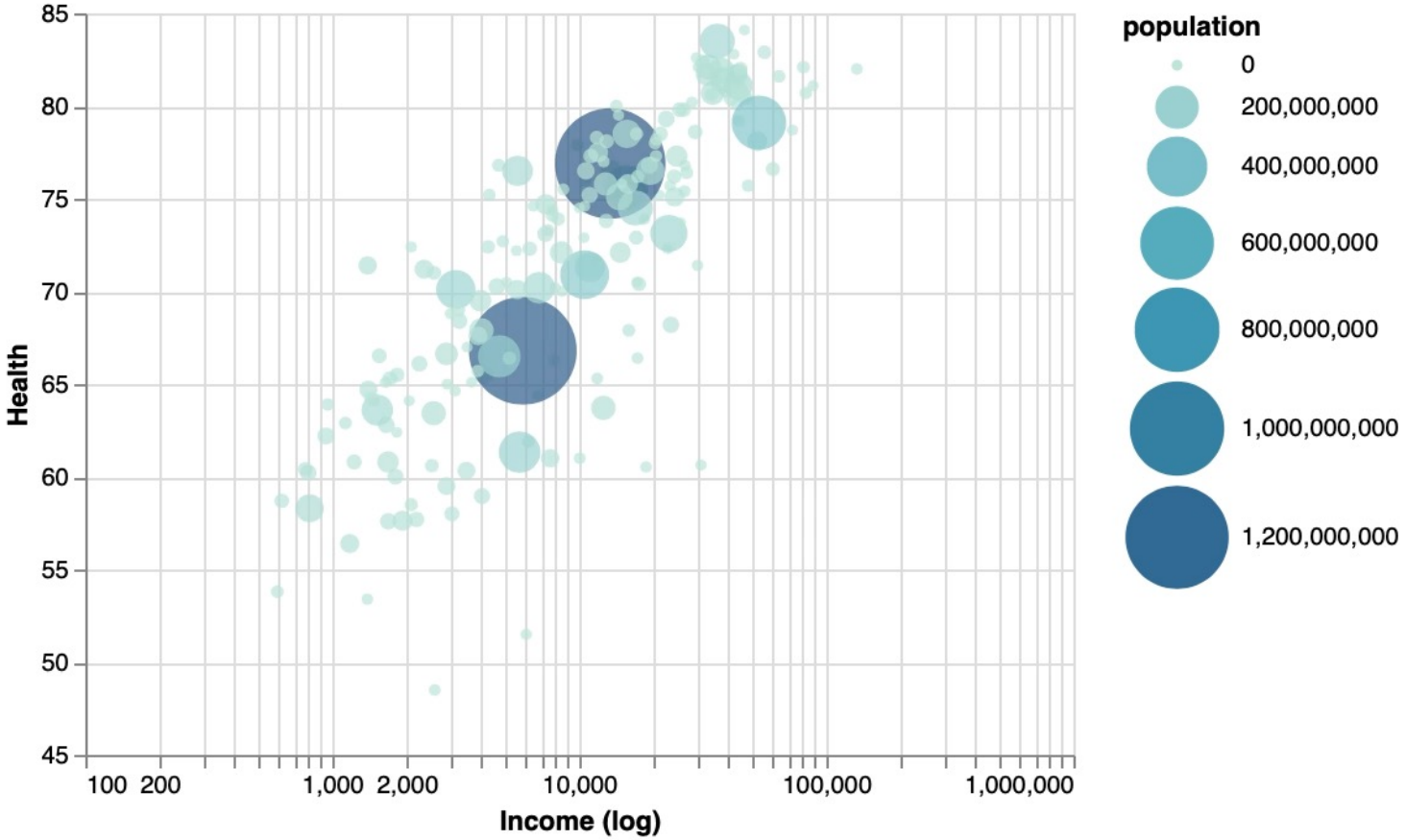


day_05/basic_charts/scatter.py

Scatterplot



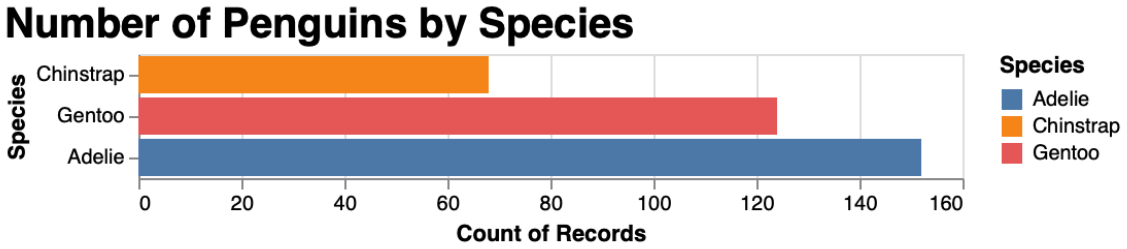
- Can also encode additional channels (since using point marks)
  - Color
  - Area
    - not radius – take square root since area grows quadratically
  - Size

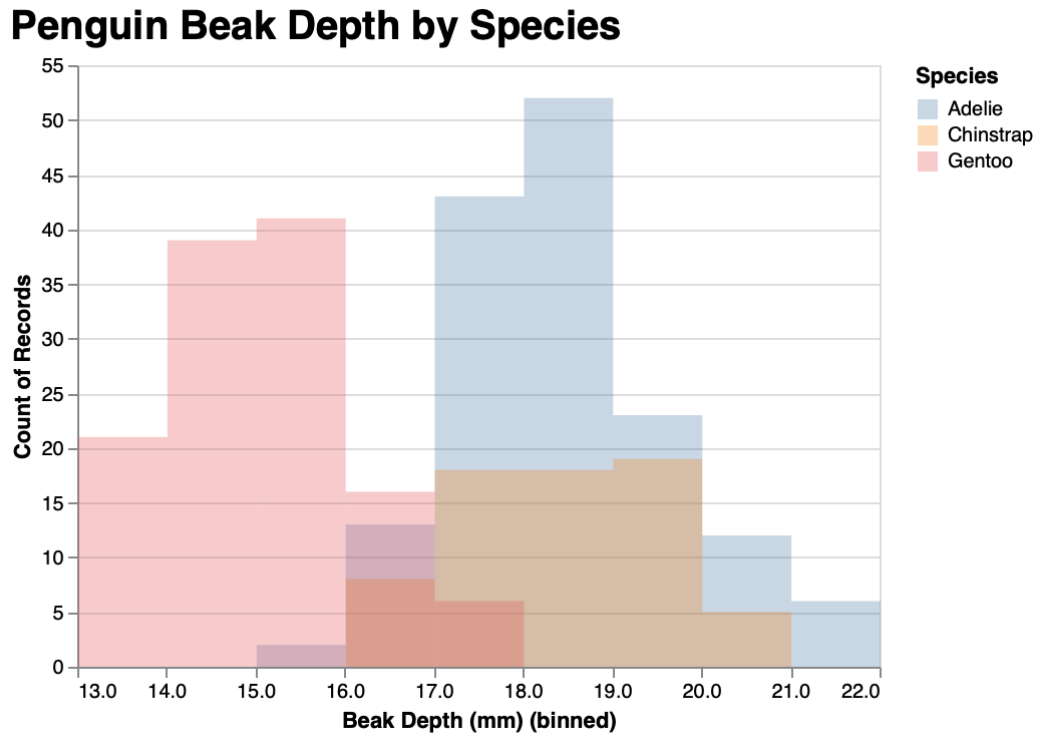


day_05/basic_charts/scatter.py

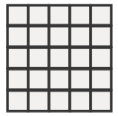
Bar Chart/Histogram

- one key, one value
  - 1 categorical attribute, 1 quantitative attribute
- mark: lines
- channels
  - length to express quantitative values
  - spatial regions: one per mark
    - ordered by label (alphabetical),
    - ordered by length attribute (data-driven)
- task
  - compare, lookup values
- scalability
  - dozens to hundreds of levels for key attribute



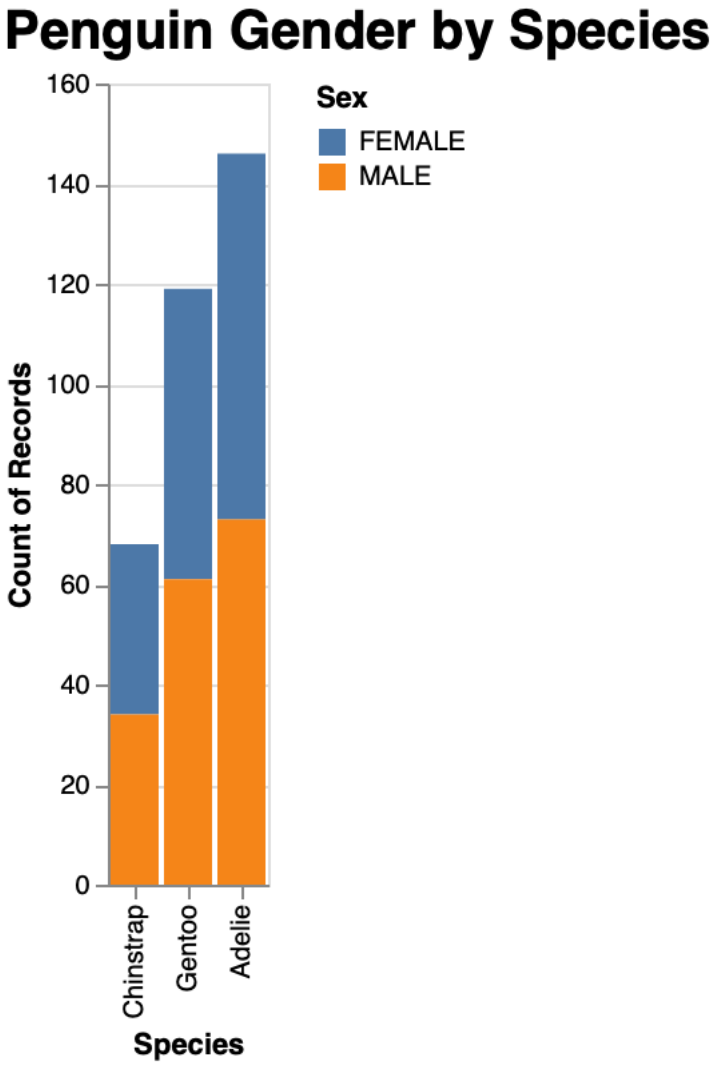


day_05/basic_charts/bar.py



Stacked Bar Chart

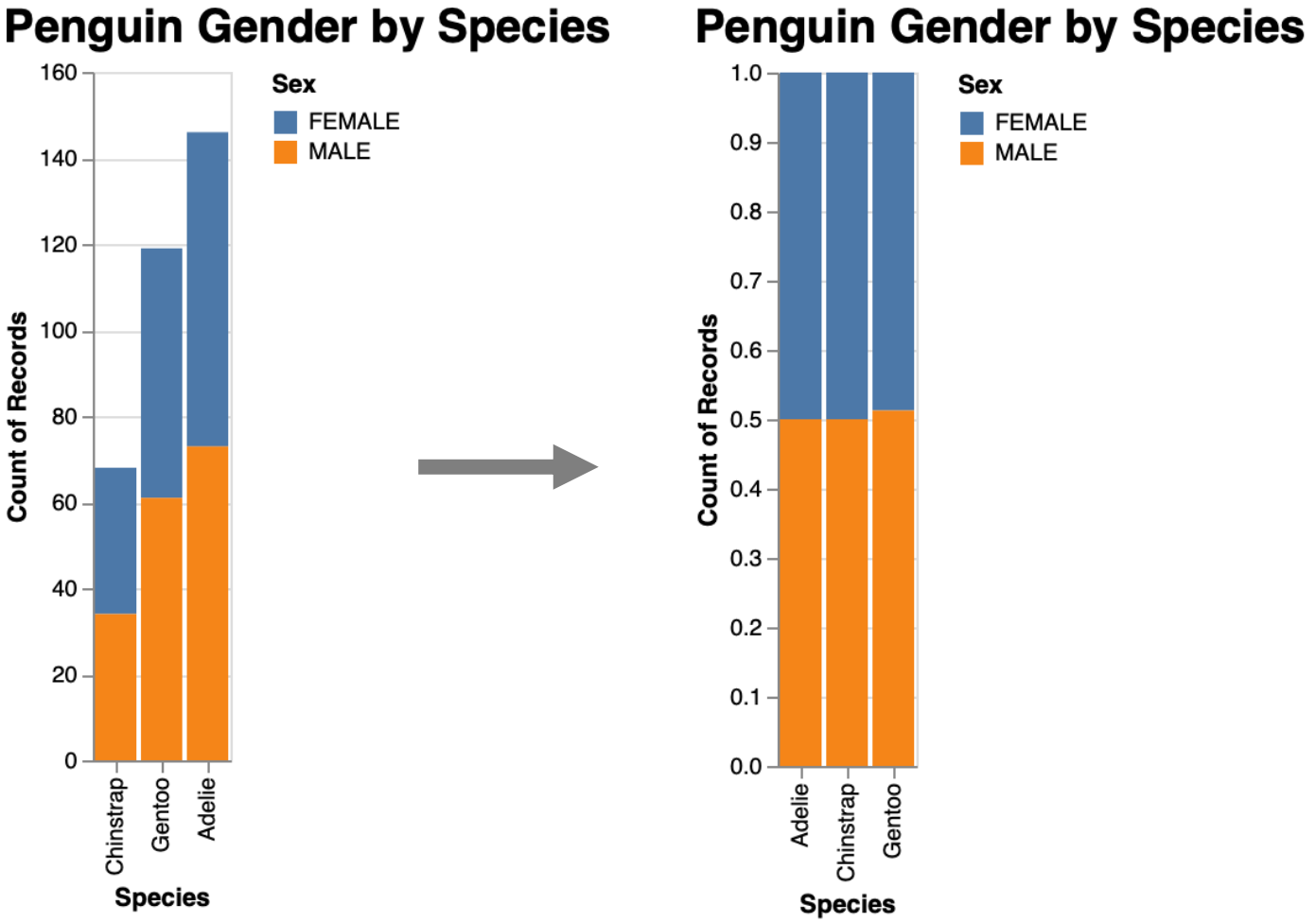
- data: 2 categorical attributes, 1 quantitative attribute
- mark: vertical stack of line marks
- channels
  - length
  - color hue
  - spatial regions
    - one per stacked bar
- task
  - part-to-whole relationship
- scalability
  - several to one dozen levels for stacked attribute



