Introduction to Data Visualization

Veera Muangsin

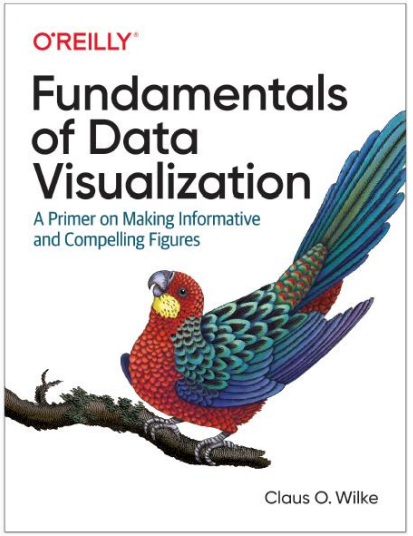
References

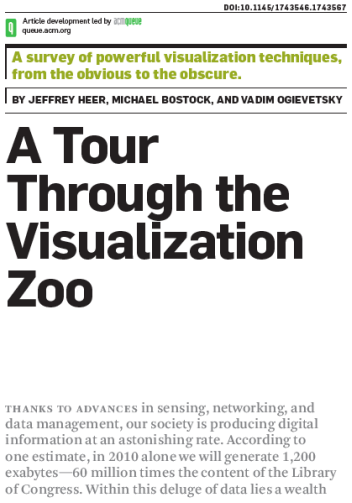
- Book: Fundamentals of Data Visualization, Claus O. Wilke, 2019.

  https://clauswilke.com/dataviz/

- A Tour Through the Visualization Zoo, Jeffrey Heer, et al, Communications of the ACM, 2010.

  https://dl.acm.org/citation.cfm?id=1743567





Examples

- https://public.tableau.com/en-us/s/gallery
- https://community.powerbi.com/t5/Data-Stories-Gallery/bd-p/DataStoriesGallery
- https://www.gapminder.org/tools/
- https://flowingdata.com/
- https://truth-and-beauty.net/
- https://www.dataviz-inspiration.com/
- https://www.data-to-viz.com/

What is Data Visualization?

The process of transforming data

into visual representations

that reveal patterns, relationships, and insights

to support understanding, communication, and decision-making.

Raw data vs. Visualization

country	region	income per person	life expectancy	population
Afghanistan	asia_west	1840	57.2	30700000
Albania	europe_east	10400	77	2920000
Algeria	africa_north	13200	76.8	37600000
Andorra	europe_west	41900	82.6	82400
Angola	africa_sub_saharan	6000	61.7	25100000
Antigua and Barbuda	america_north	19100	77	96800
Argentina	america_south	19200	76.1	42100000
Armenia	europe_east	7510	74.3	2880000
Australia	east_asia_pacific	42600	82.3	22800000
Austria	europe_west	44400	80.9	8520000
Azerbaijan	europe_east	15900	70.2	9260000
Bahamas	america_north	23000	73.7	372000
Bahrain	asia_west	41500	76.3	1300000
Bangladesh	asia_west	2710	71.3	156000000
Barbados	america_north	15400	76.8	282000
Belarus	europe_east	17500	71.8	9470000
Belgium	europe_west	41000	80.3	11100000
Belize	america_north	7970	71.6	337000
Benin	africa_sub_saharan	1860	62.6	9730000
Bhutan	asia_west	7030	72.9	753000
Thailand	east_asia_pacific	14400	77.2	67800000
Timor-Leste	east_asia_pacific	2030	72	1160000
Togo	africa_sub_saharan	1260	60.4	6860000
Tonga	east_asia_pacific	5130	70	105000
Trinidad and Tobago	america_north	31300	72.8	1340000
Tunisia	africa_north	10400	77.1	10900000
Turkey	europe_east	20300	78.6	74600000
Turkmenistan	asia_west	12200	68.8	5270000
Uganda	africa_sub_saharan	1640	58.6	36300000
Ukraine	europe_east	8320	71.1	45300000
United Arab Emirates	asia_west	59800	76.4	8900000
United Kingdom	europe_west	36700	80.7	64300000
United States	america_north	50500	78.9	313000000
Uruguay	america_south	18500	76.5	3400000
Uzbekistan	asia_west	4770	69.3	29500000
Vanuatu	east_asia_pacific	2900	63.3	247000
Venezuela	america_south	17700	75.3	29900000
Vietnam	east_asia_pacific	4910	73.6	90500000
Yemen	asia_west	3790	67.9	24900000
Zambia	africa_sub_saharan	3510	54.5	14700000
Zimbabwe	africa_sub_saharan	1850	54.1	14700000

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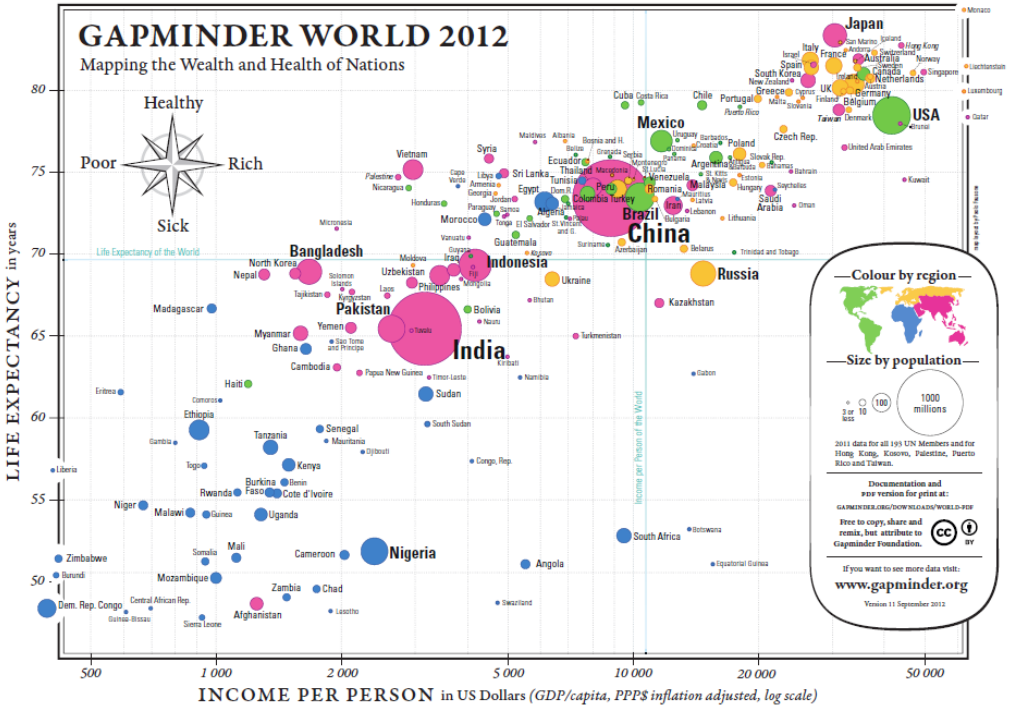
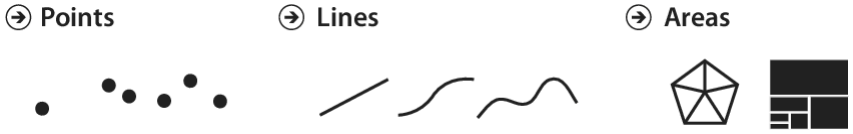


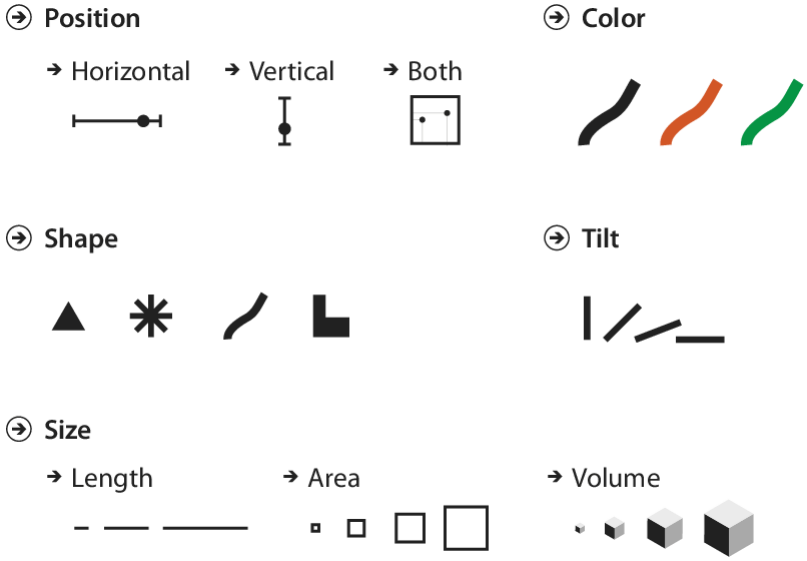
Visual Representation

Data visualization displays measured quantities using a combination of geometric primitives.

Marks are geometric primitives.

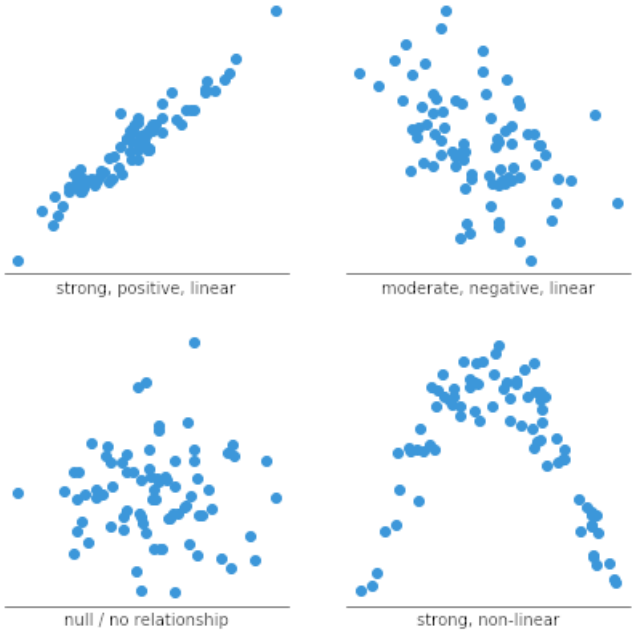


The appearance of marks corresponds to the data.

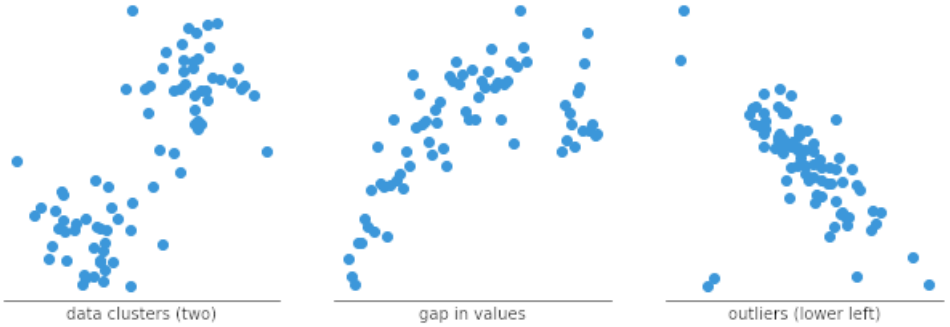


What a simple visualization can do

A scatter plot can reveal correlational relationships



and other patterns

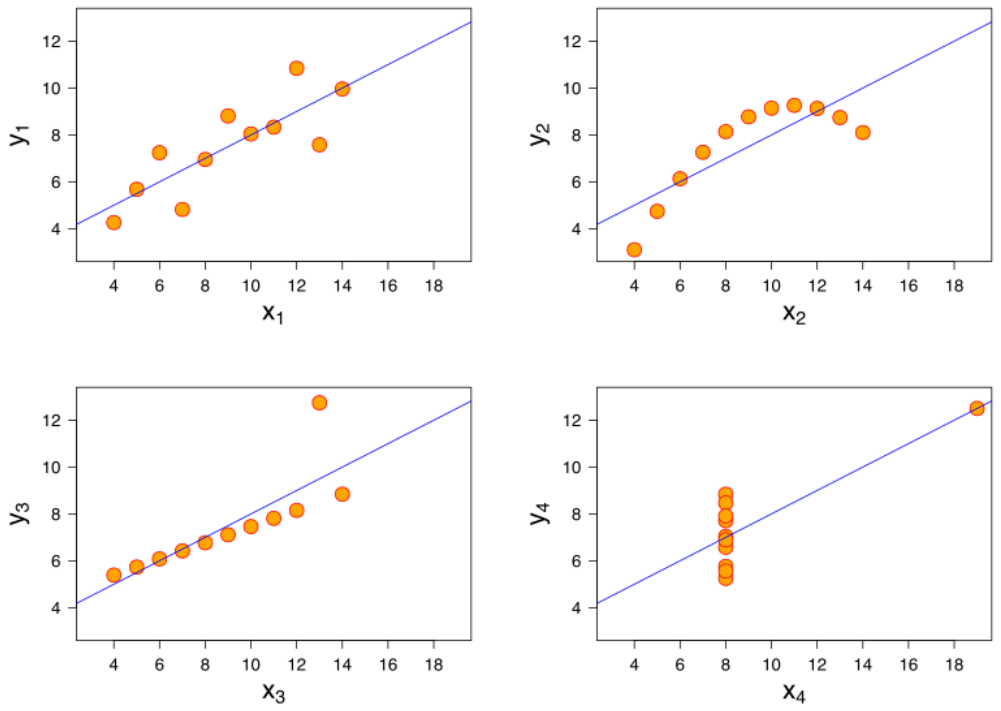


Anscombe's quartet

- Demonstrate the importance of visual representation of data
- All four datasets have almost identical statistics but different graphs