day_05/basic_charts/stacked_bar.py

Normalized Stacked Bar Chart

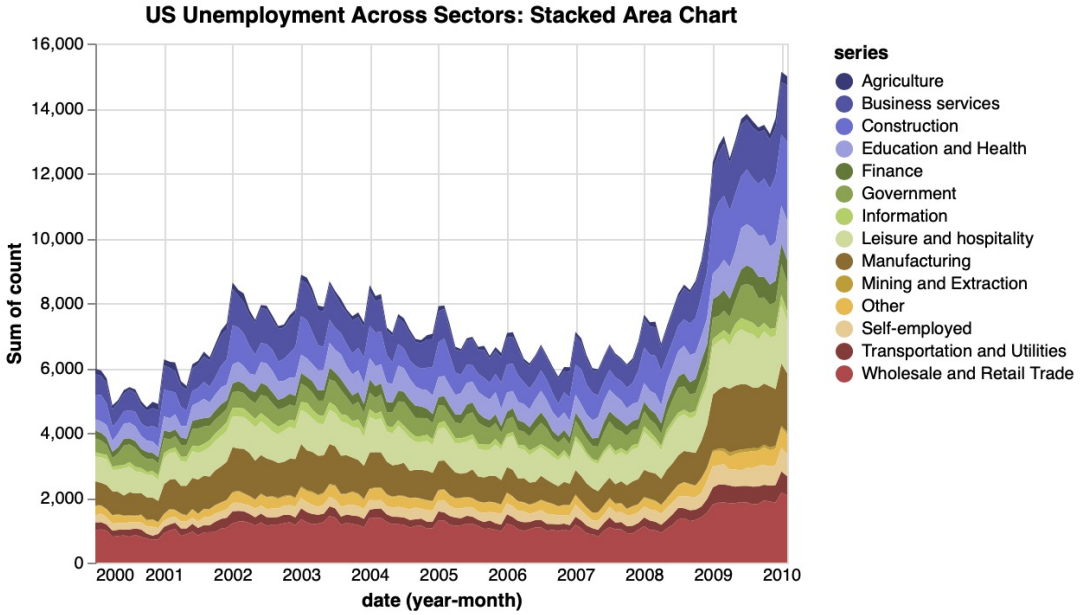
- stacked bar chart normalized to full vertical height
- comparisons between groups easier (part-to-whole relationships)

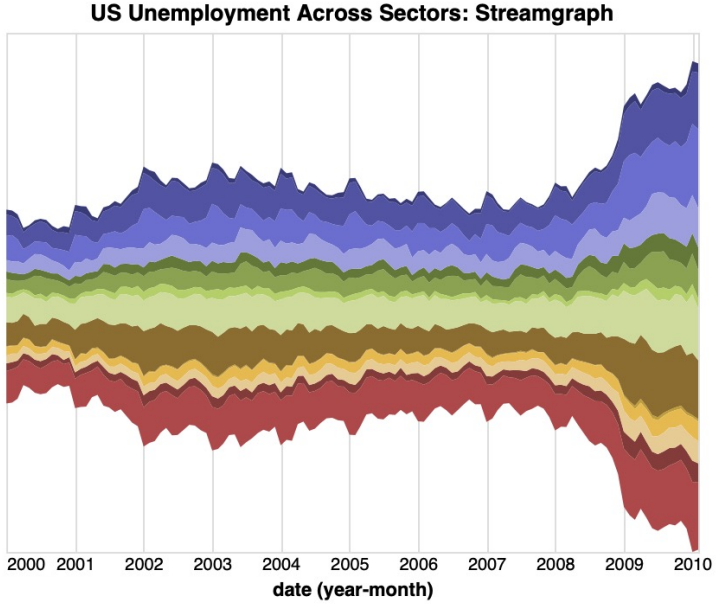


day_05/basic_charts/stacked_bar.py

Streamgraph

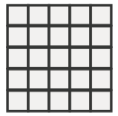
- generalized stacked graph
  - emphasizing horizontal continuity vs. vertical items
- data
  - 1 categorical key attribute (artist)
  - 1 ordered key attribute (time)
  - 1 quantitative value attribute (counts)
- derived data
  - geometry: layers -> height encodes counts
  - 1 quantitative attribute (layer ordering)
- scalability
  - hundreds of time keys
  - dozens to hundreds of artist keys
    - more than stacked bars, since most layers don't extend across whole chart





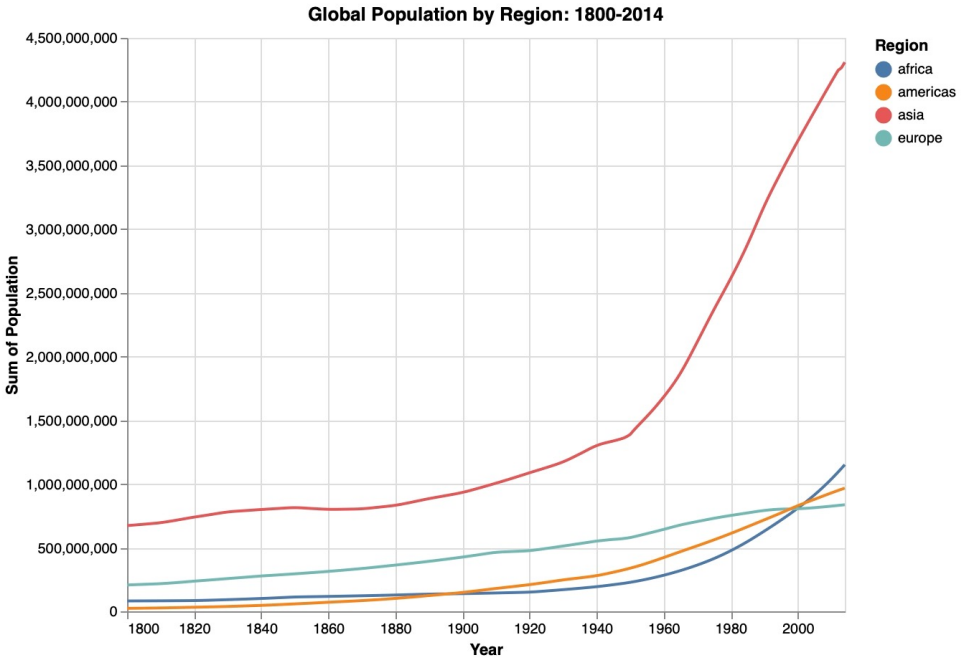
day_05/basic_charts/streamgraph.py
https://altair-viz.github.io/gallery/streamgraph.html

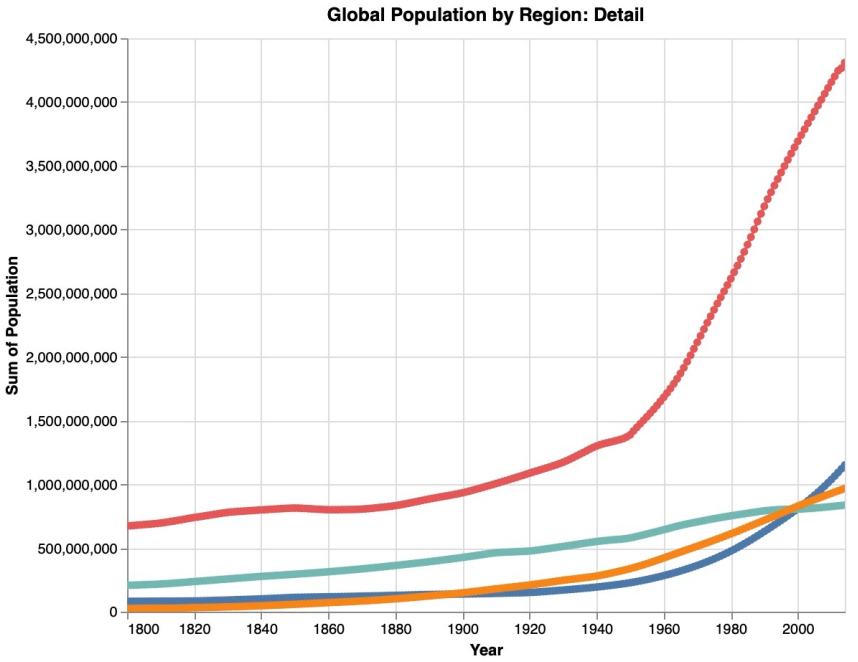
➔ 2 Keys
Matrix



Line/Dot Chart

- one key, one value
  - 2 quantitative attributes (for each line in chart)
- mark: points + line (connection marks)
  - lines explicitly show relationship between items
- channels
  - length (position) to express quantitative values
  - separated and ordered by key attribute
- task
  - find trend



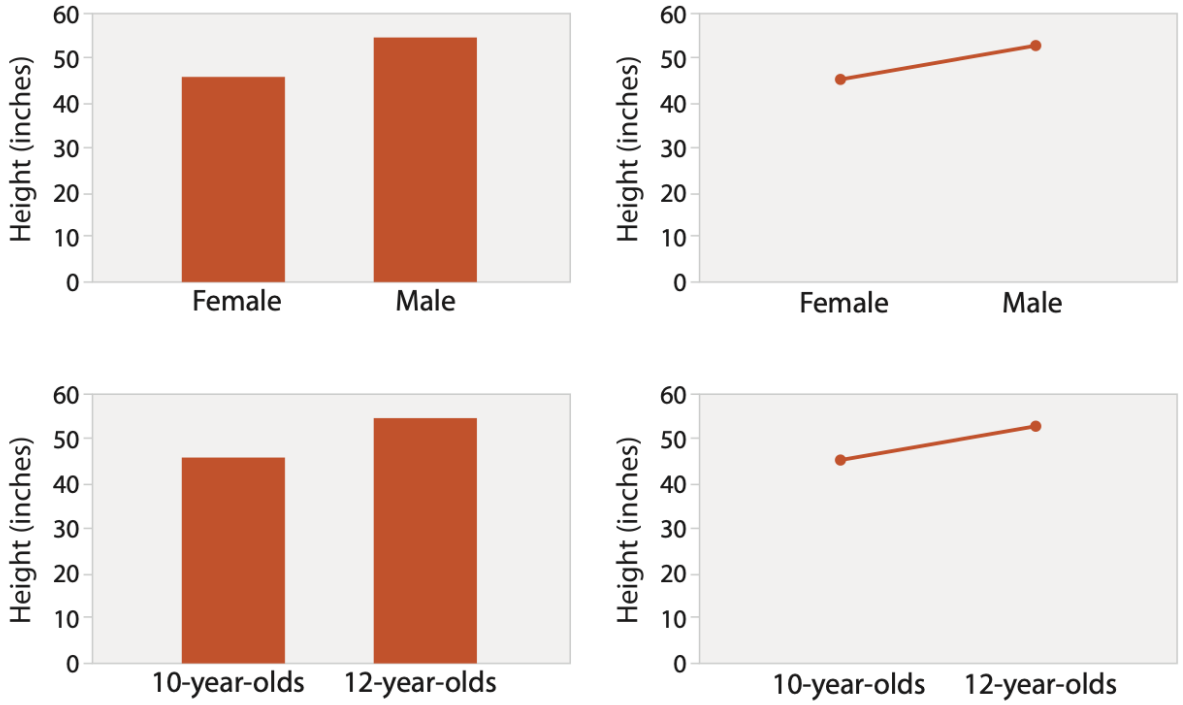


➔ *1 Key*
List

day_05/basic_charts/line.py

In Practice: Bar vs Line

- depends on type of key attribute
  - bar charts if categorical
  - line charts if ordered (quantitative)

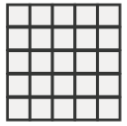


after [Bars and Lines: A Study of Graphic Communication. Zacks and Tversky. Memory and Cognition 27:6 (1999), 1073–1079.]

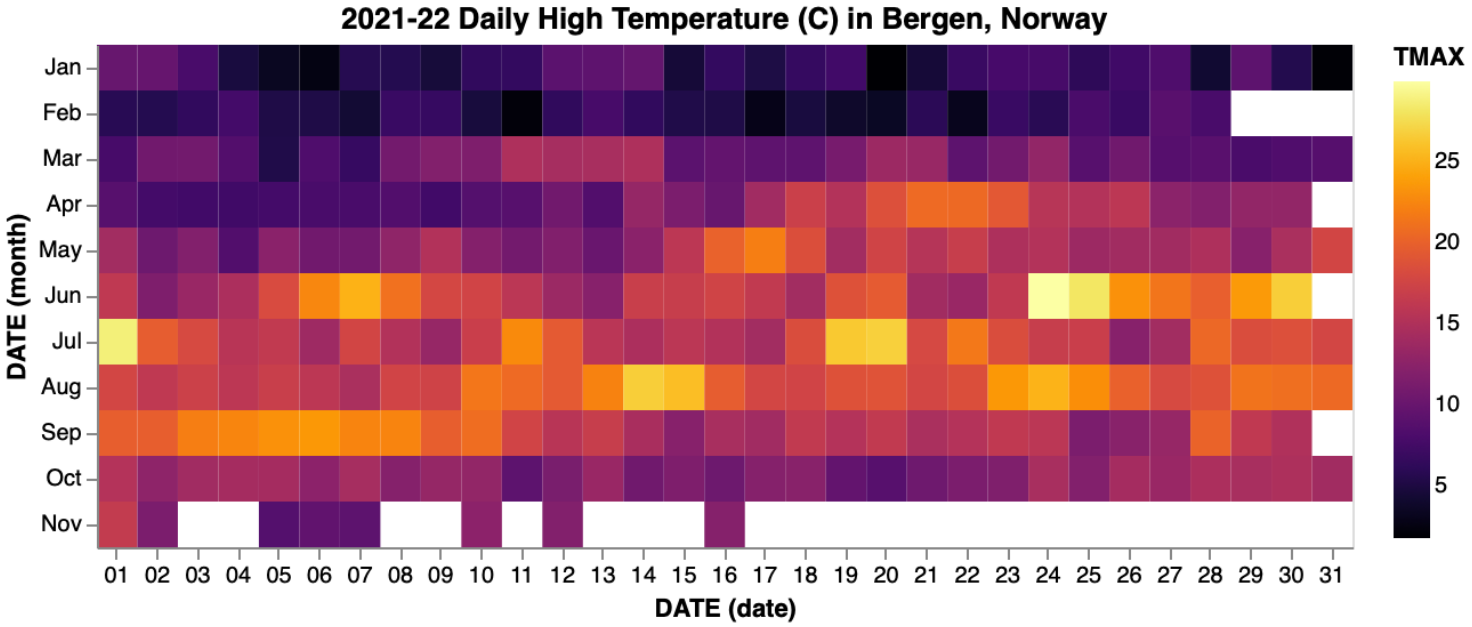
Heatmap

➔ *2 Keys*

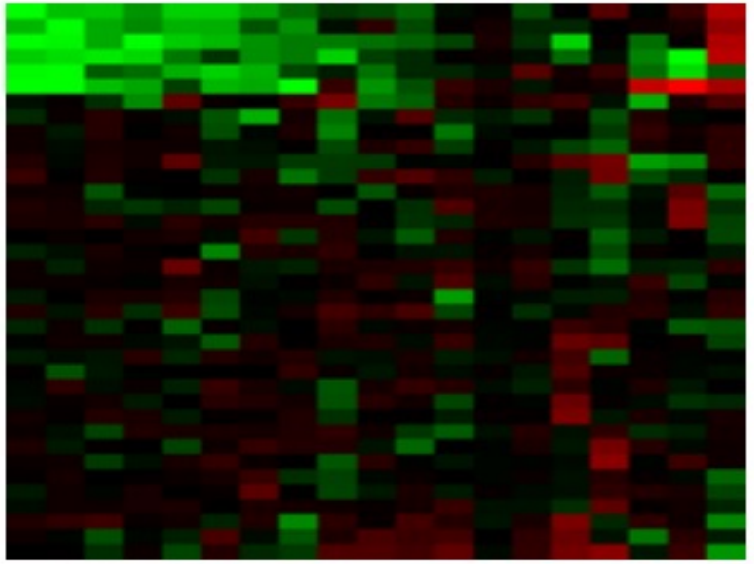
Matrix



- two keys, one value
  - 2 categorical attributes (gene, experimental condition)
  - 1 quantitative attributes (expression levels)
- marks: area
  - separate and align in 2D matrix
    - indexed (ordered) by 2 categorical attributes
- channels
  - color by quantitative attribute
    - ordered vs. diverging color map
- task
  - find clusters, outliers
- scalability
  - 1K categorical levels, 1M items; only ~10 quantitative attribute levels

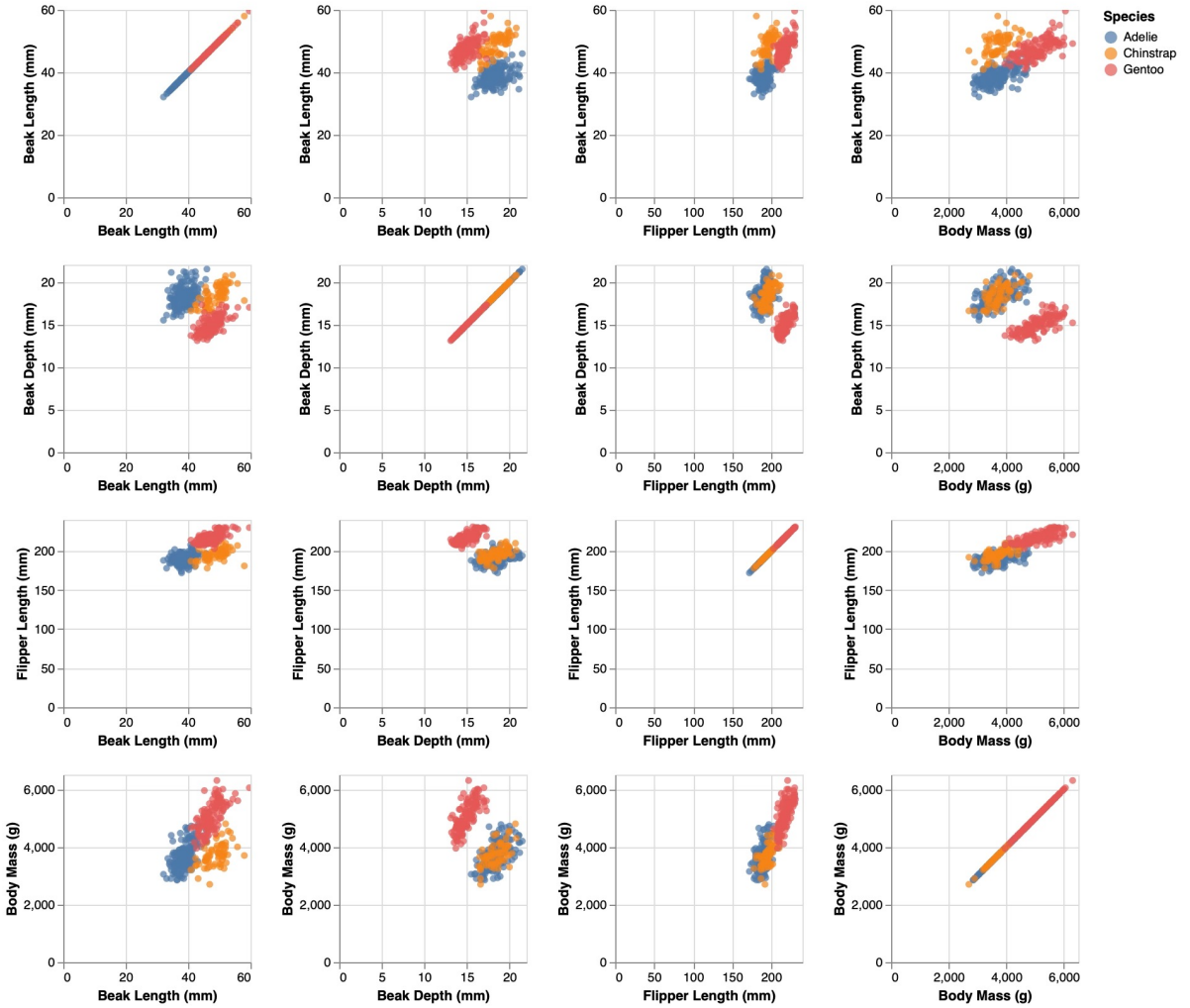


day_05/basic_charts/heatmap.py



Scatterplot Matrix

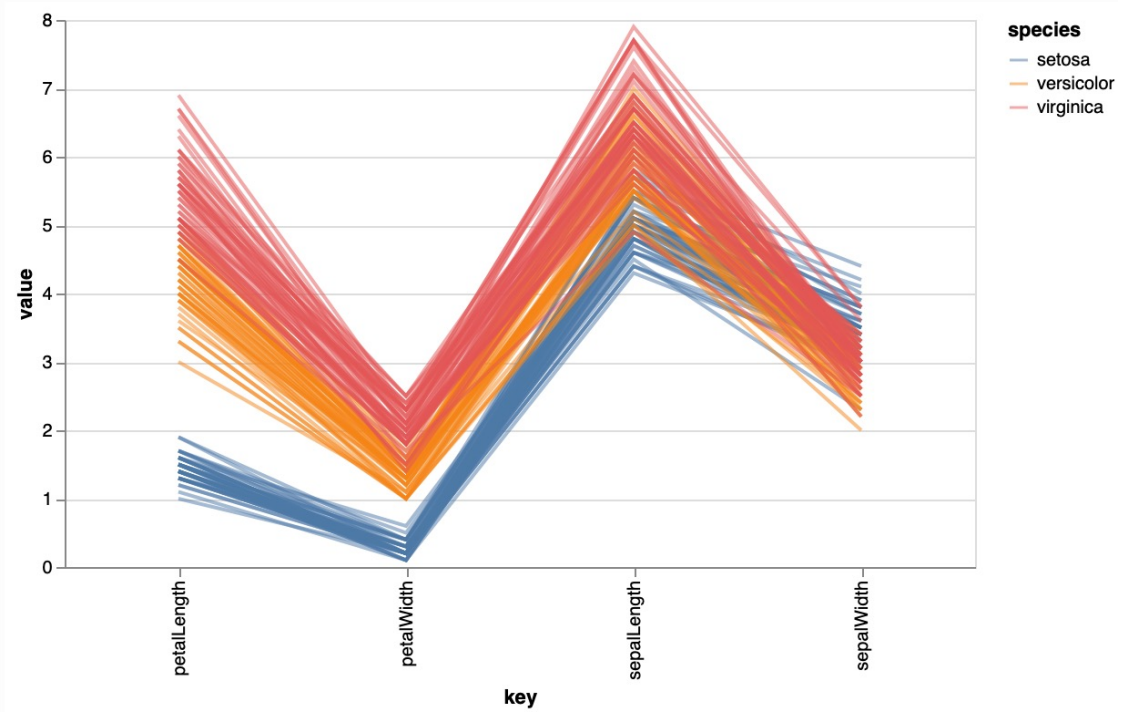
- rectilinear axes, point mark
  - all possible pairs of axes
- scalability
  - one dozen attributes
  - dozens to hundreds of items



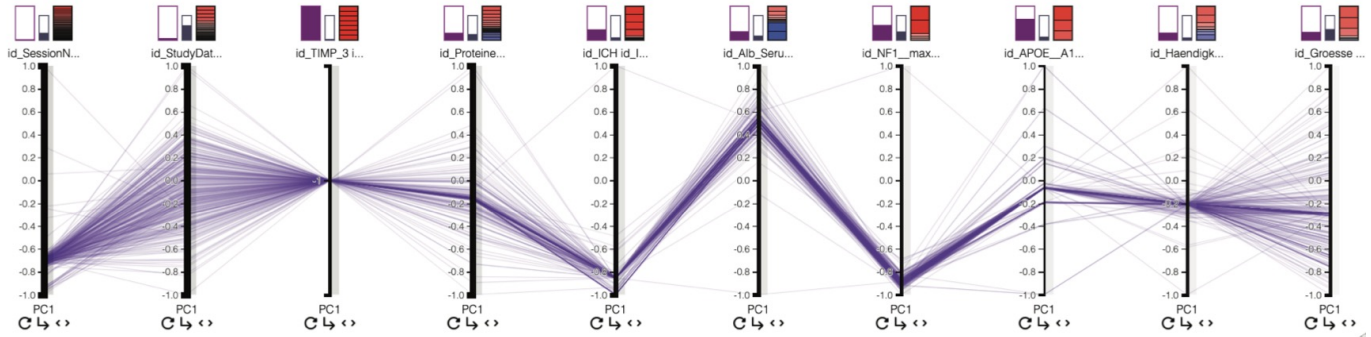
day_05/basic_charts/scatter-matrix.py

Parallel Coordinates

- parallel axes, jagged line representing item
  - parallel axes, item as point
    - axis ordering is major challenge
  - scalability
    - dozens of attributes
    - hundreds of items