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Property	Value
Mean of *x*	9
Sample variance of *x*	11
Mean of *y*	7.50
Sample variance of *y*	4.125
Correlation between *x* and *y*	0.816
Linear regression line	$y = 3.00 + 0.500x$
Coefficient of determination of the linear regression	0.67



https://en.wikipedia.org/wiki/Anscombe%27s_quartet

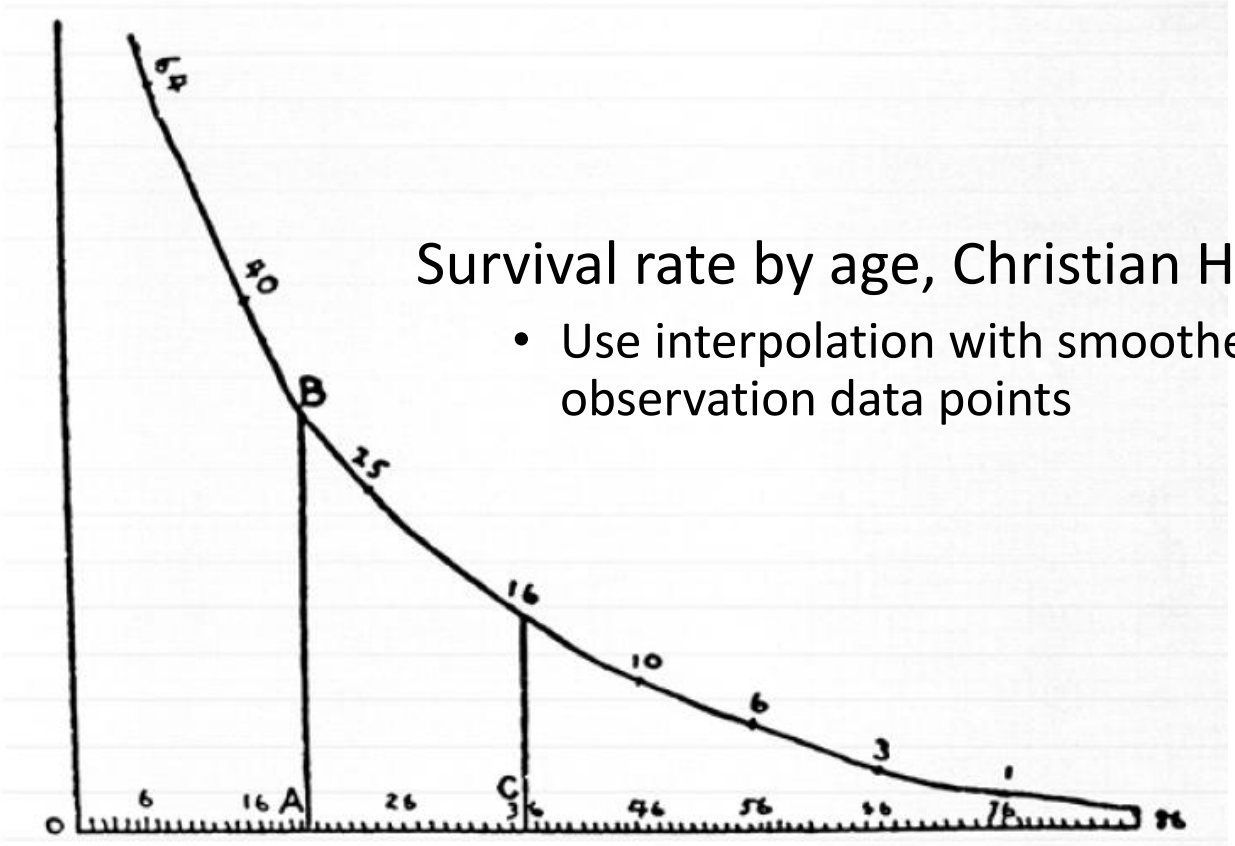
Types of Visualization

Main types of data visualization

- Relational graphics
- Time-series
- Spatial data map
- Network graph

Relational Graphics

Show quantitative relationships between variables



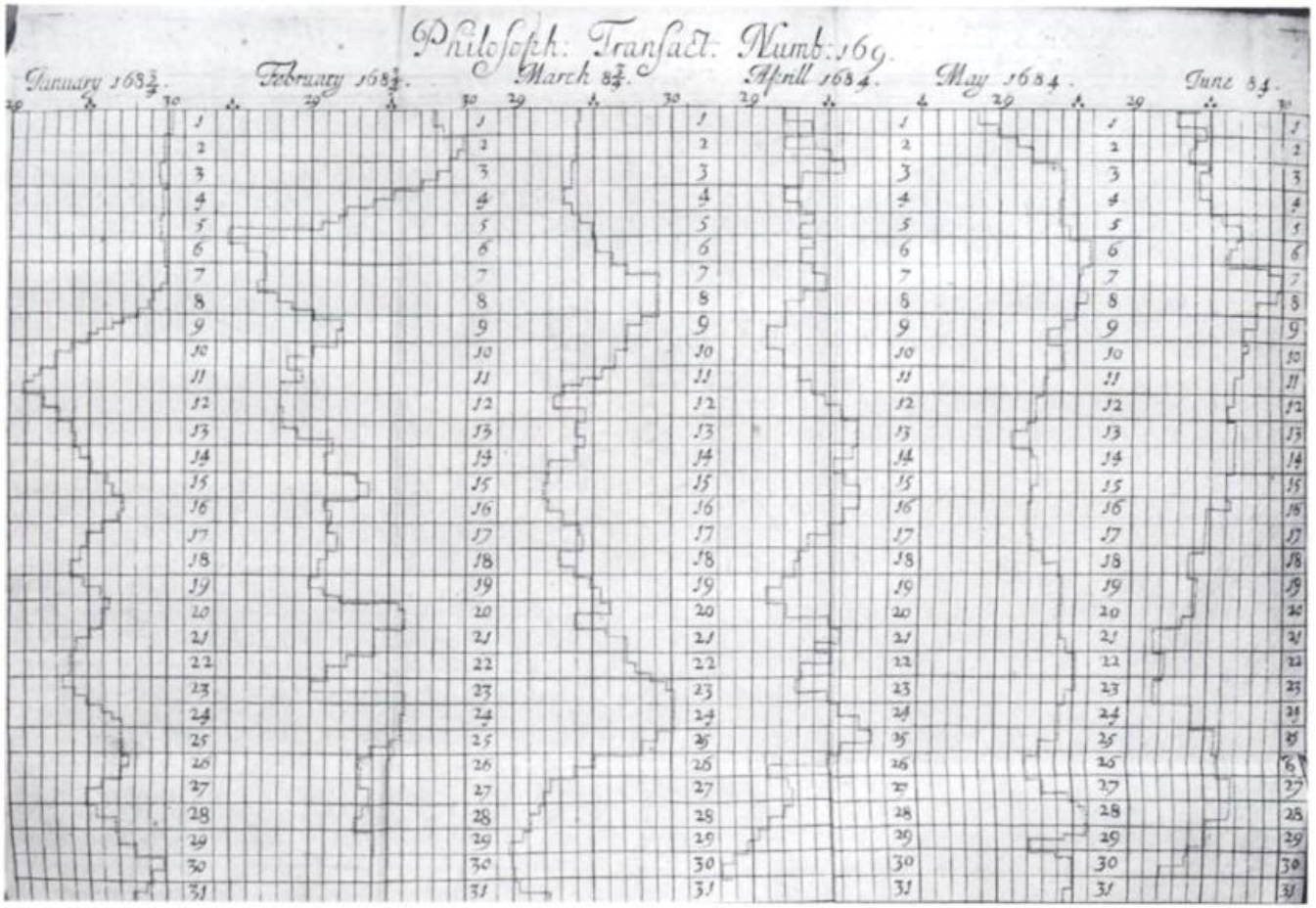
Survival rate by age, Christian Huygens, 1669

- Use interpolation with smoothed curve from observation data points

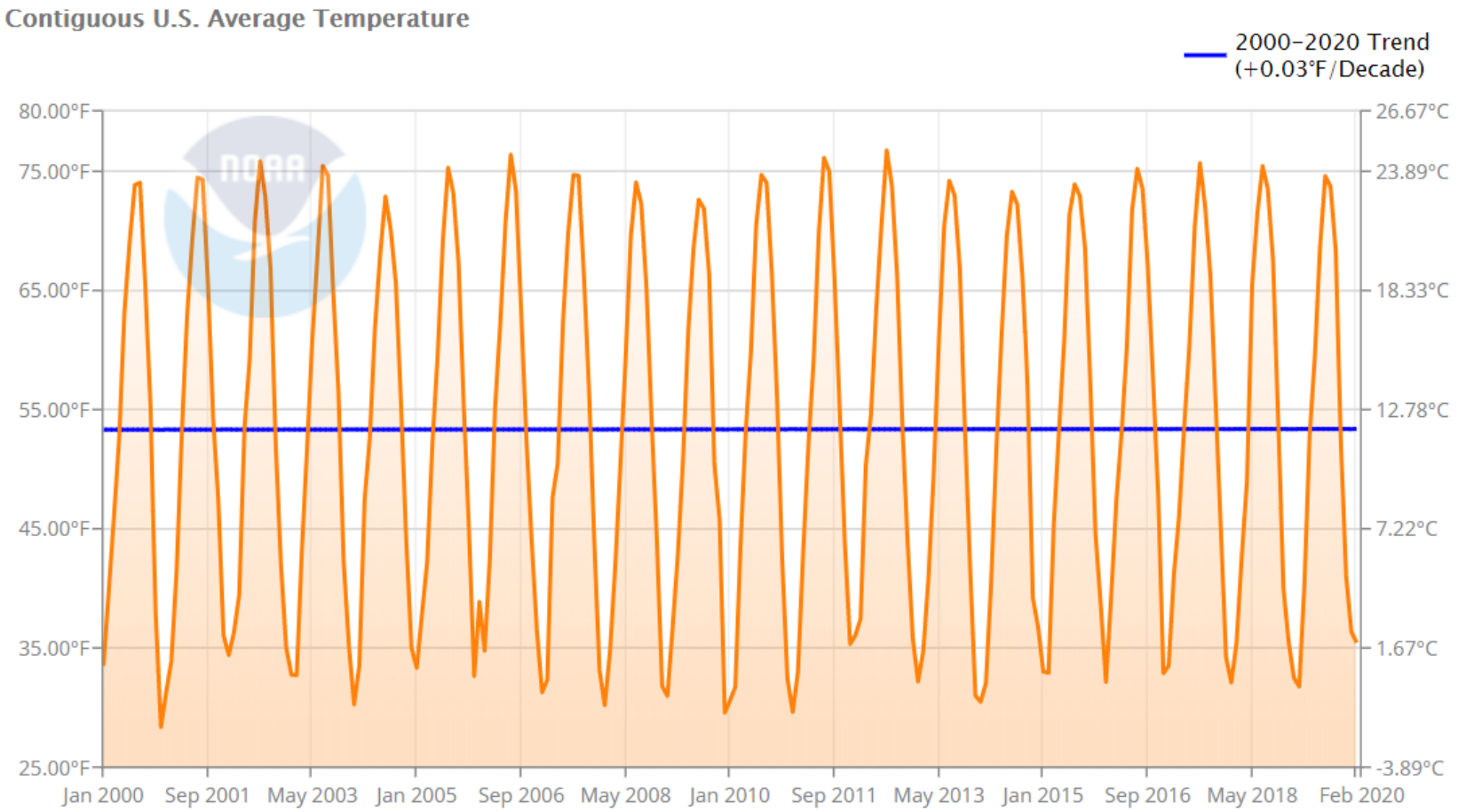
Time series

Show change over time and repeating patterns

Daily barometric pressure in Oxford, Robert Plot, 1685



Time series



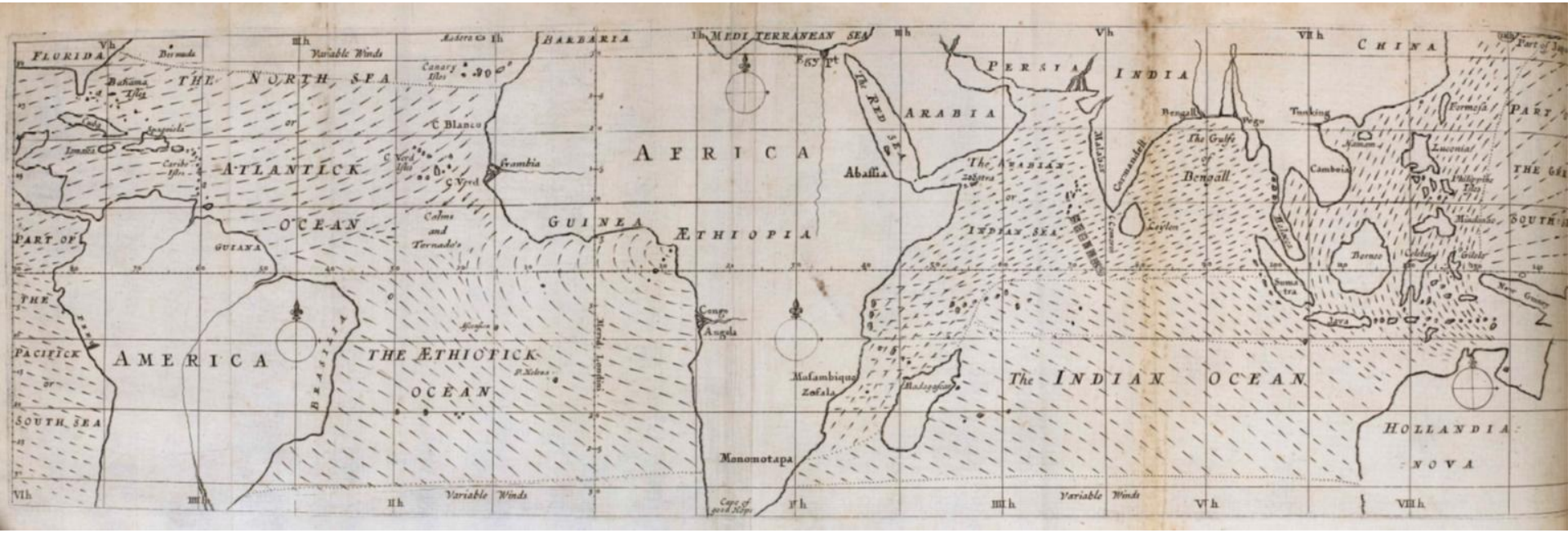
https://www.ncdc.noaa.gov/cag/national/time-series/