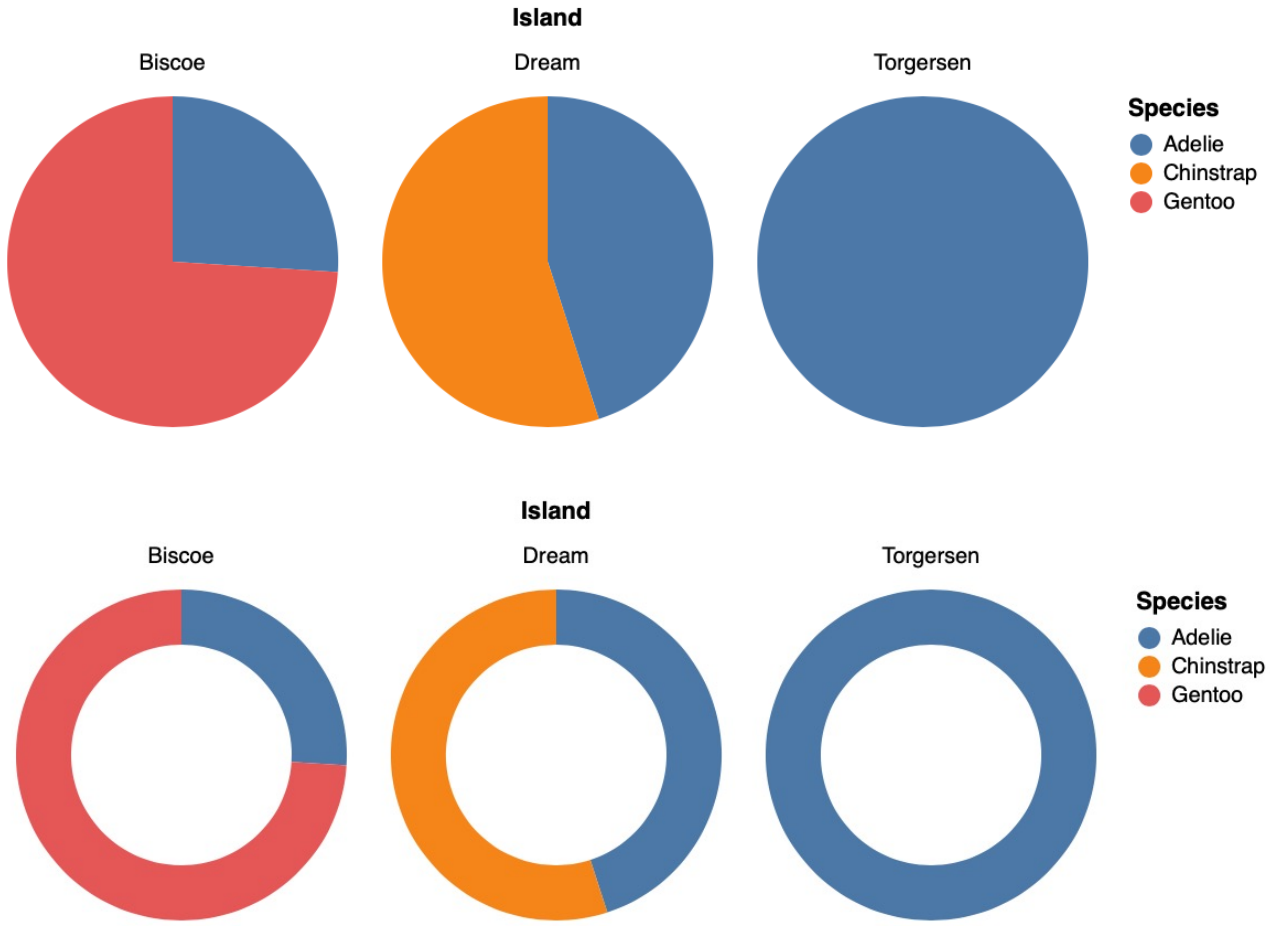
https://altair-viz.github.io/gallery/parallel_coordinates.html



Garrison L, Muller J, Schreiber S, Oeltze-Jafra S, Hauser H, Bruckner S. DimLift: Interactive Hierarchical Data Exploration Through Dimensional Bundling. IEEE Trans Vis Comput Graph. 2021 Jun;27(6):2908-2922.

Pie/Donut Charts

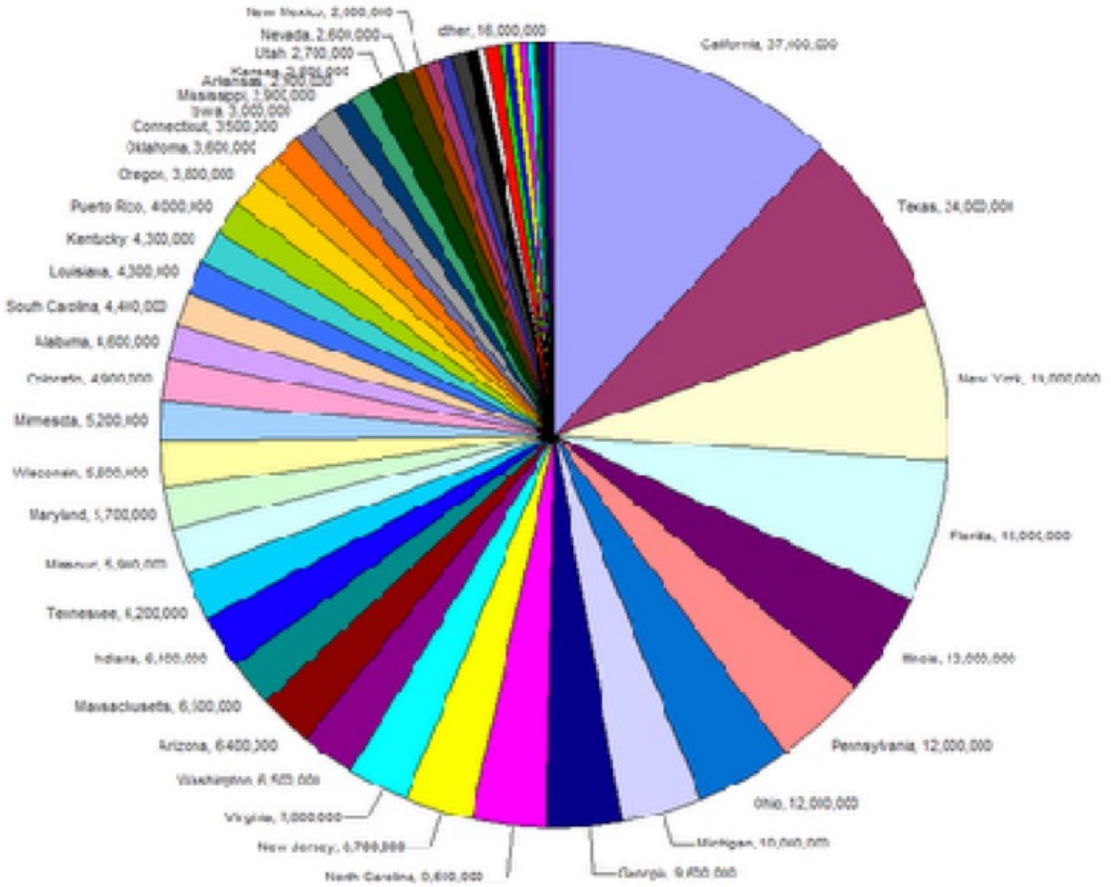
- data
  - 1 categorical key attribute
  - 1 quantitative value attribute
- pie/donut chart
  - area marks with angle channel
  - accuracy: **angle/area much less accurate**
- task
  - part-to-whole judgements (ok for 2-4 categories)



day_05/basic_charts/pie-polar.py

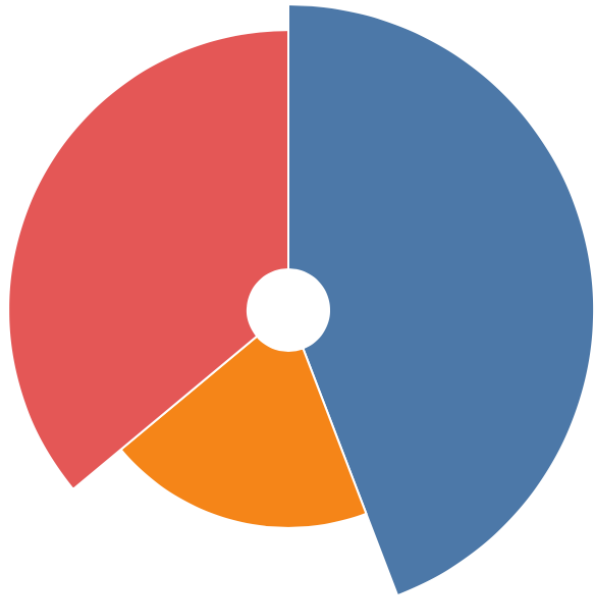
Pie/Donut Charts

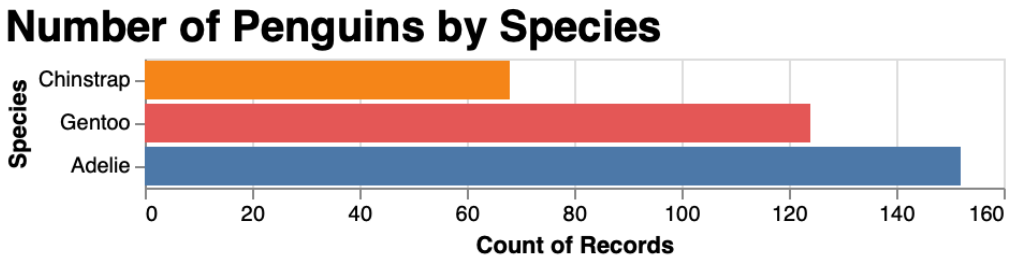
- Bad for many small categories
- Consider normalized stacked bar chart as alternative for part-to-whole tasks when you have many categories
  - also take up less space



Polar Area Charts

- data
  - 1 categorical key attribute
  - 1 quantitative value attribute
- polar area chart
  - area marks with length channel
  - more direct analog to bar charts (but width increasing)
- task
  - part-to-whole judgements (ok for 2-4 categories)

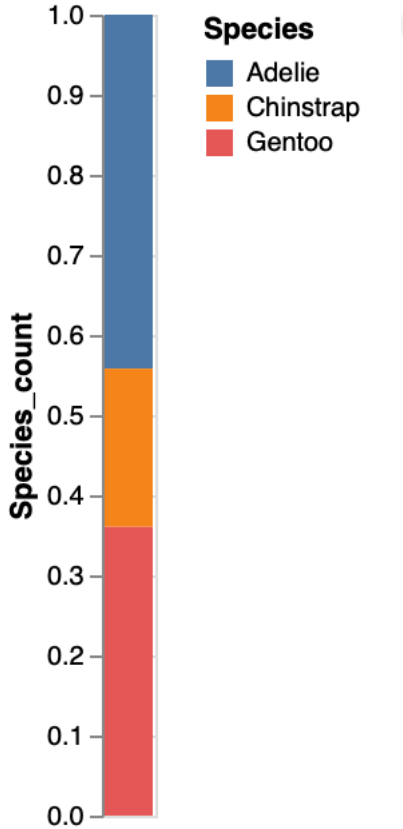




day_05/basic_charts/pie-polar.py

Polar Area Charts

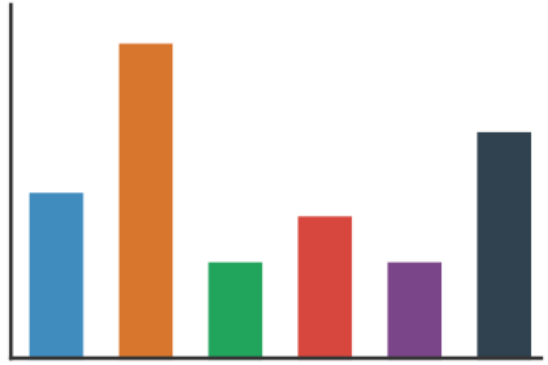
- data
  - 1 categorical key attribute
  - 1 quantitative value attribute
- polar area chart
  - area marks with length channel
  - more direct analog to bar charts (but width increasing)
- task
  - part-to-whole judgements (ok for 2-4 categories)

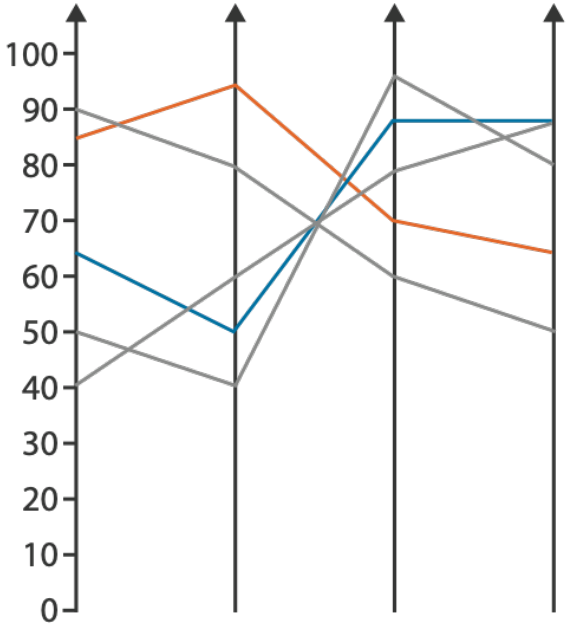


day_05/basic_charts/pie-polar.py

In Practice: Orientation Limitations

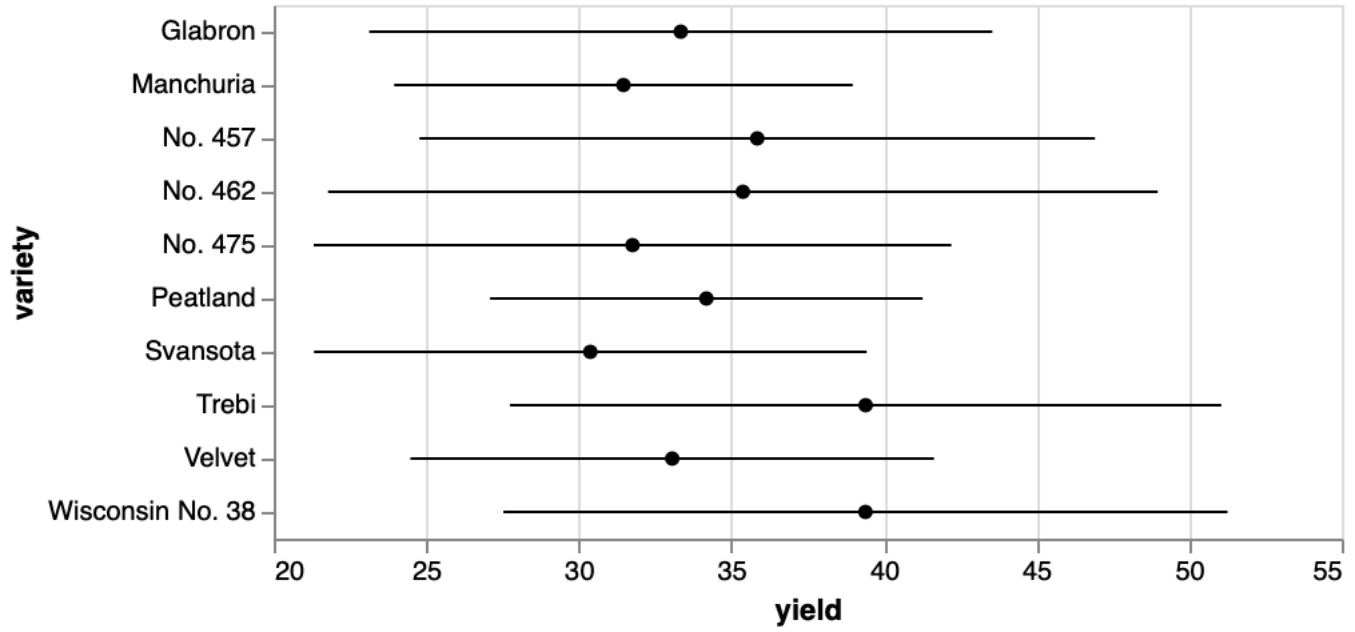
- Rectlinear
  - scalability (2 ideal)
- Parallel
  - unfamiliar, longer training time
- Radial
  - arc < length precision
  - length not aligned with radial layouts
  - less accurately perceived compared to rectilinear alignment





Communicating Uncertainty

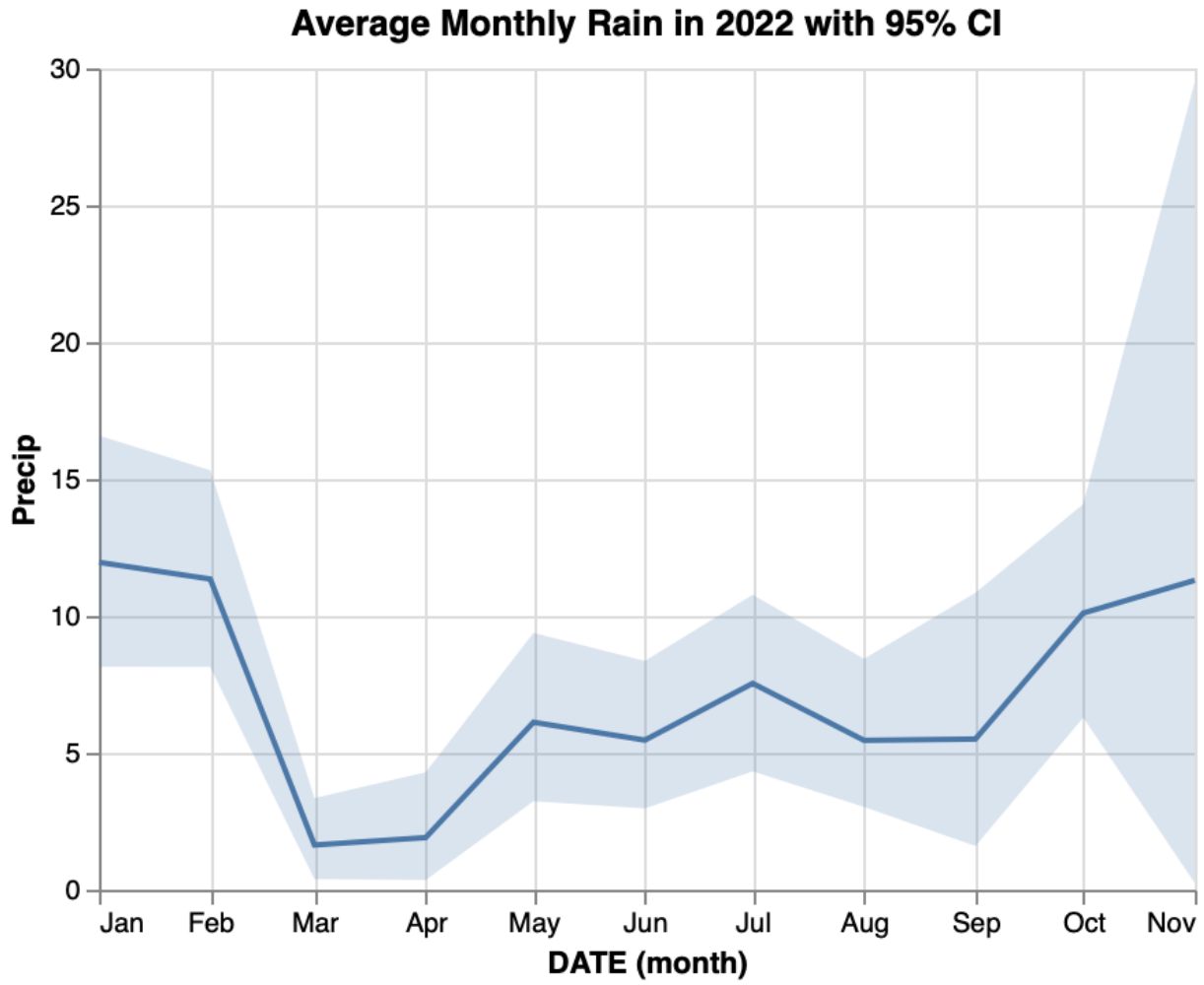
- Error bars



https://altair-viz.github.io/gallery/errorbars_with_std.html

Communicating Uncertainty

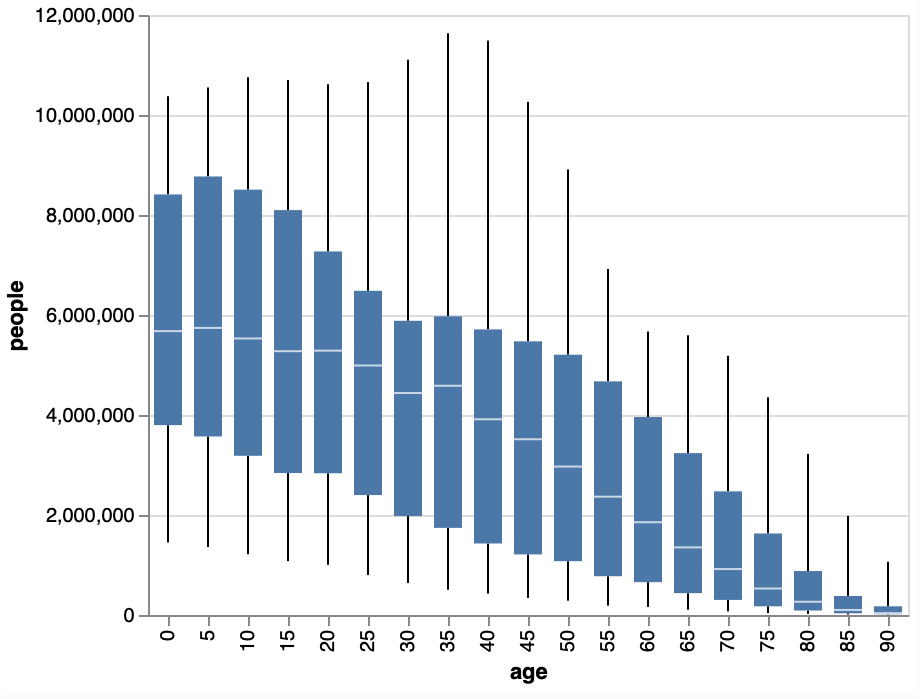
- Error bars
- Confidence intervals



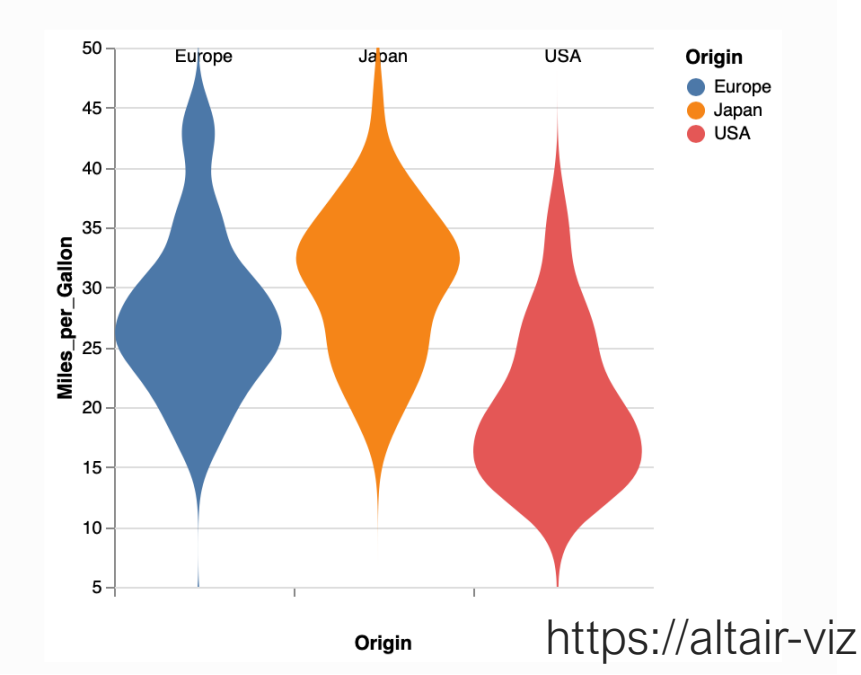
day_05/basic_charts/confidence_interval.py

Communicating Uncertainty

- Error bars
- Confidence intervals
- Summary statistics
- Density distribution



https://altair-viz.github.io/gallery/boxplot.html



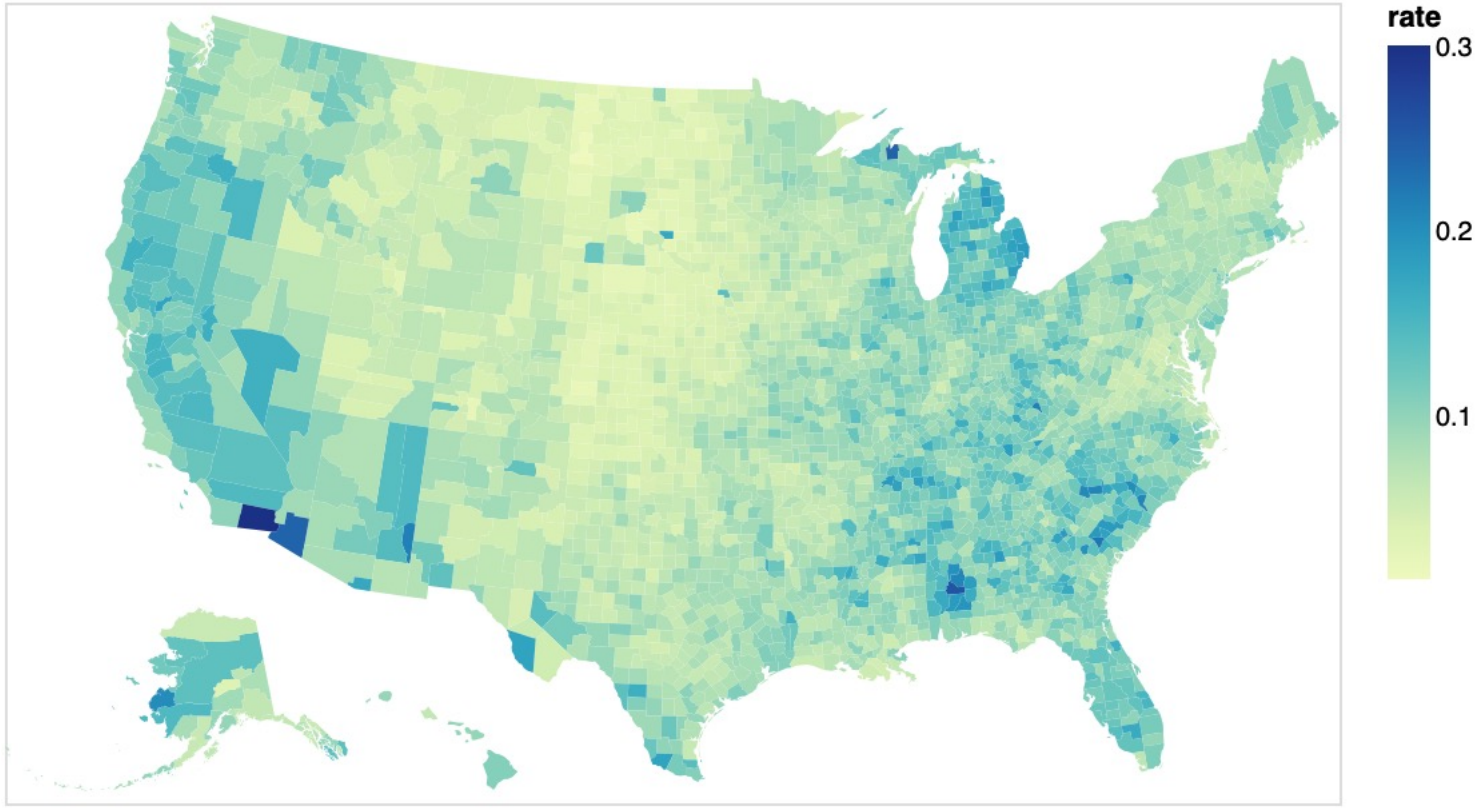
https://altair-viz.github.io/gallery/violin_plot.html