Spatial data map

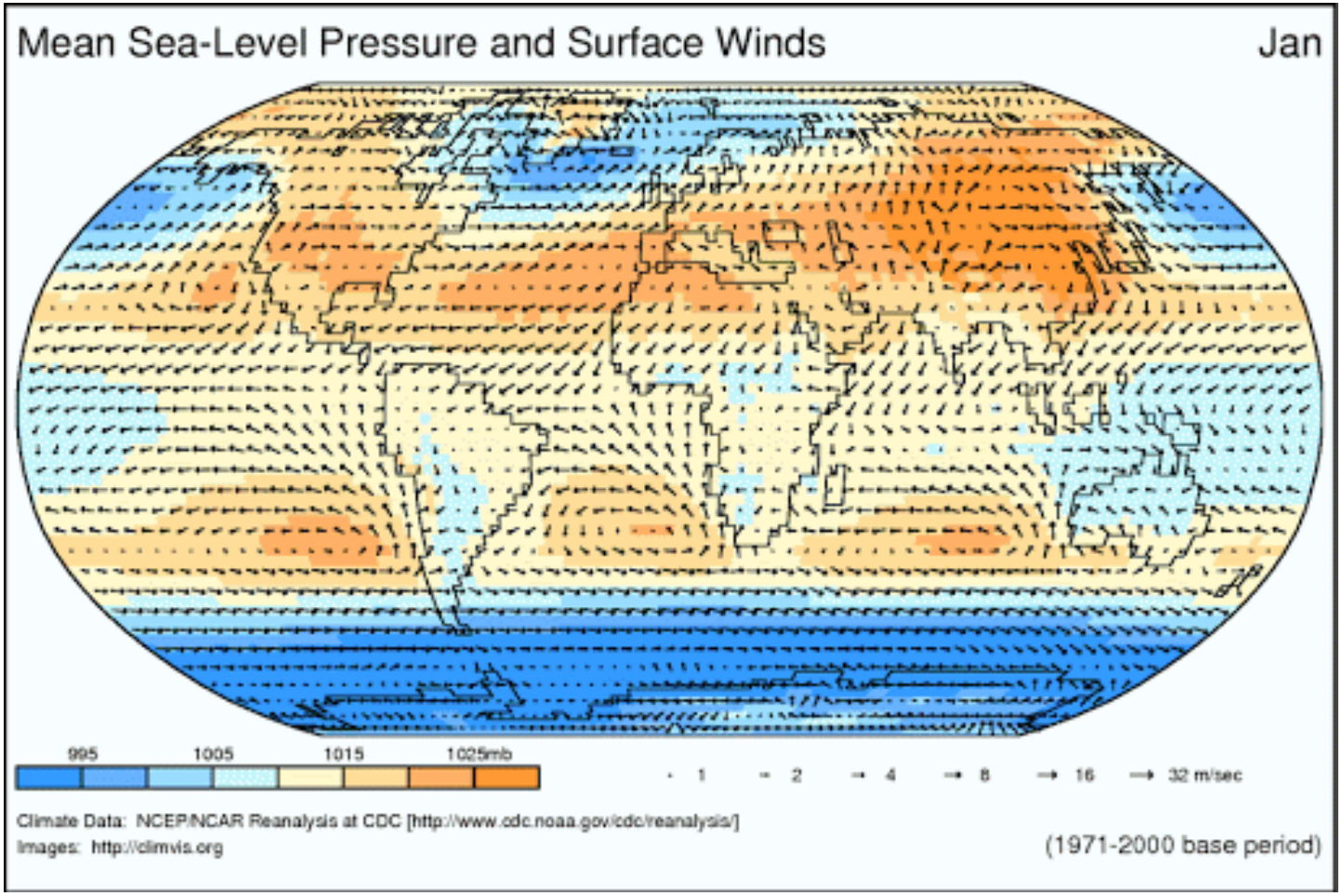
Show relationships between data and geolocation on map

Map of Trade Winds and Monsoons, Edmond Halley, 1686

- Use line symbols to represent direction



Spatial data map



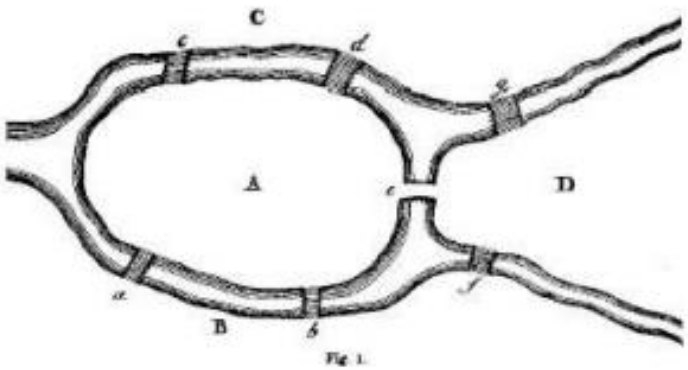
Network graph

Show relationships between members of a set

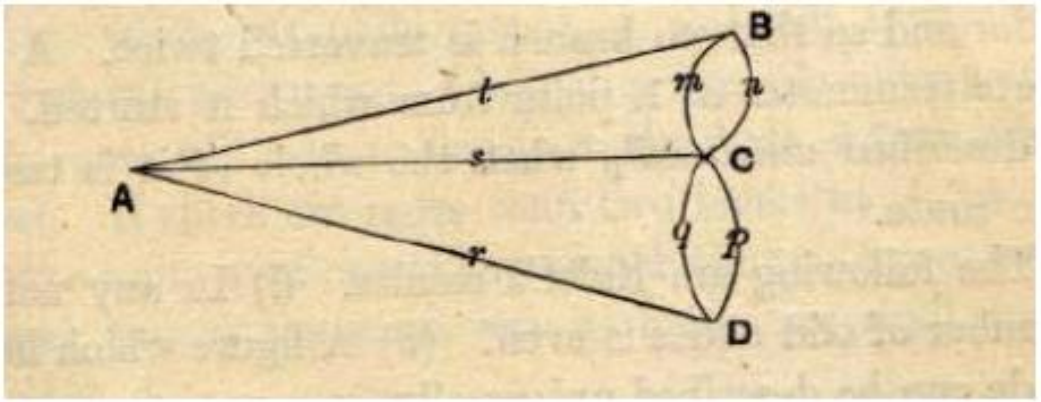
Node=entity Edge=relationship

The seven bridges of Königsberg problem, Euler (1736), Rouse Ball (1892)

Is it possible to take a walk through the town in such a way as to cross over every bridge once, and only once?



(a)



(b)

Network Graph

Facebook friendships (2010)

Each line connects between two cities, weighted by the number of friendships and geographic distance.

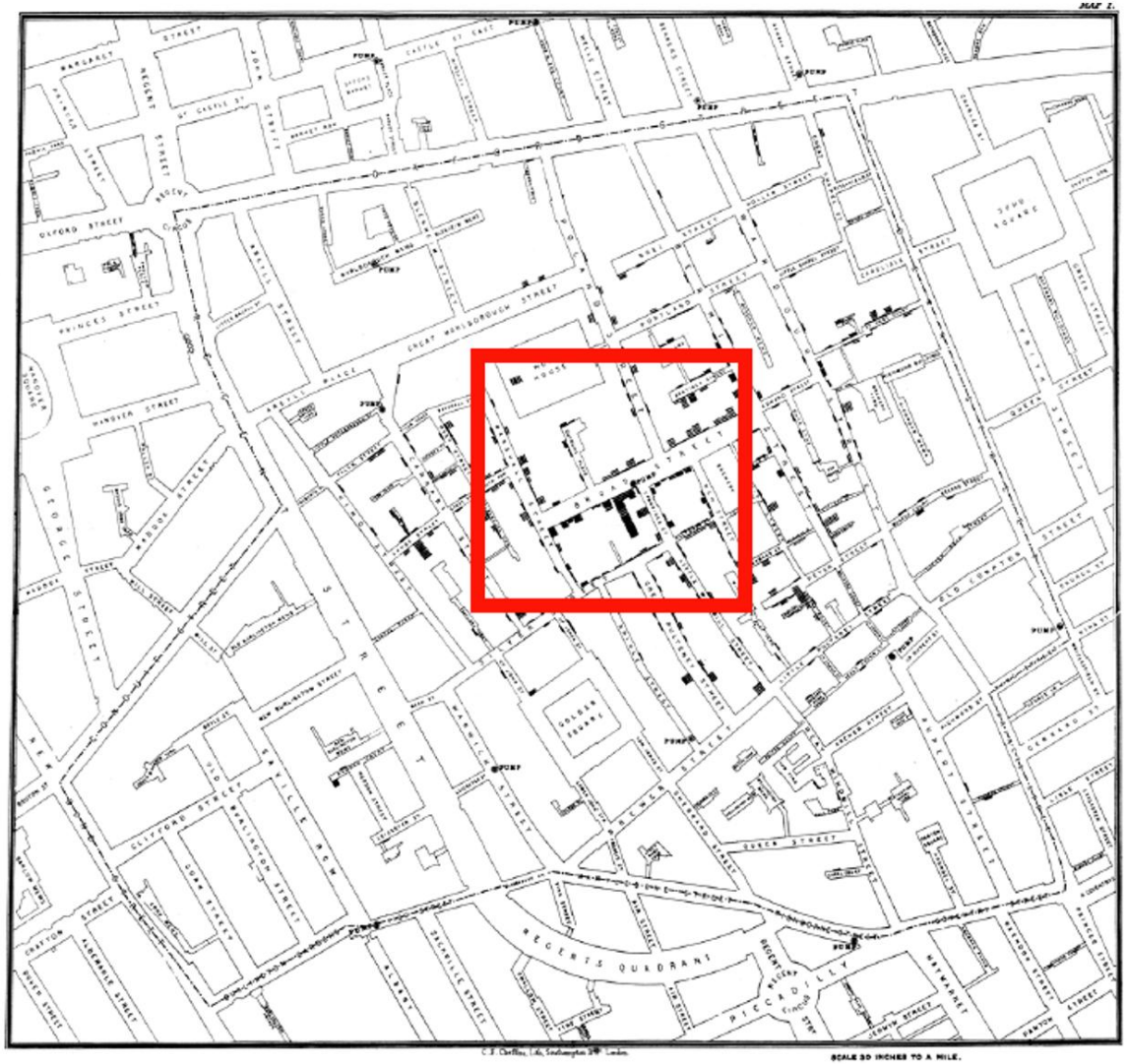
https://www.facebook.com/notes/10158791468612200/

Data Visualization Tools

Type	Examples	Specialty
Dashboard	PowerBI, Tableau, Looker Studio (aka Google Data Studio)	
	Grafana	monitoring
Software package	ArcGIS, QGIS	map
	Gephi	network
Programming libraries	Python matplotlib, plotly, streamlit	
	Python streamlit, dash	web app
	Python folium, pydeck	map
	Python networkX, scikit-network, pyvis	network
	Javascript D3	
	R ggplot	

Examples

Classic Example: Dr.John Snow's Cholera Map (1855)



To stop the outbreak of cholera in London in 1854, **Dr. John Snow marked the cholera deaths on a map**. This map visualization indicated that the water from a pump on **Broad Street** was to blame as a large number of deaths were marked close to that pump. Snow's visualization is one of the most important early examples of epidemiology, that **clearly linked cholera's spread to water and not air**.

Snow, 1855 in
On the Mode of Communication of Cholera

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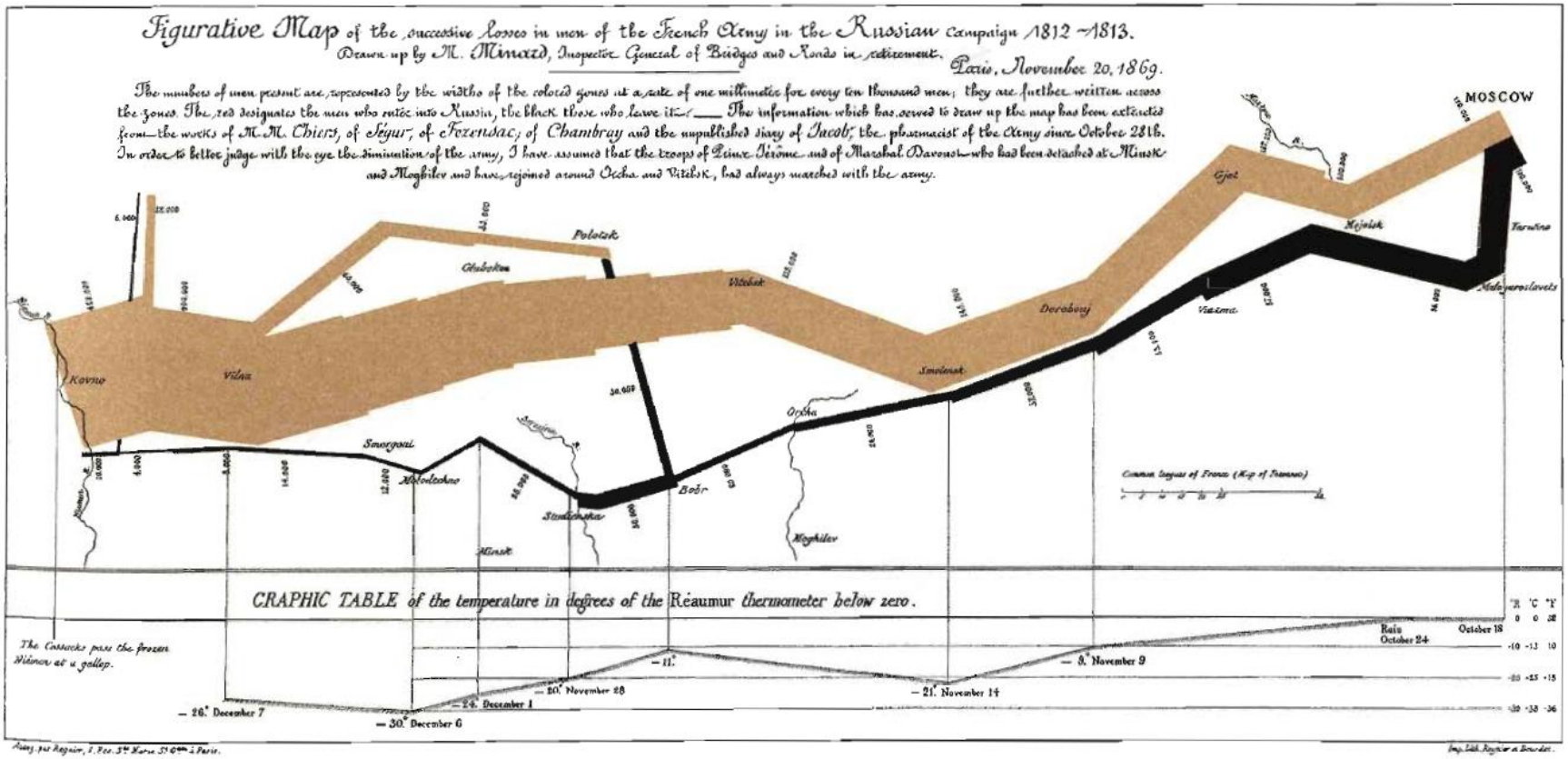
Snow, 1855 in
On the Mode of Communication of Cholera