Spatial Data

Chloropleth Map

table with 1 quantitative attribute per region

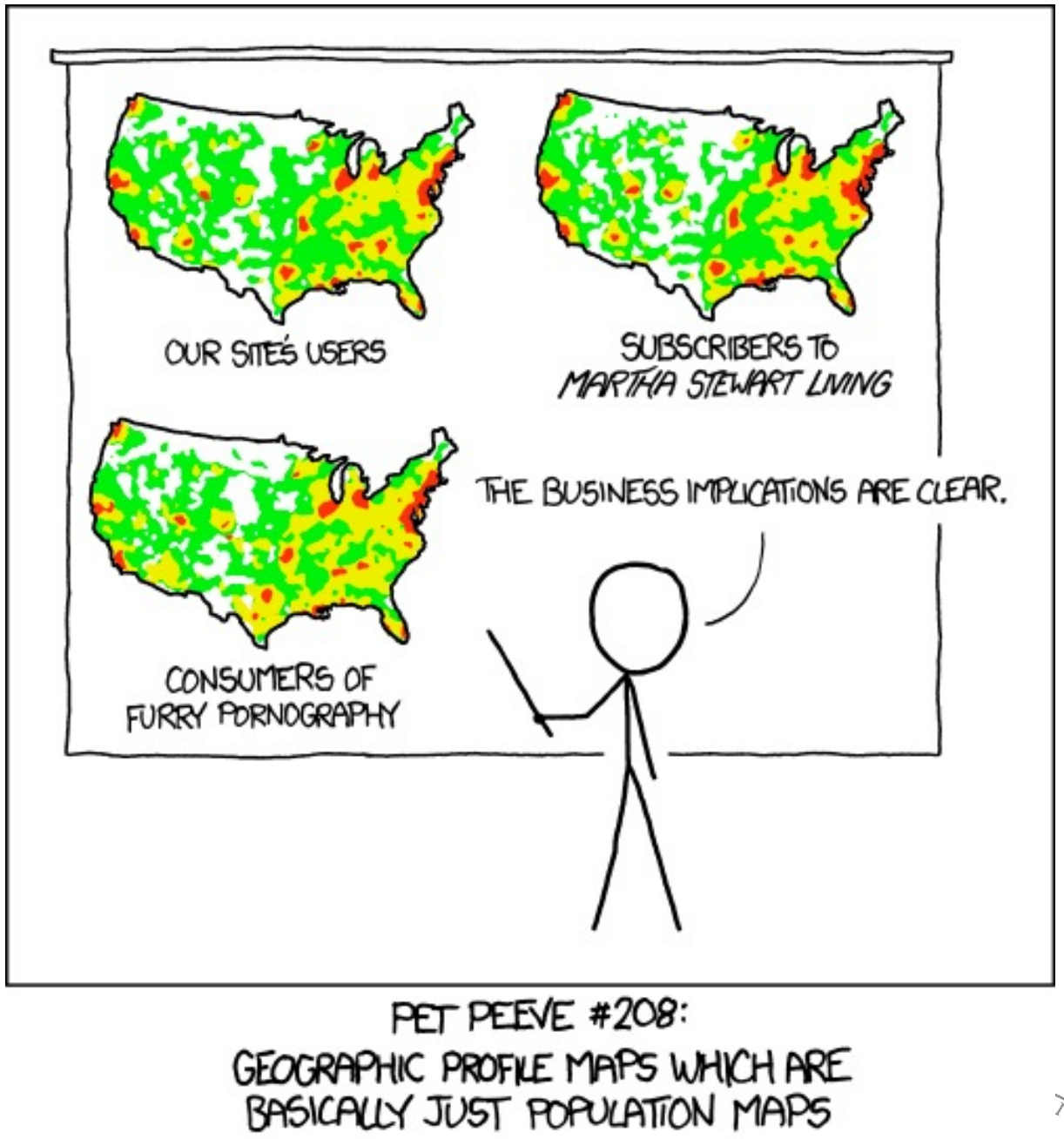
- encoding
  - geometry for area mark boundaries
  - sequentially segmented color map
- task
  - understanding spatial relationships



https://altair-viz.github.io/gallery/choropleth.html

Chloropleth Map

- Spurious correlations
  - solve by normalizing
    - e.g., Apple users per 100 people
- Large regions (e.g., Texas) emphasized when they maybe shouldn't
  - Consider granularity of color encoding

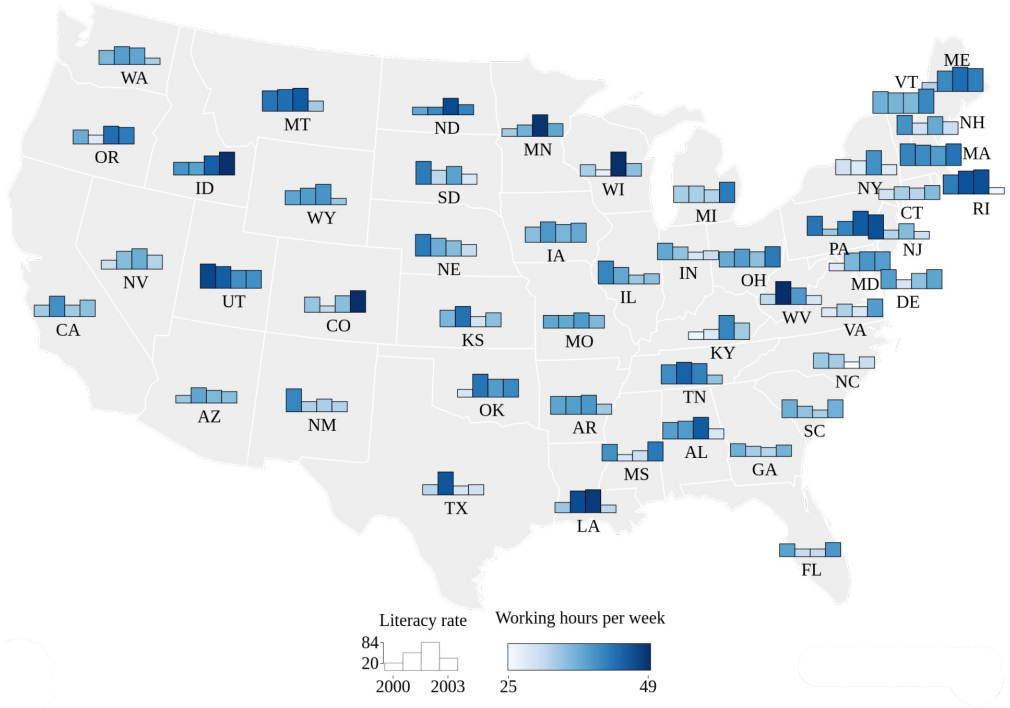


https://xkcd.com/1138

Symbol Maps

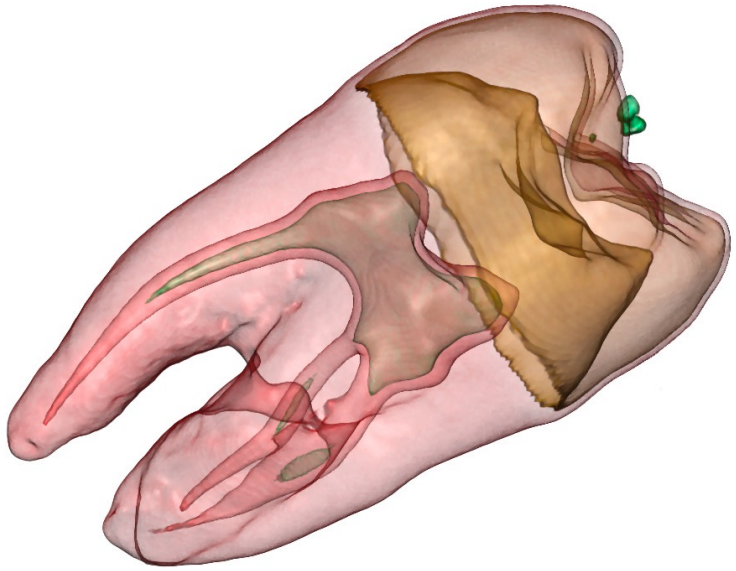
- Symbol represents aggregated data
- Retain spatial positions in background
- Avoids some of issues with chloropleth map

https://altair-viz.github.io/gallery/airports_count.html



Isosurfaces & Direct Volume Rendering

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

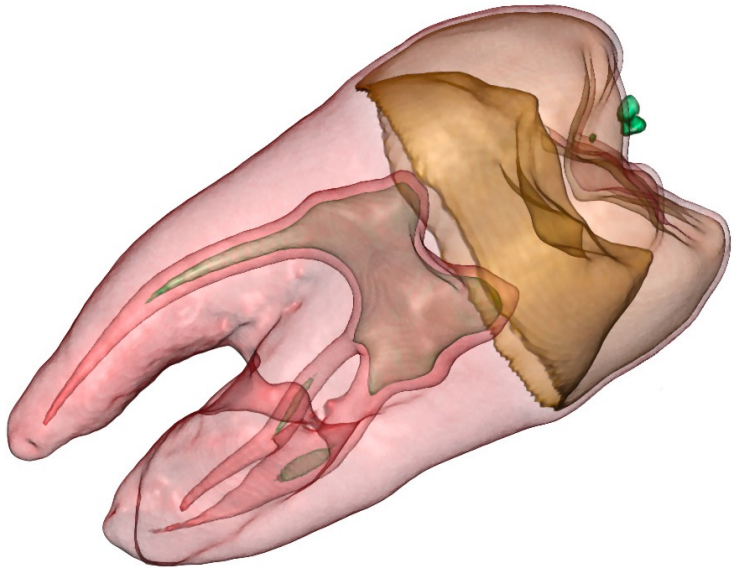


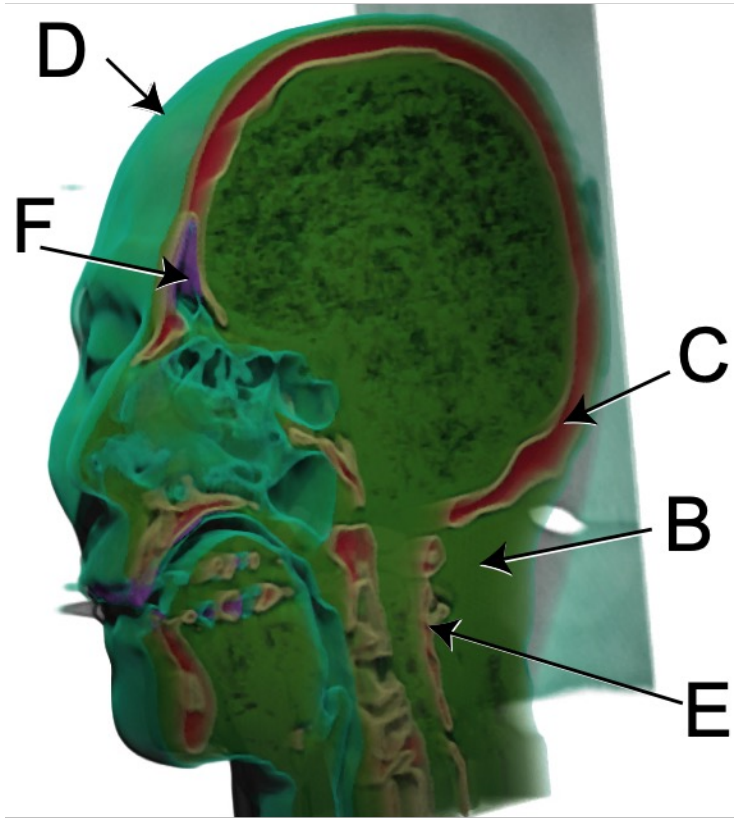
[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

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

Isosurfaces & Direct Volume Rendering

- data
  - scalar spatial field (3D volume)
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships
- isosurface
  - derived data: isocontours computed for specific levels of scalar values
- direct volume rendering
  - transfer function maps scalar values to color, opacity
    - no derived geometry



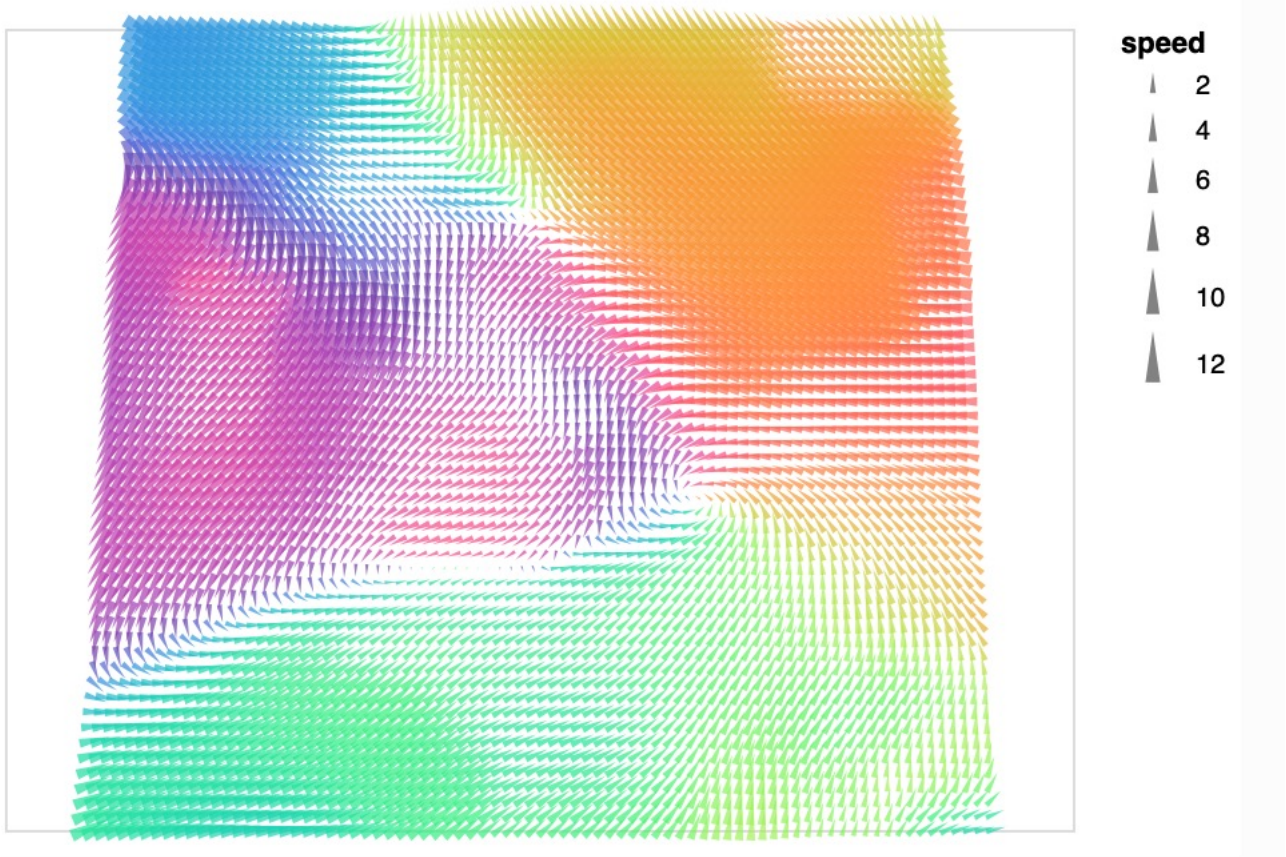


[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

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

Vector/Tensor Fields

- data
  - multiple attribs per cell (vector: 2)
- idiom families
  - flow *glyphs*
    - purely local
  - *geometric* flow
    - derived data from tracing particle trajectories
    - sparse set of seed points
  - *texture* flow
    - derived data, dense seeds
  - *feature* flow
    - global computation to detect features

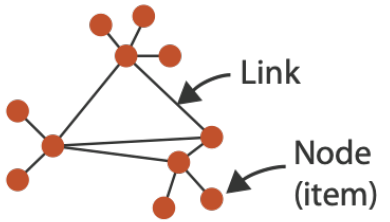


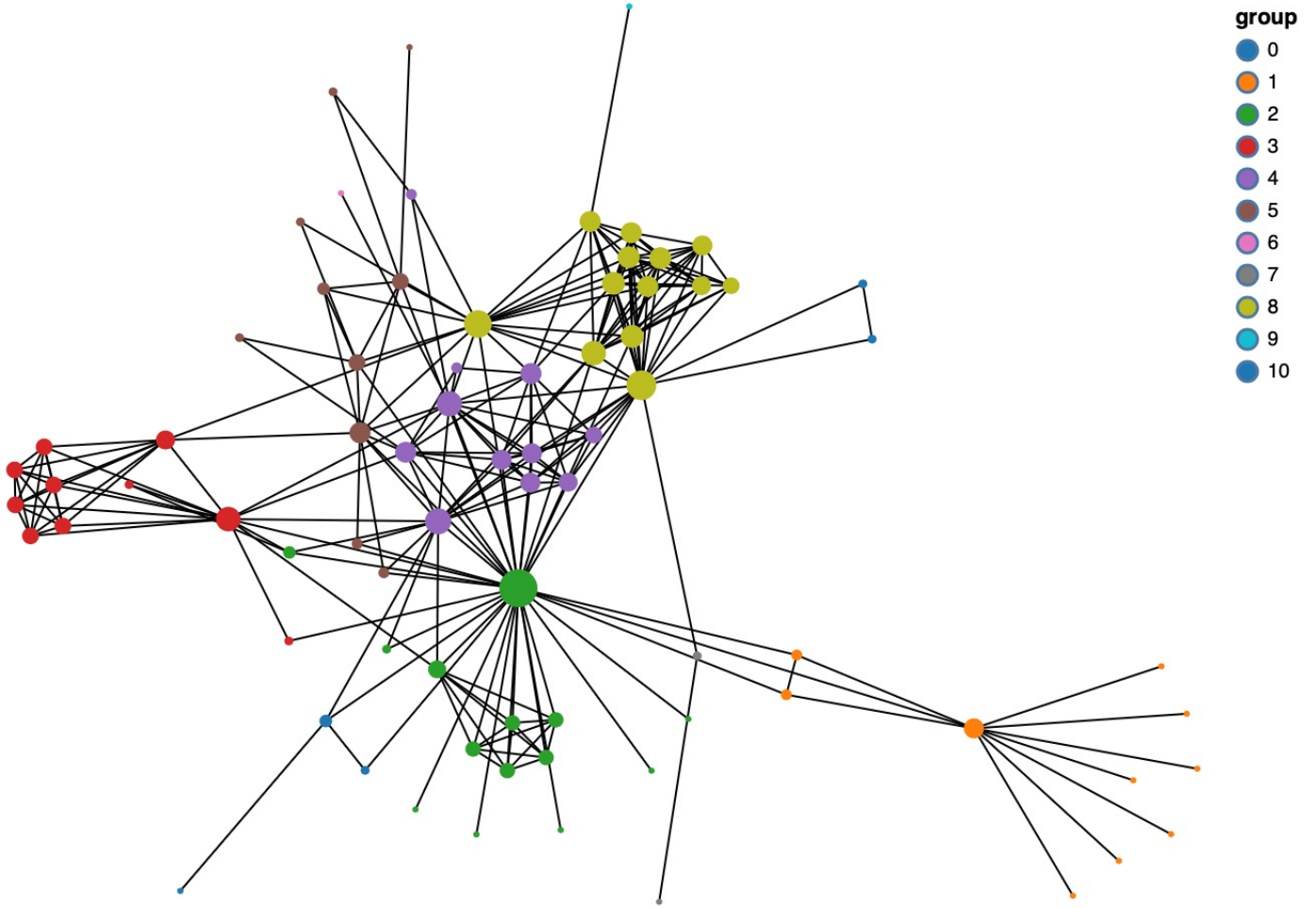
https://altair-viz.github.io/gallery/wind_vector_map.html

Network & Tree Data

Node-Link

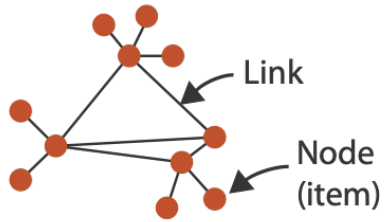
- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants
- challenges
  - edge crossings
  - space optimization
  - symmetry



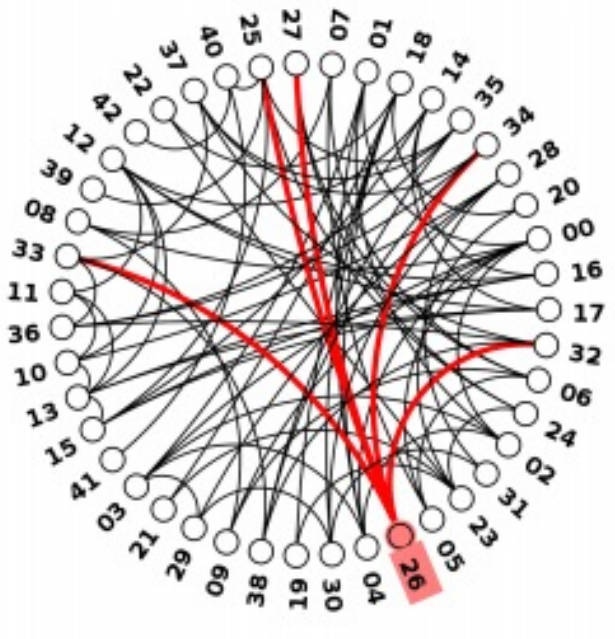


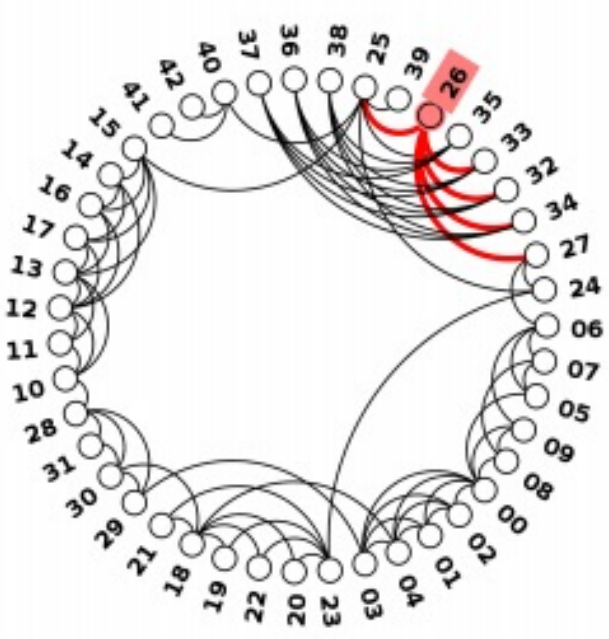
Character Relationships in *Les Miserables*
https://infovis.fh-potsdam.de/tutorials/infovis7networks.html
day_05/basic_charts/network.py

Node-Link



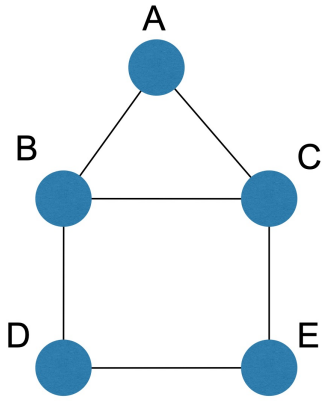
- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants
- challenges
  - edge crossings
  - space optimization
  - symmetry

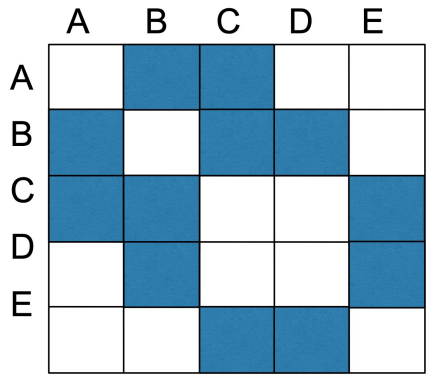




Adjacency Matrix

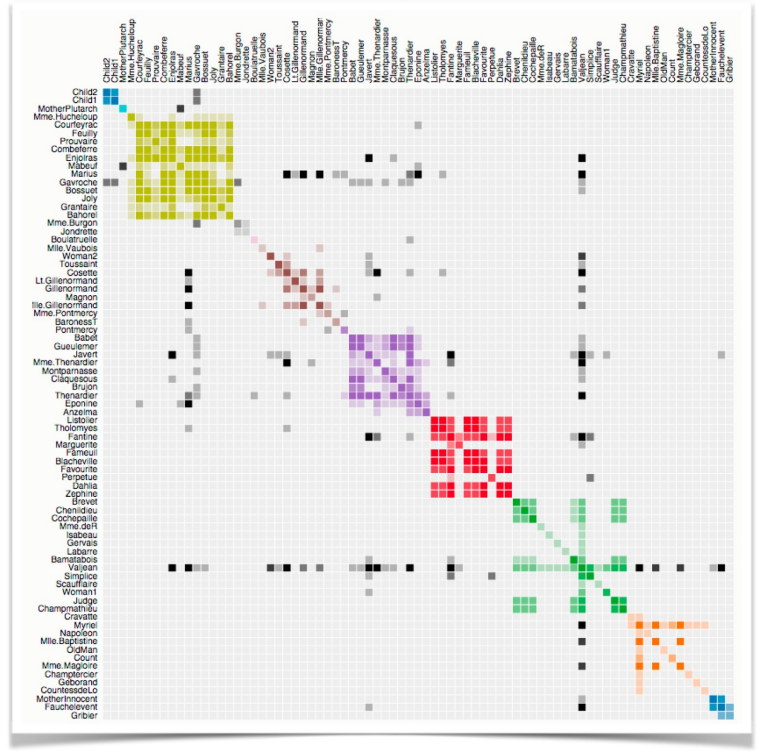
- data: network
  - transform into same data/encoding as heatmap
- derived data: table from network
  - 1 quant attrib
    - weighted edge between nodes
  - 2 categ attribs: node list x 2
- visual encoding
  - cell shows presence/absence of edge
- scalability
  - 1K nodes, 1M edges





Adjacency Matrix

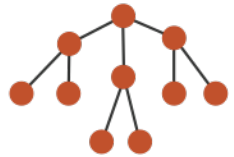
Node ordering strategy crucial to find meaningful patterns



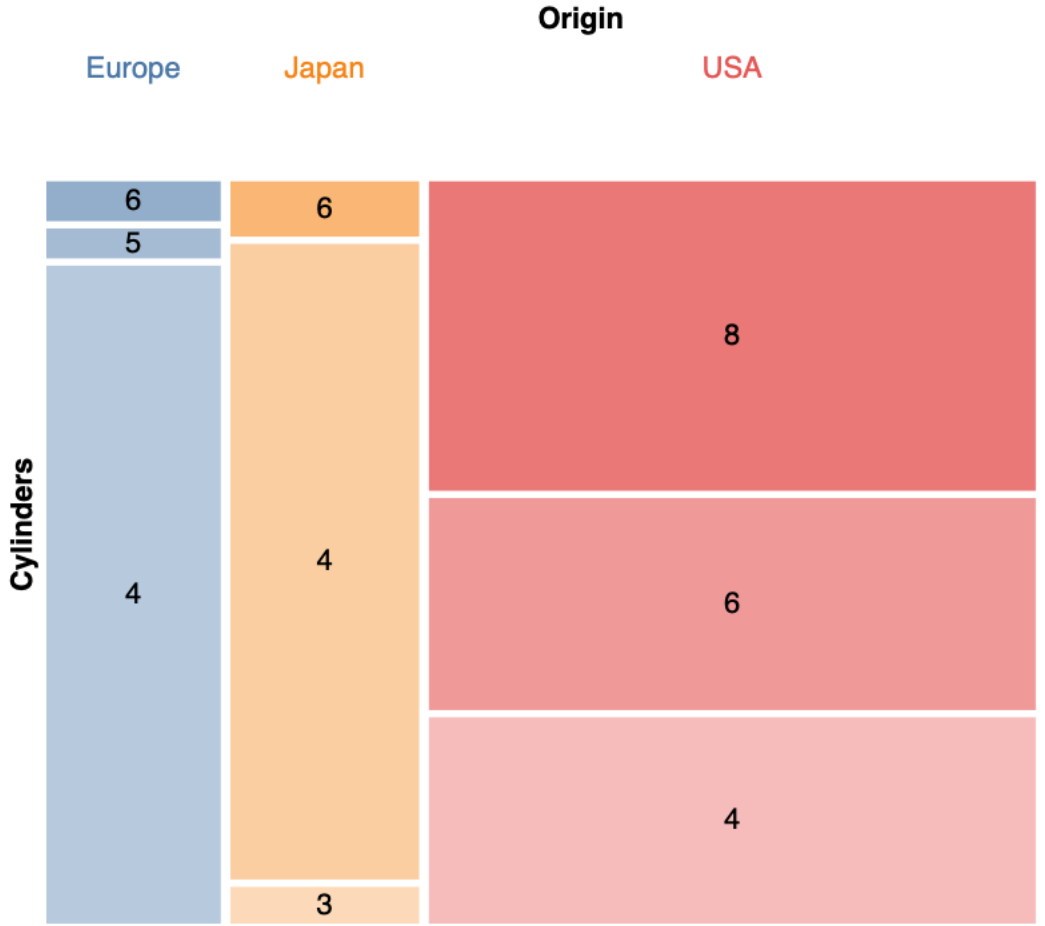
https://bost.ocks.org/mike/miserables/

Treemap

- data
  - tree
  - 1 quant attrib at leaf nodes
- encoding
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib
- tasks
  - query attribute at leaf nodes
  - ex: disk space usage within filesystem
- scalability
  - 1M leaf nodes