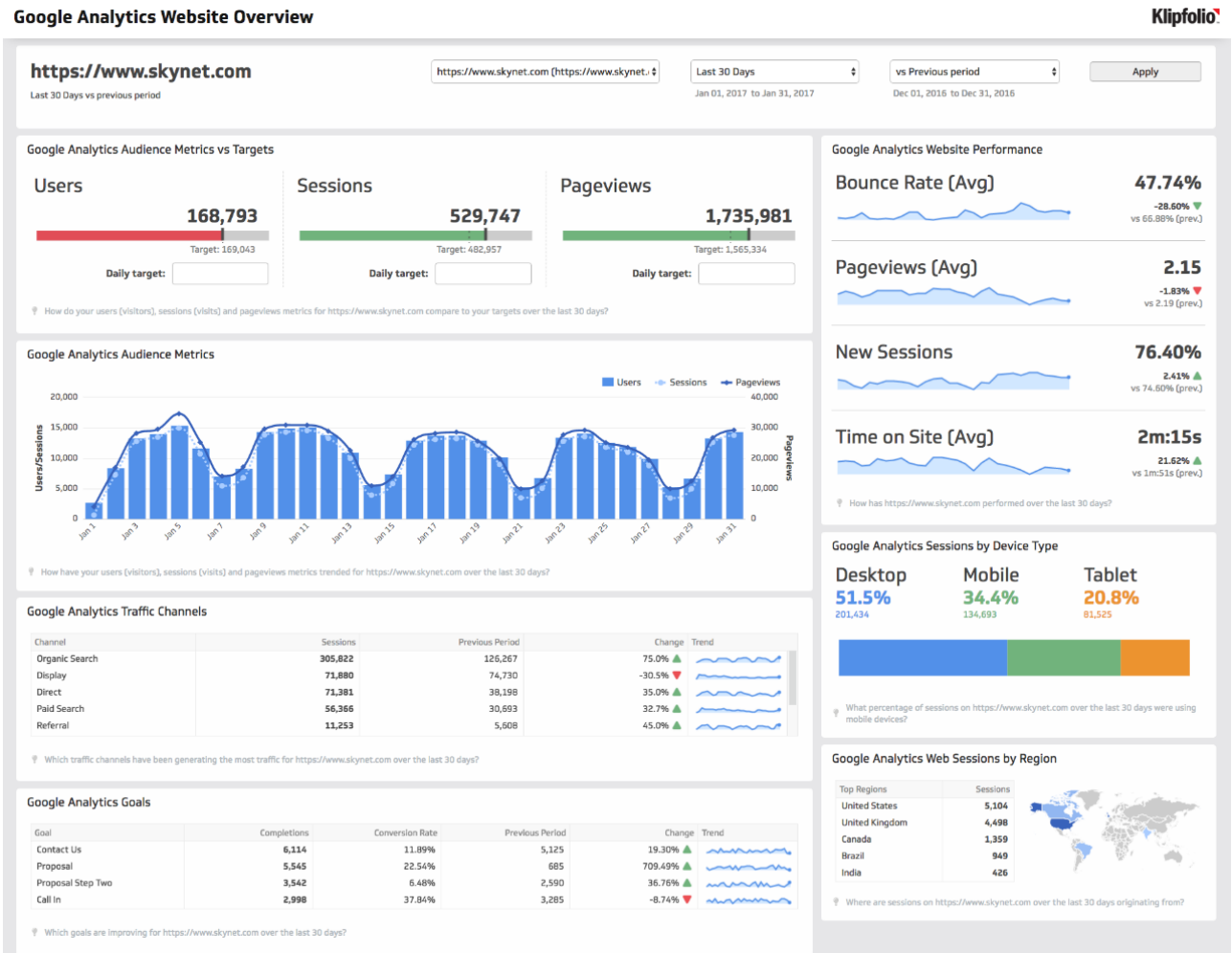
Classic Example: Napoleon's army in Russia (1869)



- Charles Joseph Minard (1869)
- In 1812-1813, Napolean led the army of 422,000 men from Poland border to Moscow (north-east direction) and then retreated. Only 10,000 men came back.
- Combined data map and time-series
- A flow line represents the route on the map, labeled with place names. Line thickness represents size of army at each place. The different colors represent the directions.
- The time-series chart show temperature and date.
- 6 variables are plotted: location of army on two-dimensional map, army's size, direction of army's movement, temperature, and date.

Modern Example: Dashboard

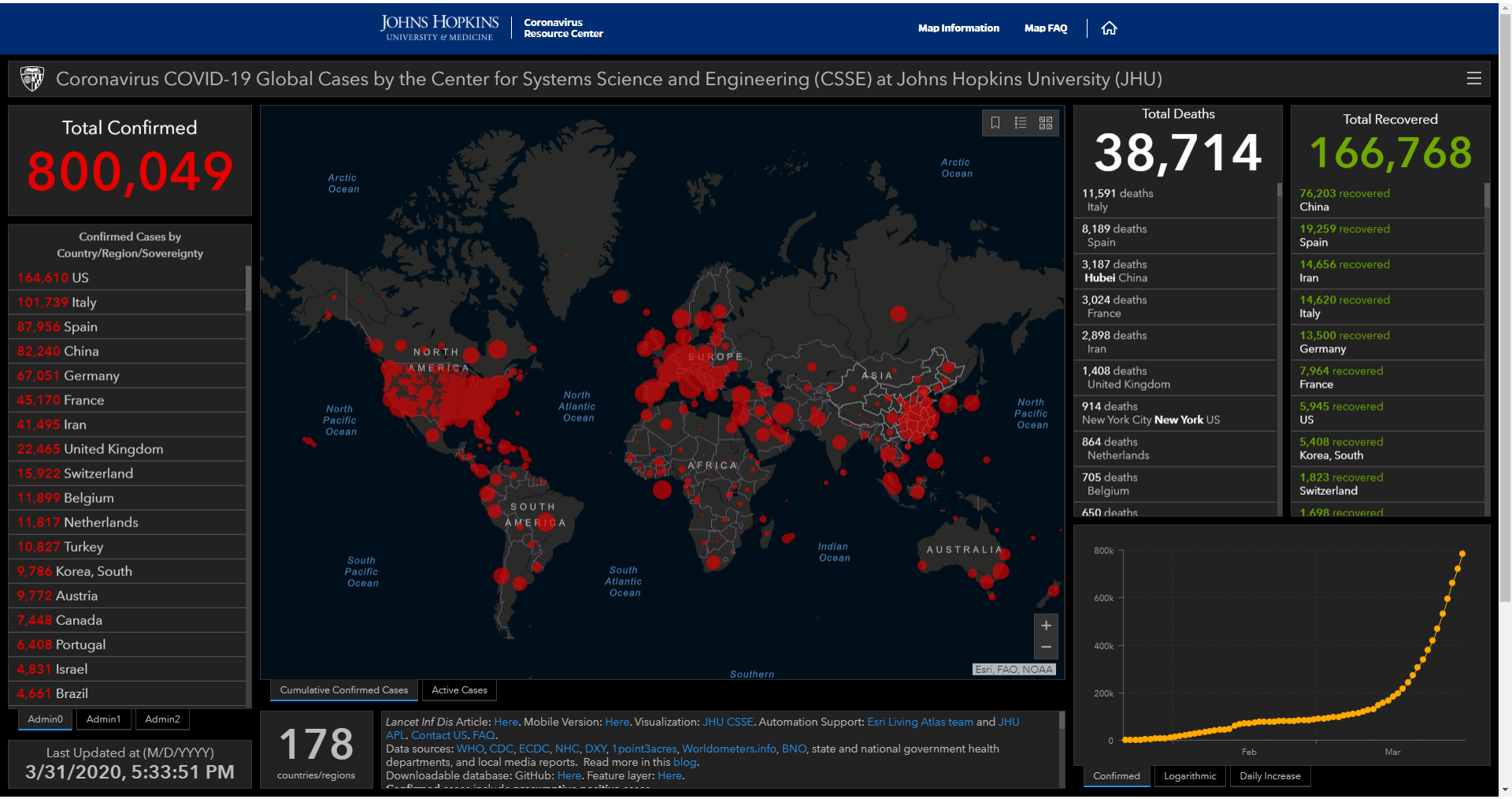
Display many measures or key performance indicators (KPIs) on different charts.



Stock Market Technical Chart

JHU COVID-19 Dashboard (2020)

https://coronavirus.jhu.edu/map.html



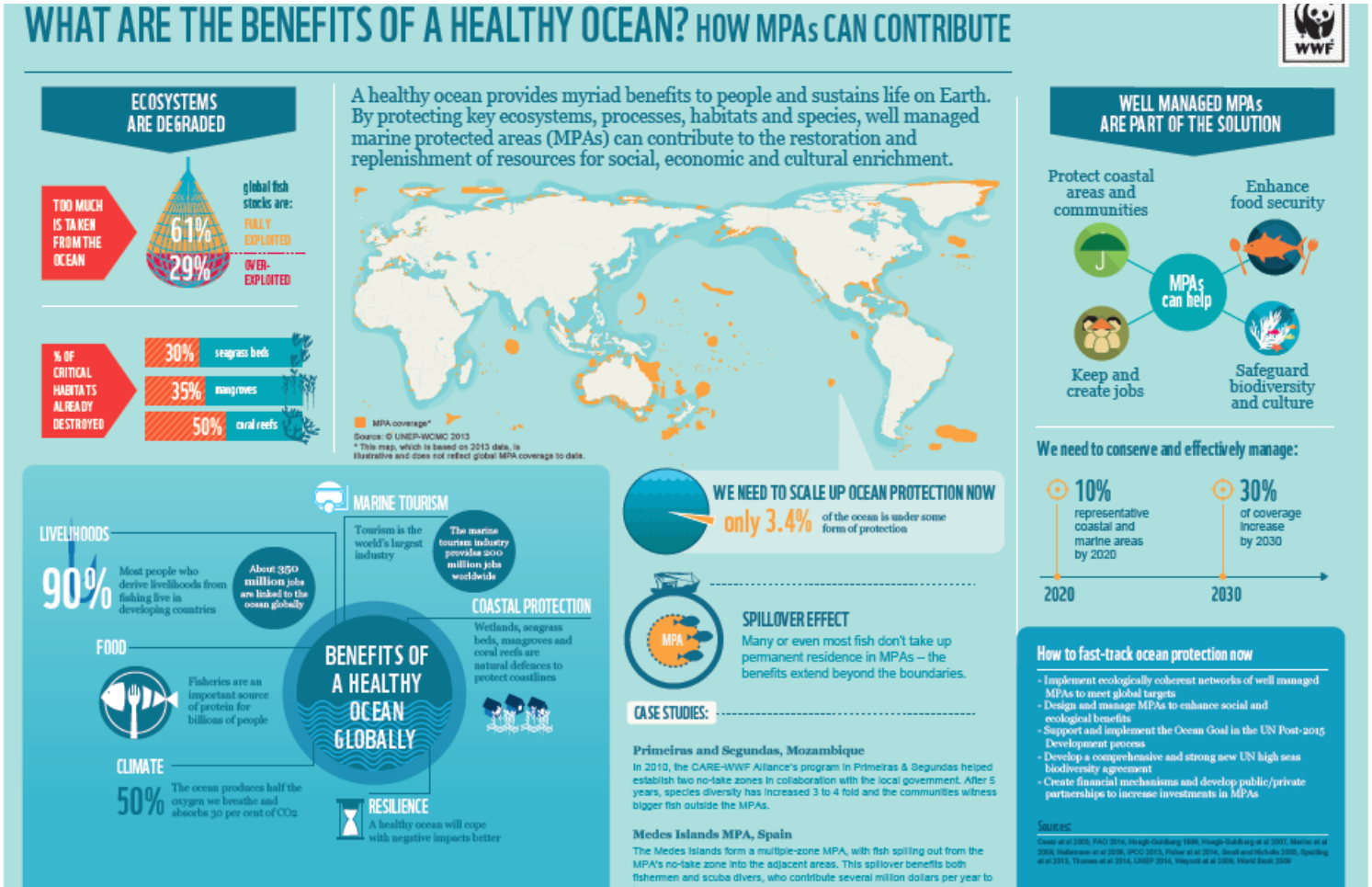
Traffic Congestion Dashboard

https://public.tableau.com/app/profile/veera.muangsin/viz/CongestionbasedonTravelTimeIndex/TravelTimeIndexTTIDashboard