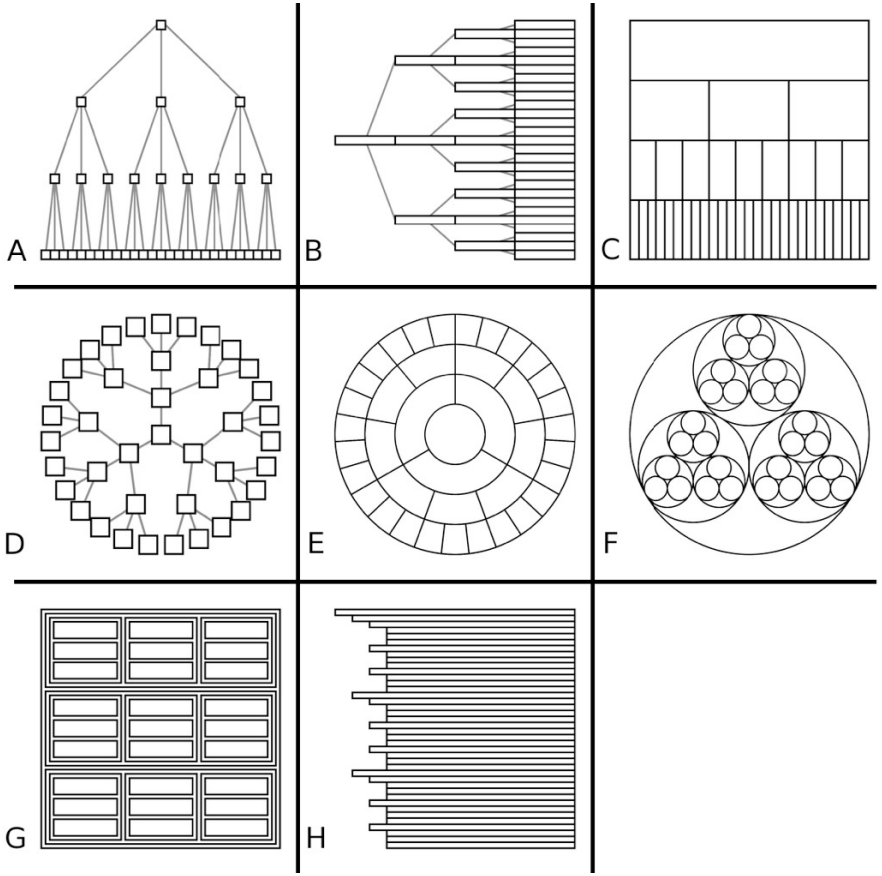


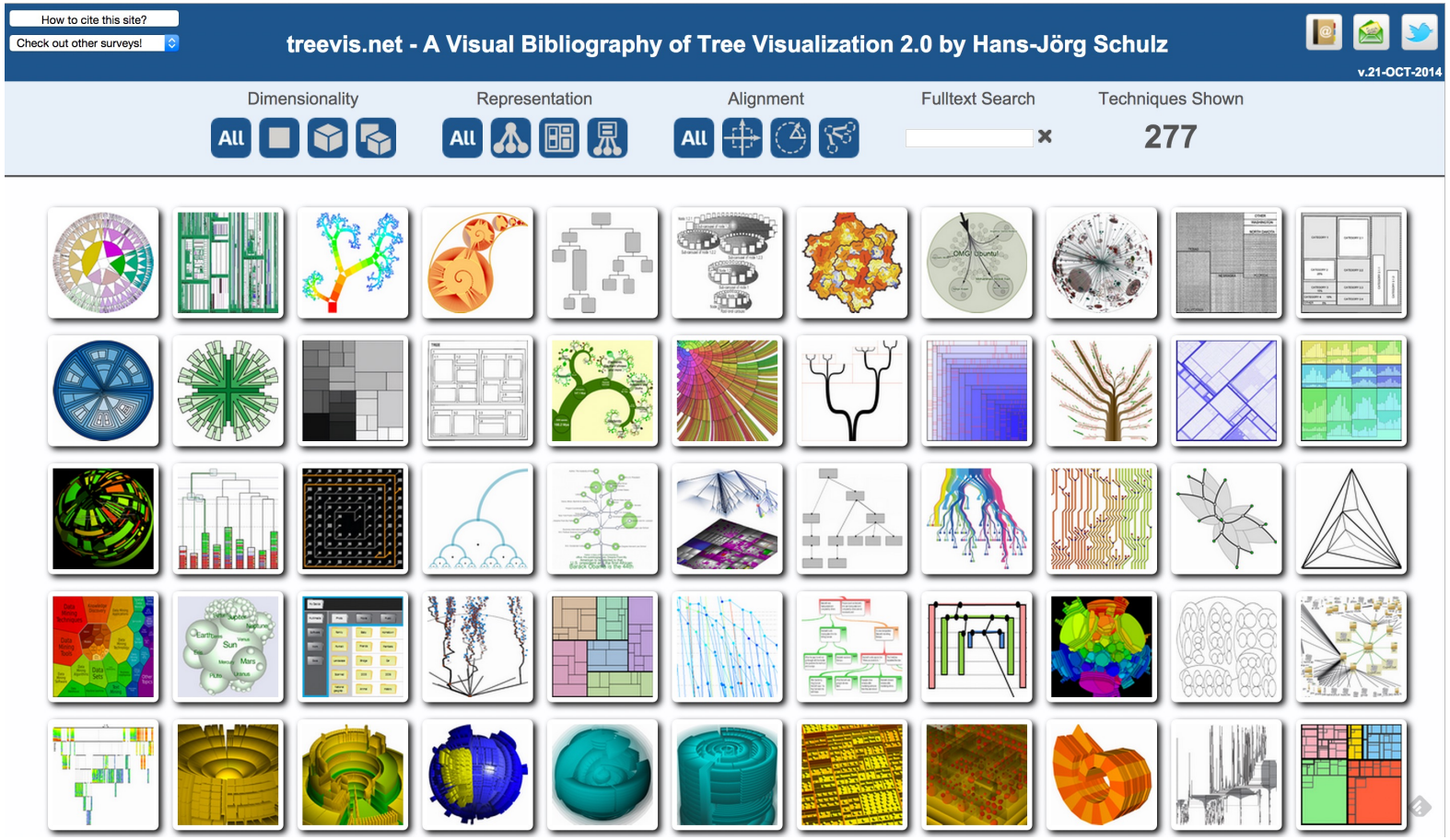
Enclosure
Containment Marks
NETWORKS TREES



day_05/basic_charts/treemap.py
https://github.com/altair-viz/altair/blob/master/altair/examples/mosaic_with_labels.py

Tree Visualization





treevis.net

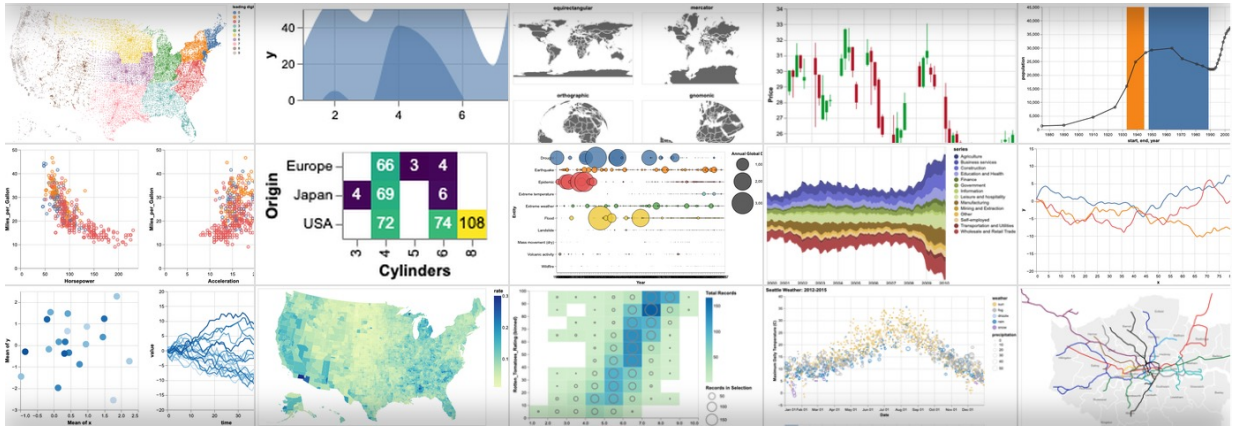
Summary

Choosing an Idiom

- Appropriate idioms for your question depend on:
  - the data
  - the task you're trying to accomplish
  - the ranking and effectiveness of marks and channels to visually encode the data
- Experiment!

Next Up

- Introduce Vega-Altair
- Case study: Bergen weather
- Mini-group project: Weather patterns or features in your city or region of choice



Questions?

Further Reading & Acknowledgement

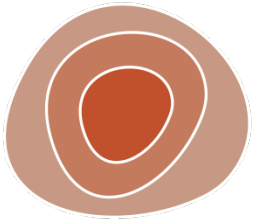
- Web material for Visual Analysis & Design:
  - https://www.cs.ubc.ca/~tmm/talks/vadbook (source material for many slides in this lecture)
- Interactive Visual Data Analysis
- Vega-Altair: Declarative Visualization in Python
  - https://altair-viz.github.io/index.html
- Exploring and Analyzing Network Data with Python
  - https://programminghistorian.org/en/lessons/exploring-and-analyzing-network-data-with-python

Munzner, T. (2014). Visualization analysis and design. AK Peters Visualization Series, CRC Press, Visualization Series
Tominski, T., Schumann, H. (2020). Interactive Visual Data Analysis. AK Peters Visualization Series, CRC Press, Visualization Series.

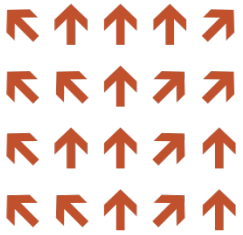
Arrange spatial data

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

  - Spatial Fields
    - *Scalar Fields (one value per cell)*
      - *Isocontours*
      - *Direct Volume Rendering*

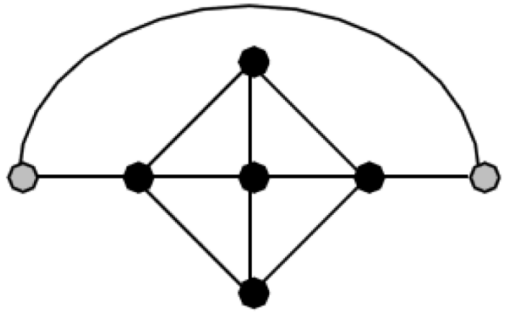


    - *Vector and Tensor Fields (many values per cell)*
      - *Flow Glyphs (local)*
      - *Geometric (sparse seeds)*
      - *Textures (dense seeds)*
      - *Features (globally derived)*



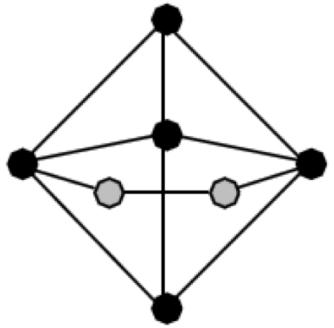
Network Vis Criteria Conflicts

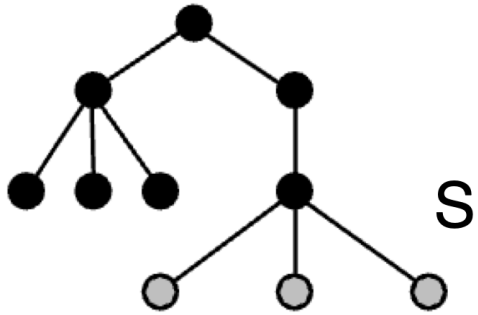
Minimum number of edge crossings



vs.

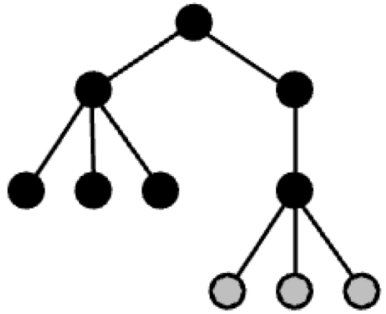
Uniform edge length





Space utilization

vs.



Symmetry