Infographics

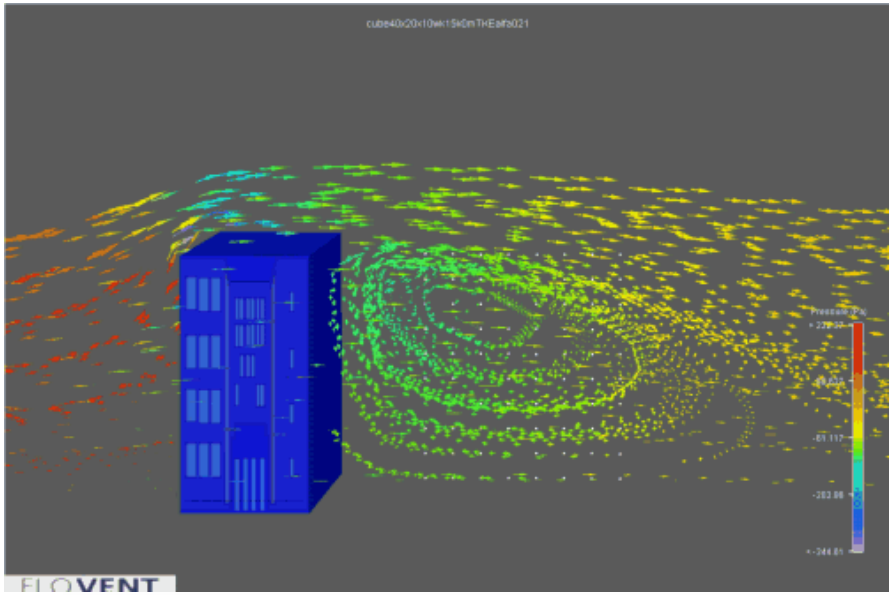
Storytelling via graphical data representation.

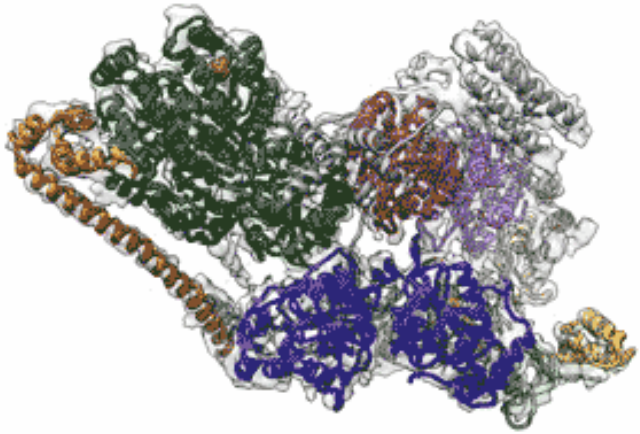
Aesthetic is more important than accuracy.

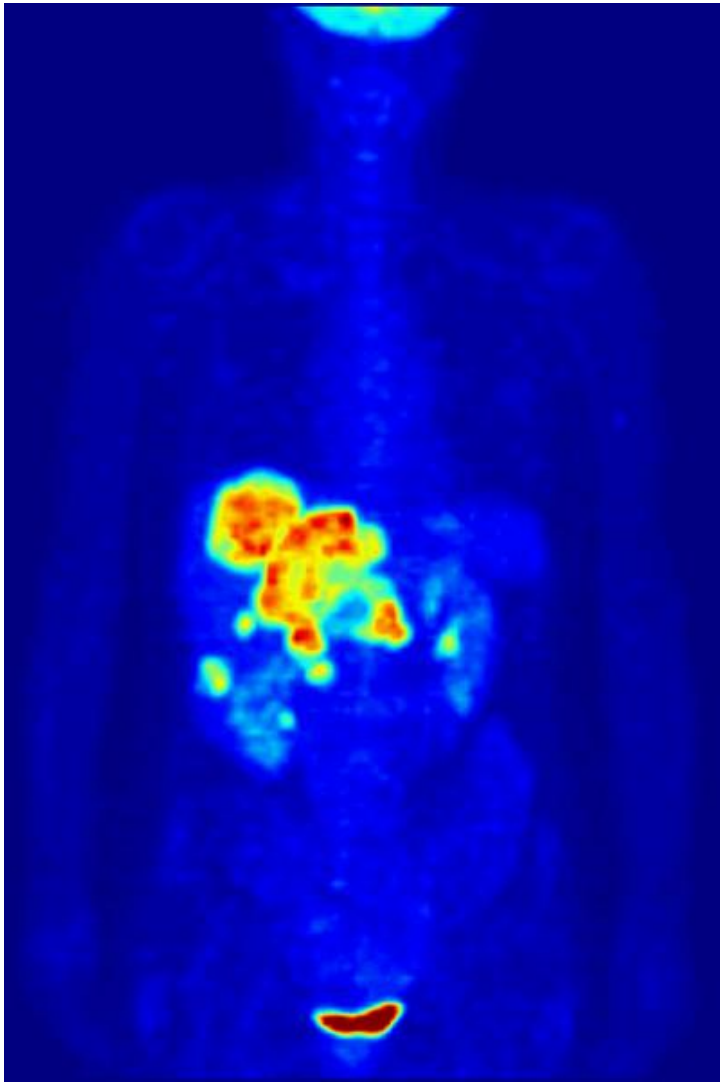


Scientific Visualization

Visualize data from scientific instruments and simulation.

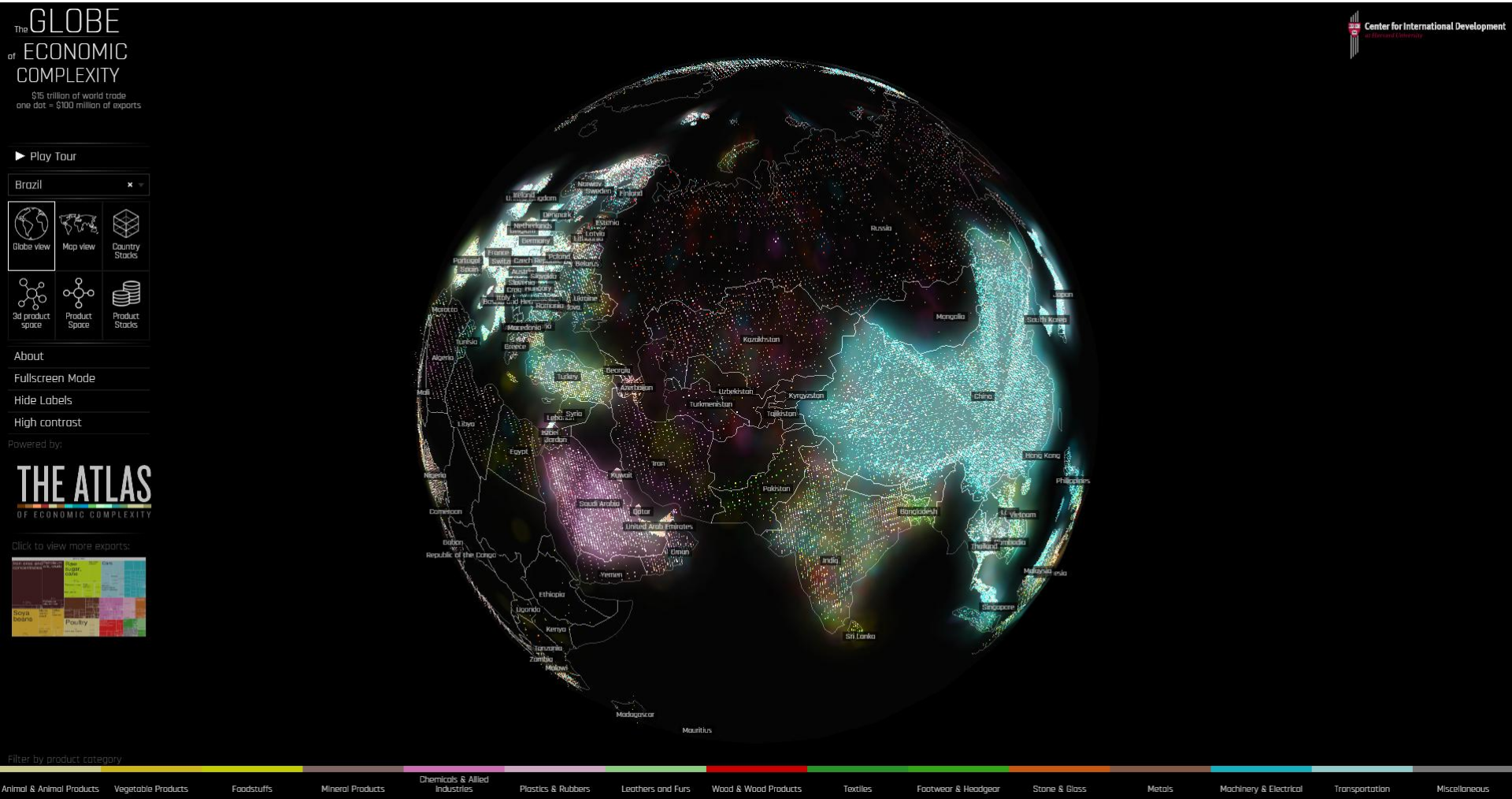






The Globe of Economic Complexity

http://globe.cid.harvard.edu/?mode=gridSphere&id=BA

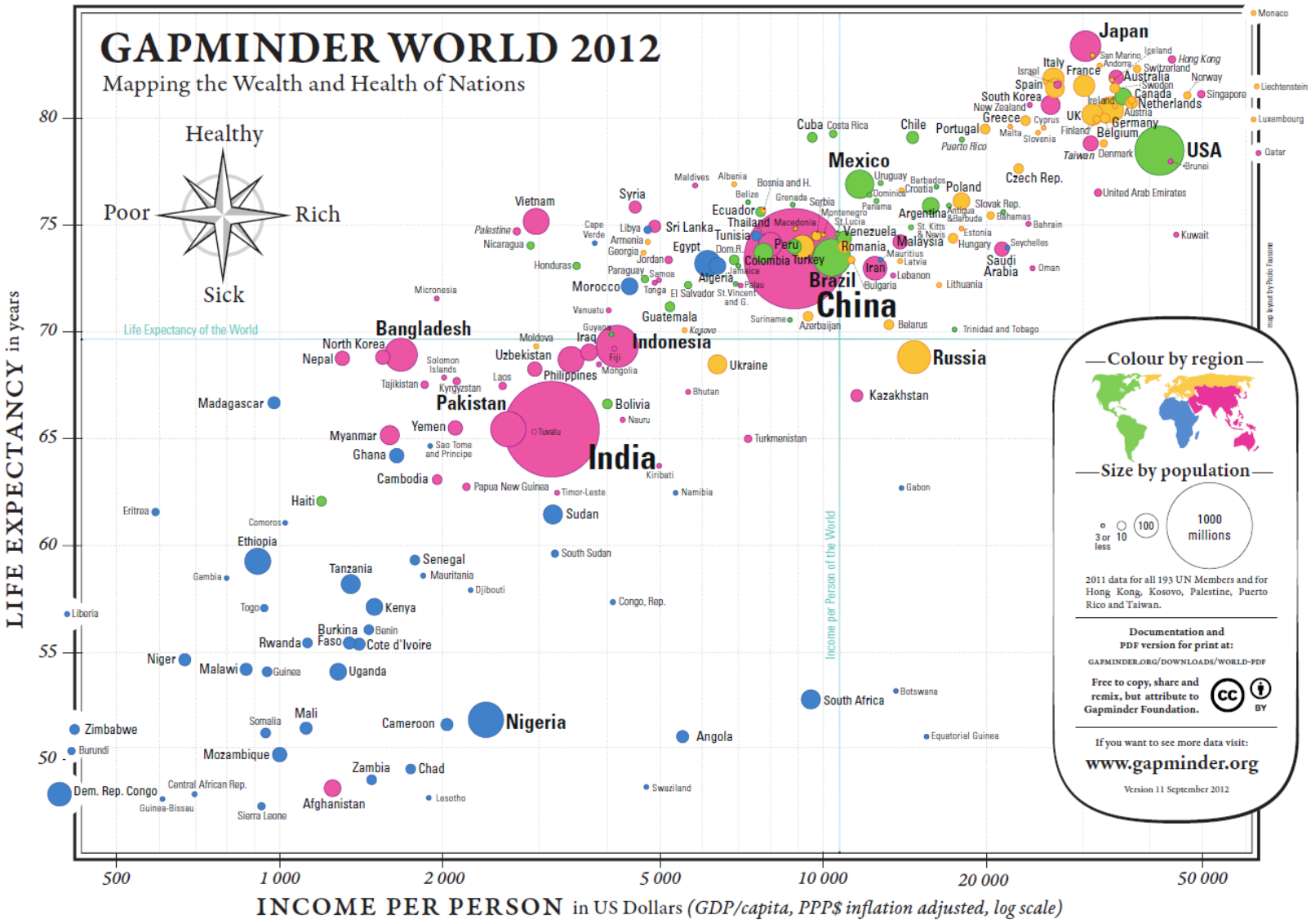


The Globe of Economic Complexity

https://youtu.be/Obuq_L2U4VU

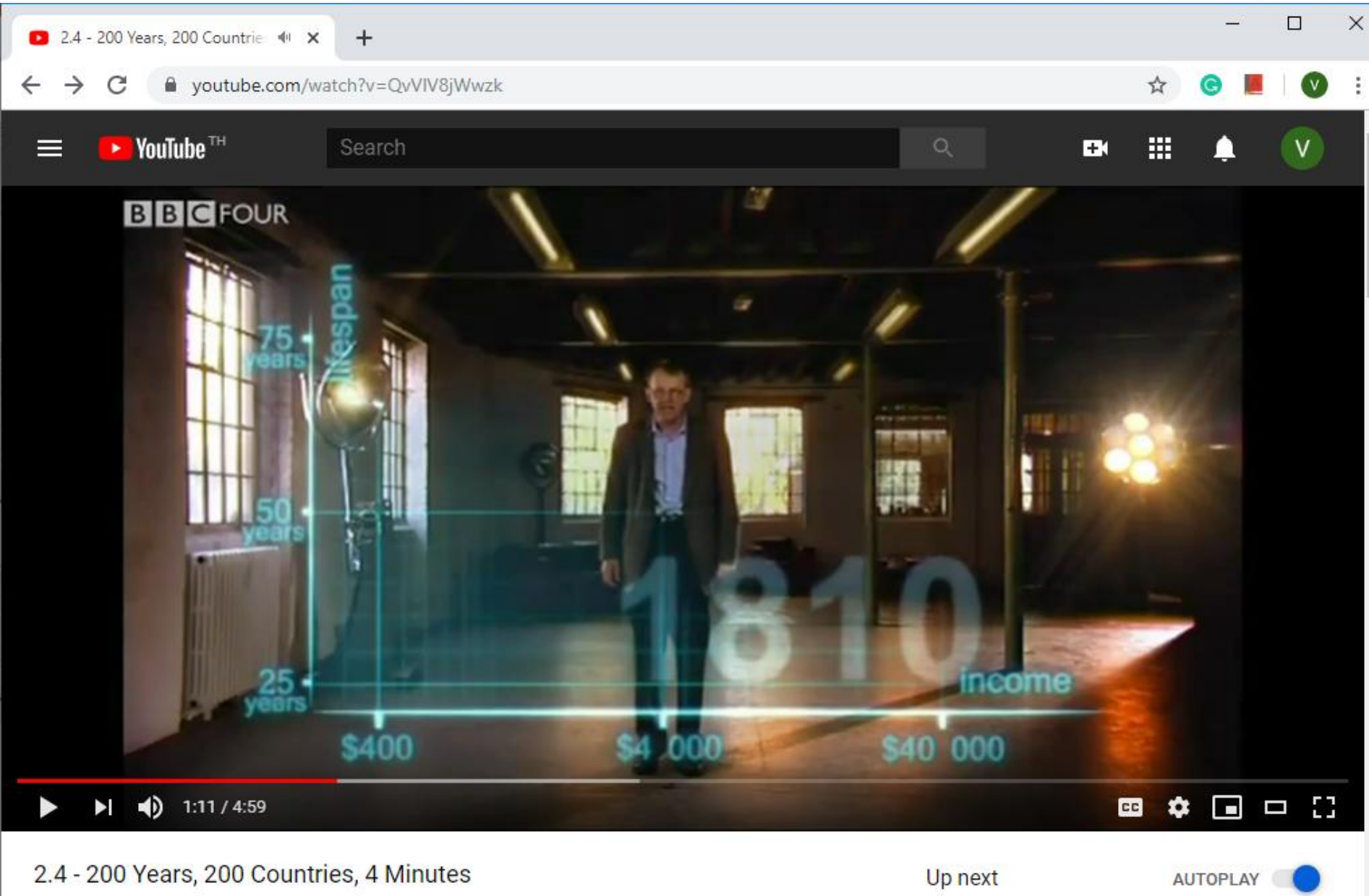
Gap Minder

https://www.gapminder.org/tools/



Story Telling with Visualization by Hans Rosling

https://www.youtube.com/watch?v=QvVlV8jWwzk



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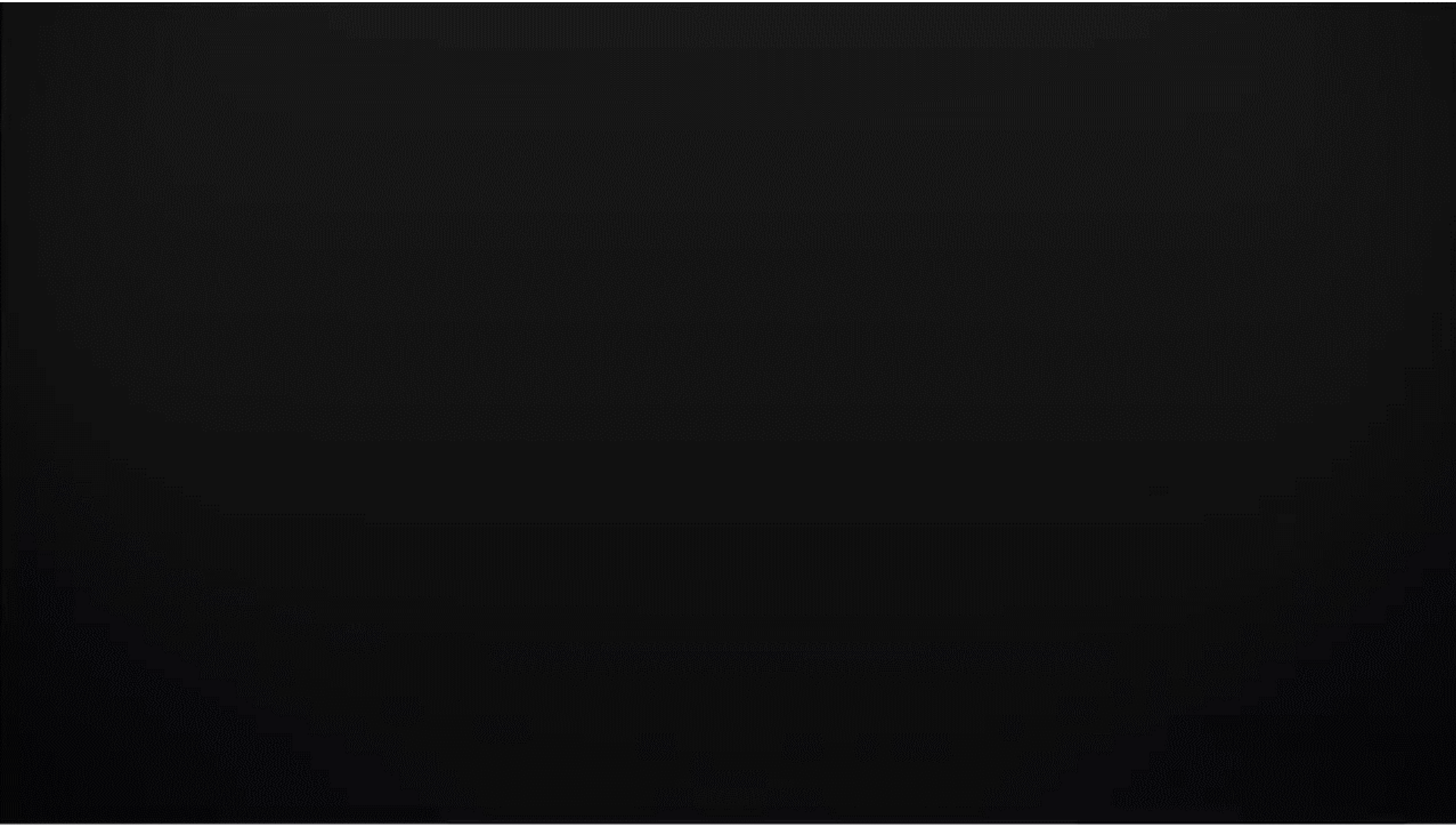
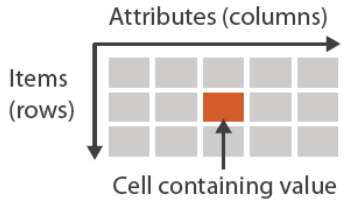


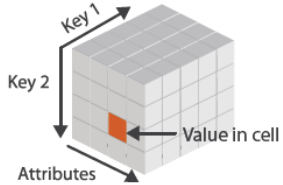
Data Types and Visual Variables

Dataset Types

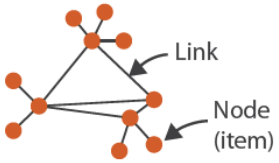
Tables



Multidimensional Table



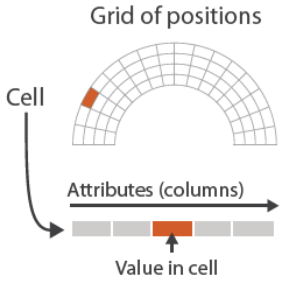
Networks



Trees

Spatial

Fields (Continuous)



Geometry (Spatial)

Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box		7/17/07
32	7/16/07	2-High	Medium Box		7/18/07
32	7/16/07	2-High	Medium Box		7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	[illegible]	5-Low	Wrap Bag	0.56	1/20/05
69	[illegible]	4-Not Specified	Small Pack	0.44	6/6/05
69	[illegible]	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05

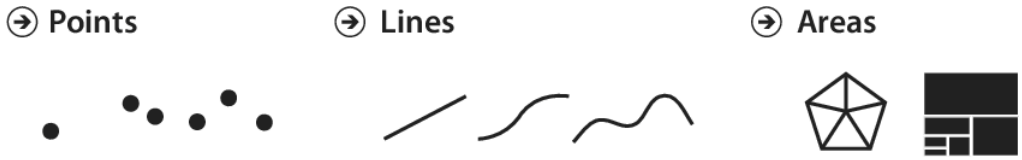
attribute

item

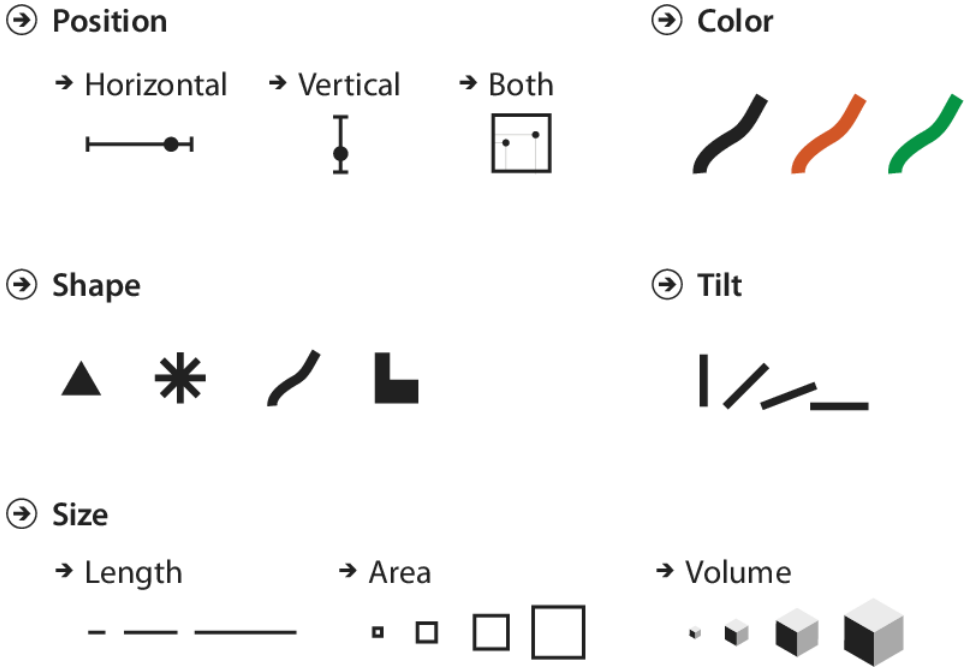
cell

Attribute Types

Marks
Geometric primitives used to construct any visualization

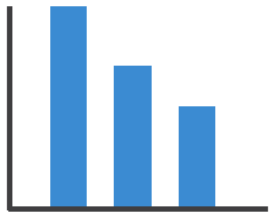


Visual Variables
The properties or appearance of marks that can be used to represent the data



Visual Encoding

- Combination of marks and visual variables (channels)



1:
vertical position

mark: line

2:
vertical position
horizontal position

mark: point

3:
vertical position
horizontal position
color hue

mark: point

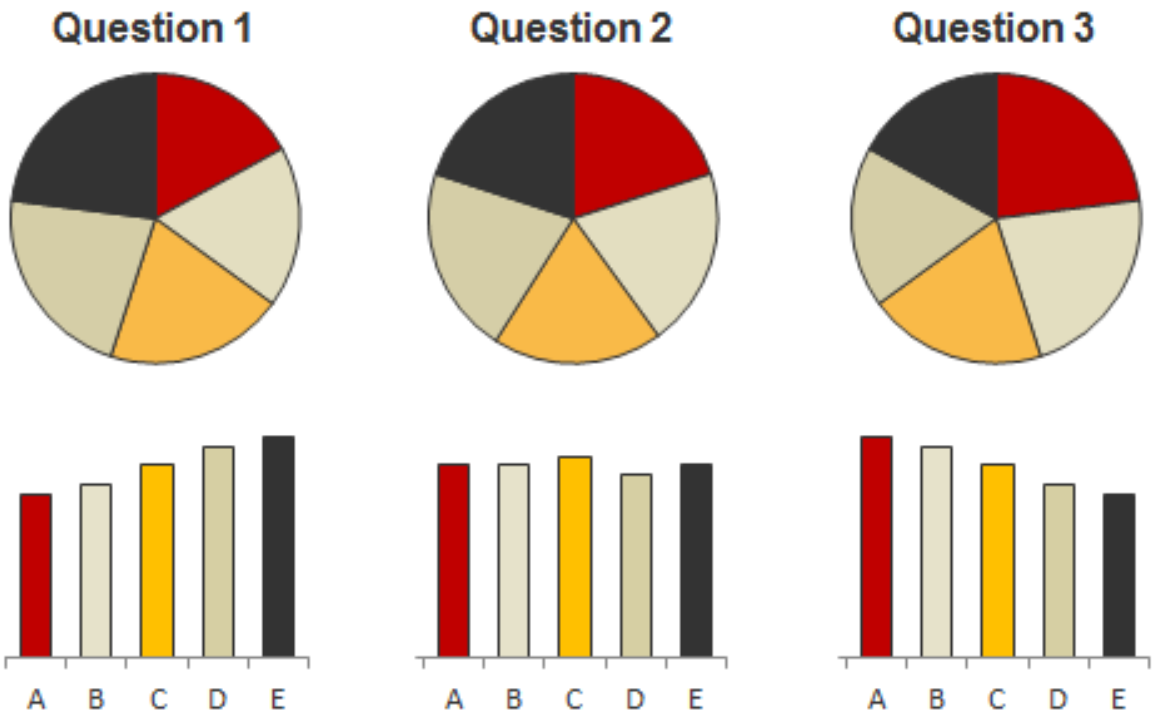
4:
vertical position
horizontal position
color hue
size (area)

mark: point

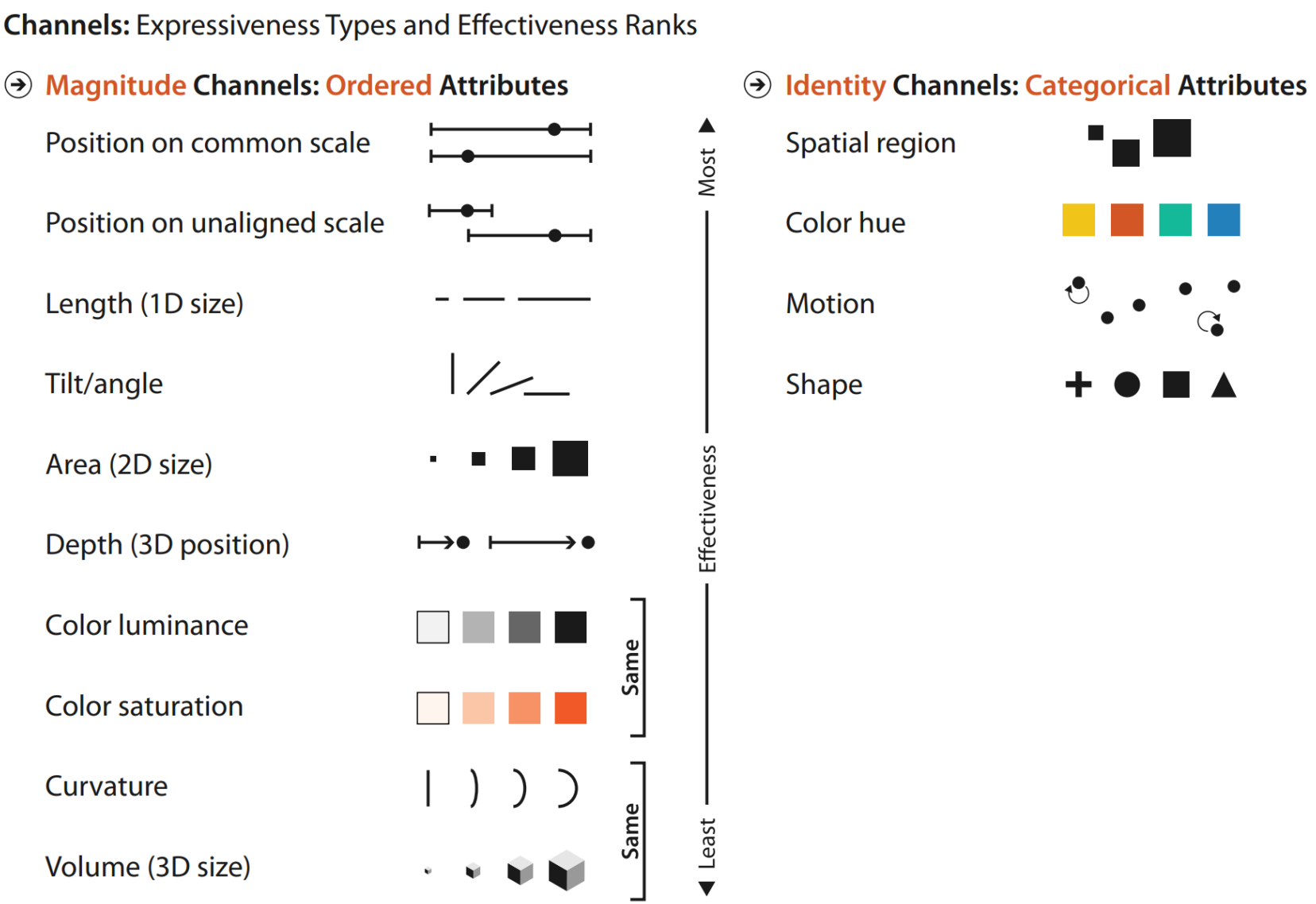
Effectiveness of Visual Variables

Pie Chart vs Bar Chart

Which one is better? Why?

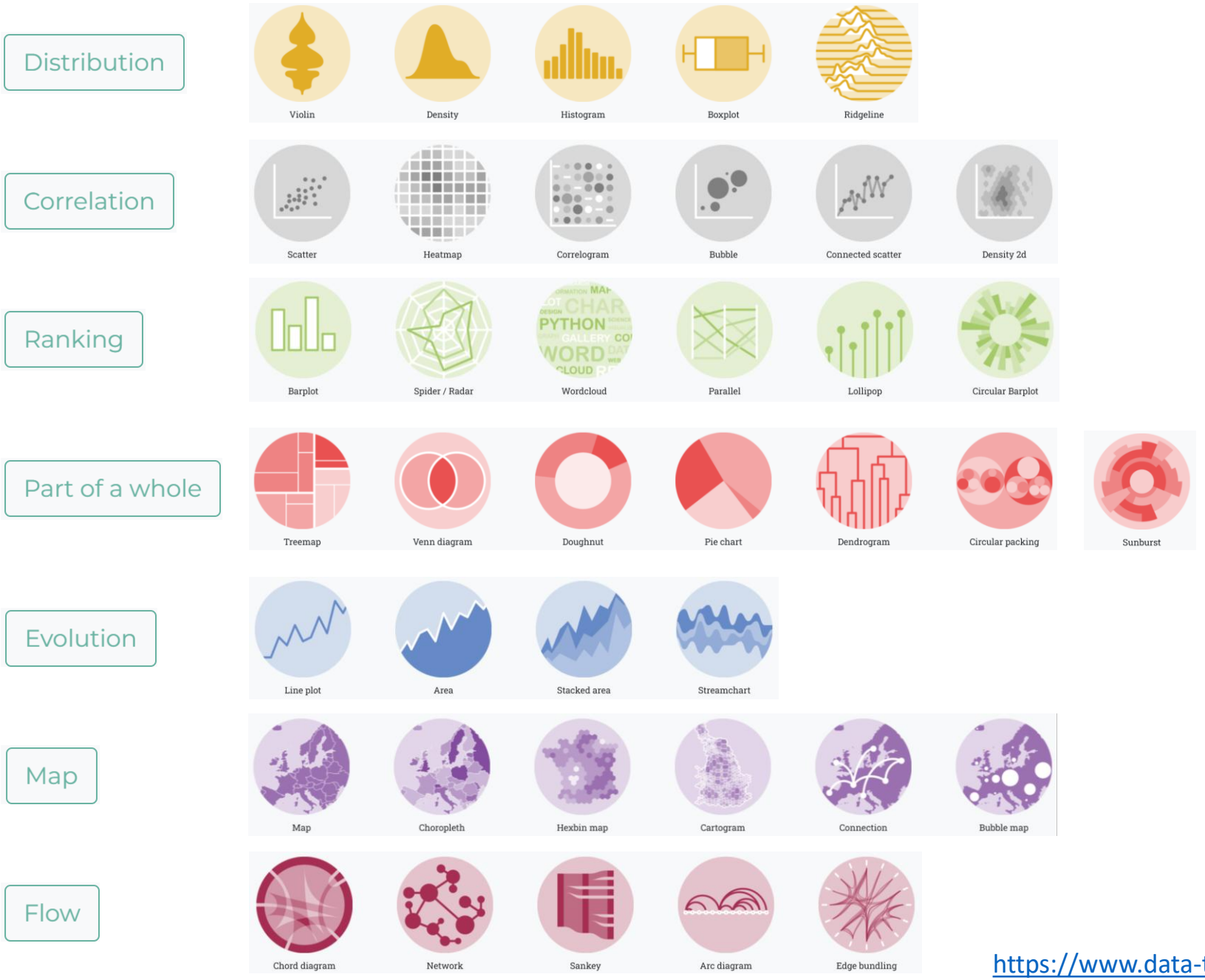


Effectiveness of a visual variable depends on type of data



Choosing the Right Chart

Chart Types



https://www.data-to-viz.com/

Idiom: **Bar Chart**

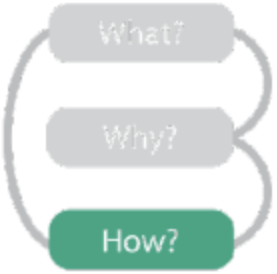
marks: lines

visual variables:
length for quantitative value,
each mark separated horizontally, aligned vertically and ordered by label or length

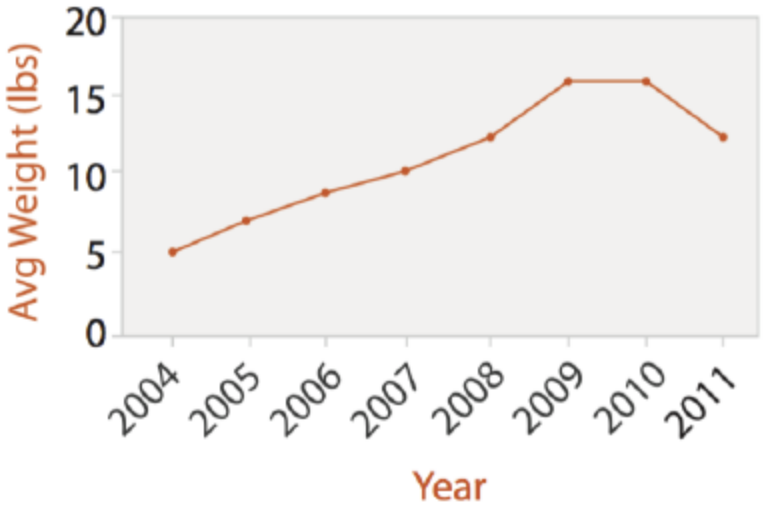
data: table with 1 category attribute (key attribute) and 1 quantitative attribute

tasks: compare, lookup values

scalability: dozens to hundreds of levels for key attribute



Idiom: **Line Chart**



marks: points (a line connects the marks)

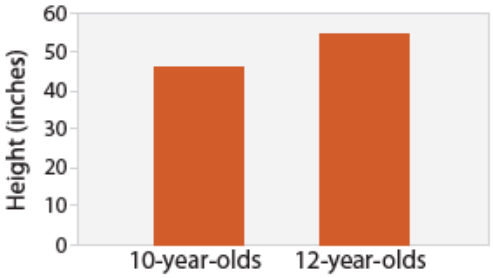
visual variables:
aligned length for quantitative value, horizontally separated and ordered by key attribute

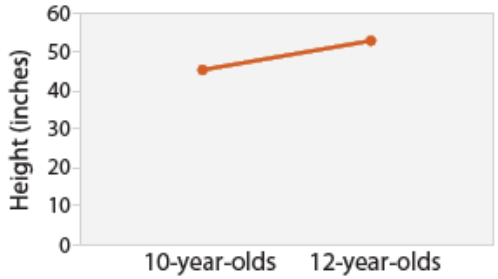
data: table with 1 ordered attribute (key attribute) and 1 quantitative attribute

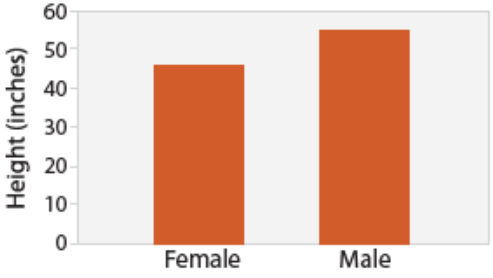
tasks: find trend (line connecting the marks emphasizes the ordering of the items along key axis)

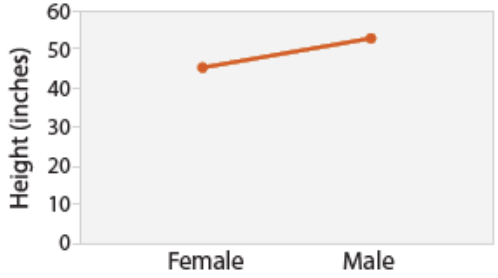
Choosing bar vs line charts

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



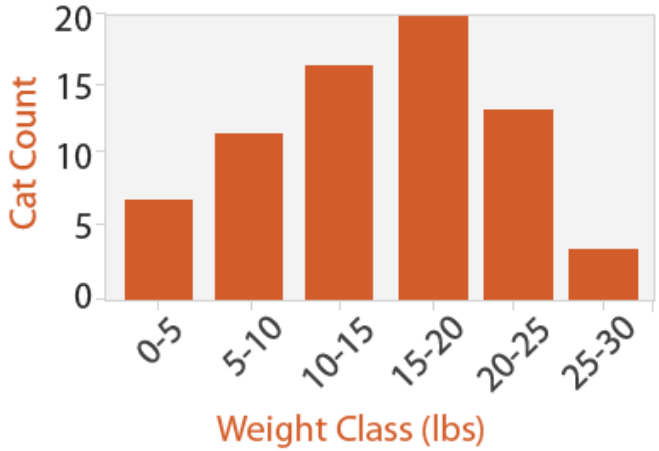




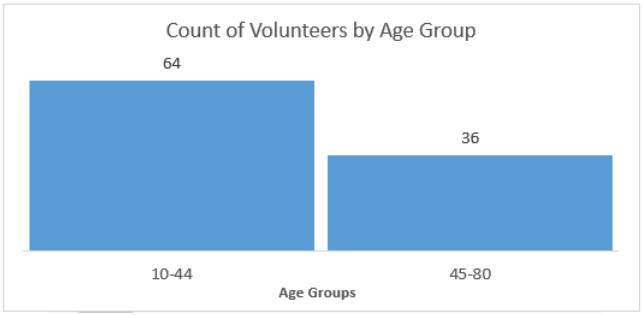


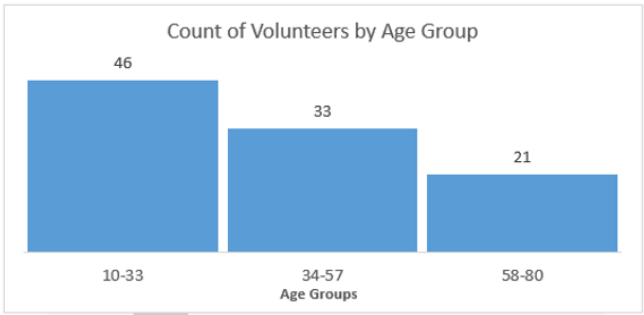
Idiom: **histogram**

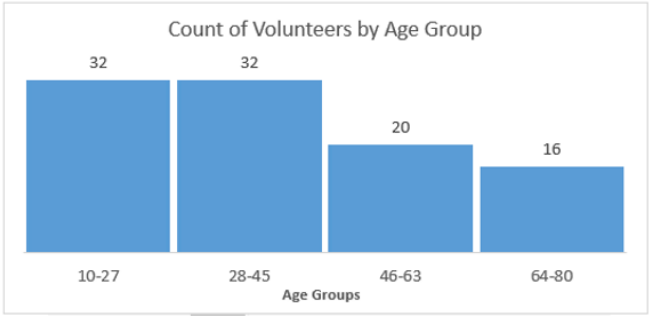
- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly

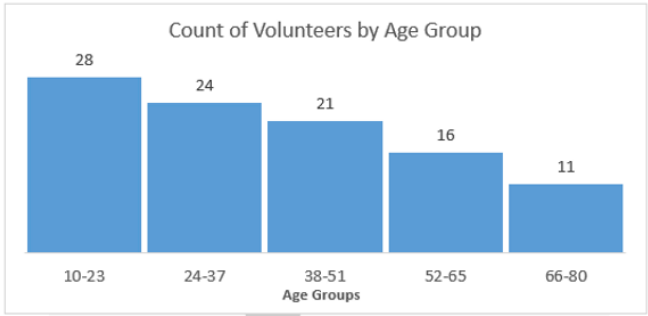


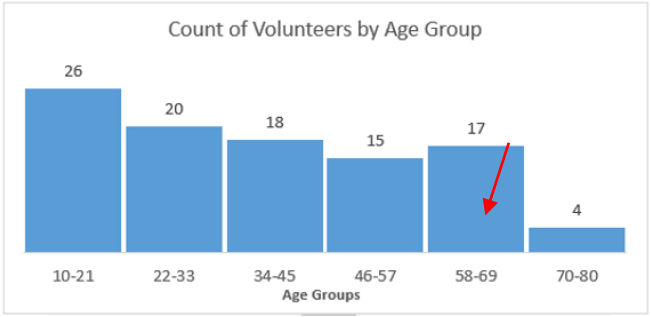
Histogram: different bin sizes tell different stories

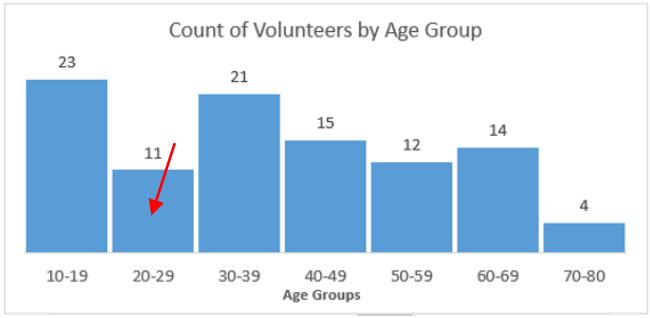




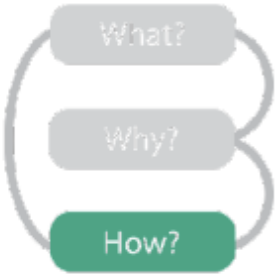








https://www.excelcampus.com/charts/dynamic-histogram/



Idiom: **Scatterplot**

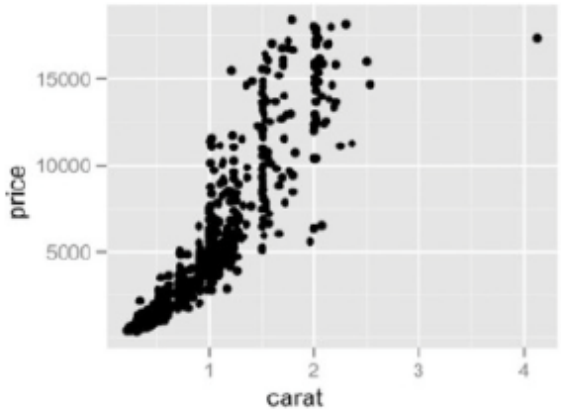
marks: points

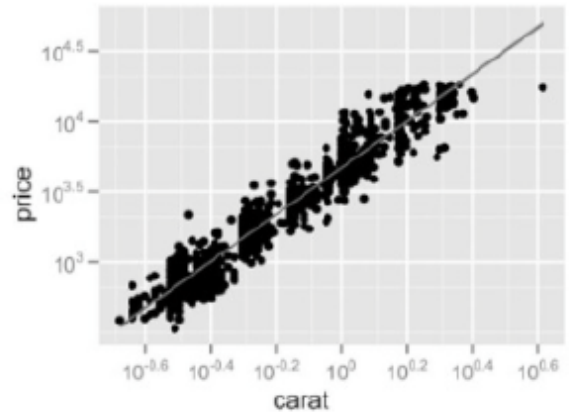
visual variables: position (horizontal + vertical)

data: table with only 2 quantitative attributes and no key (only values)

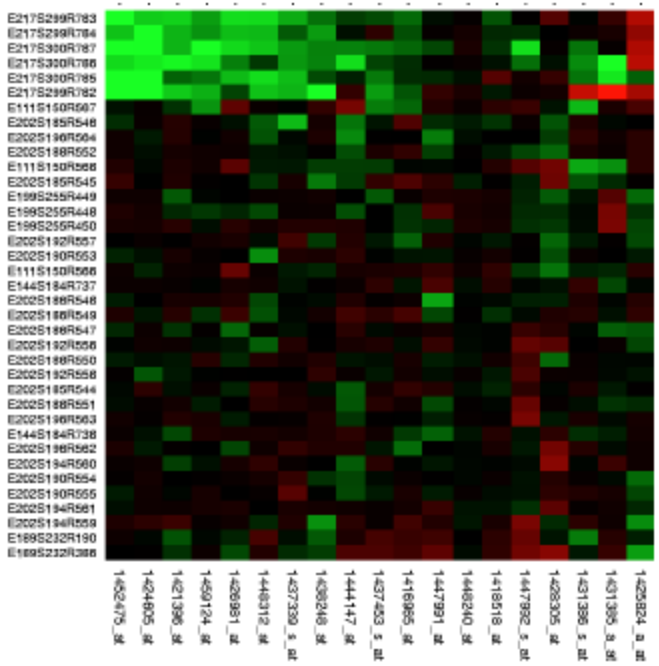
tasks: finding trends, outlier, distribution, correlation, clusters

scalability: hundreds of items





Idiom: **Heatmap**



marks: area (separated and aligned in 2D matrix and indexed by 2 categorical attributes)

visual variables:

color for quantitative attribute

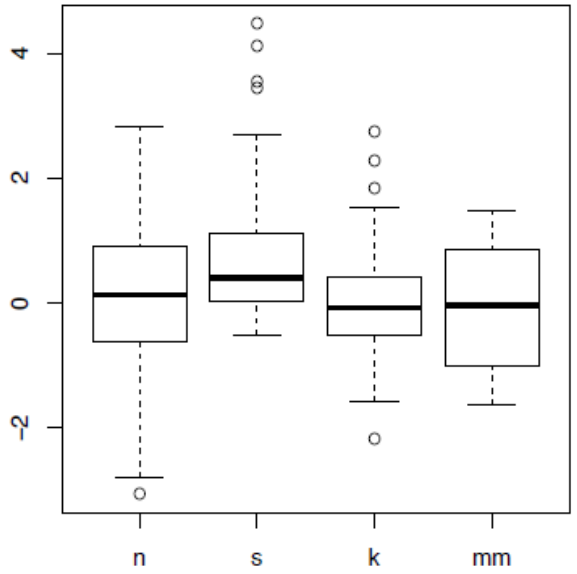
data: table with 2 categorical attributes (key attributes) and 1 quantitative attribute

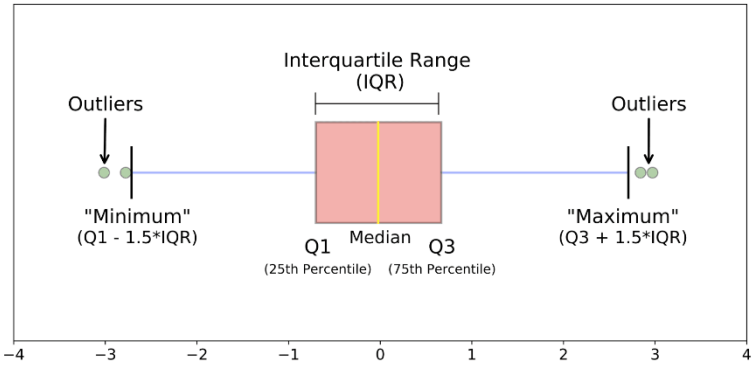
tasks: find clusters, outliers

scalability: 1 million items, hundreds of categorical levels, ~10 quantitative attribute levels

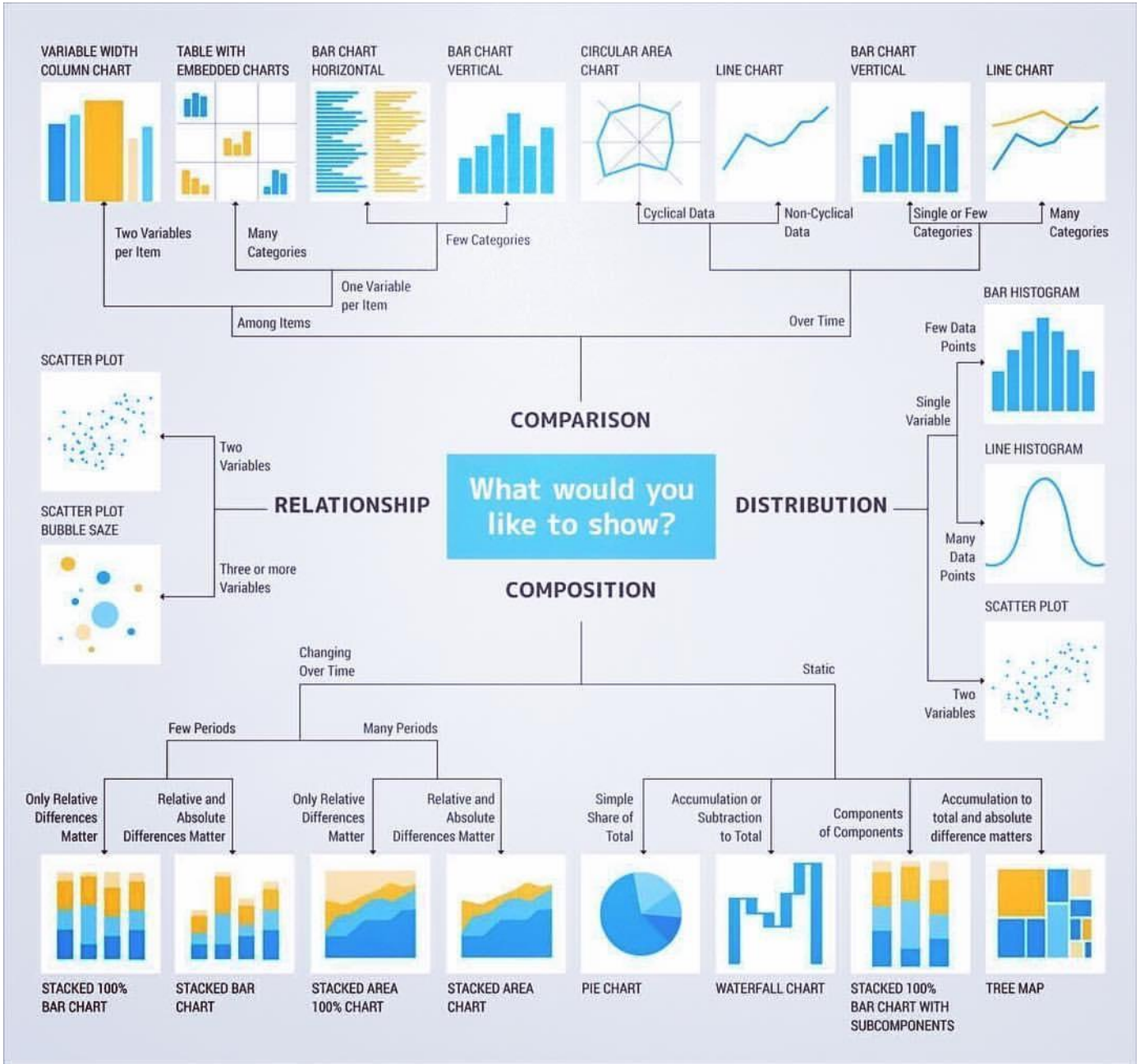
Idiom: **boxplot**

- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown





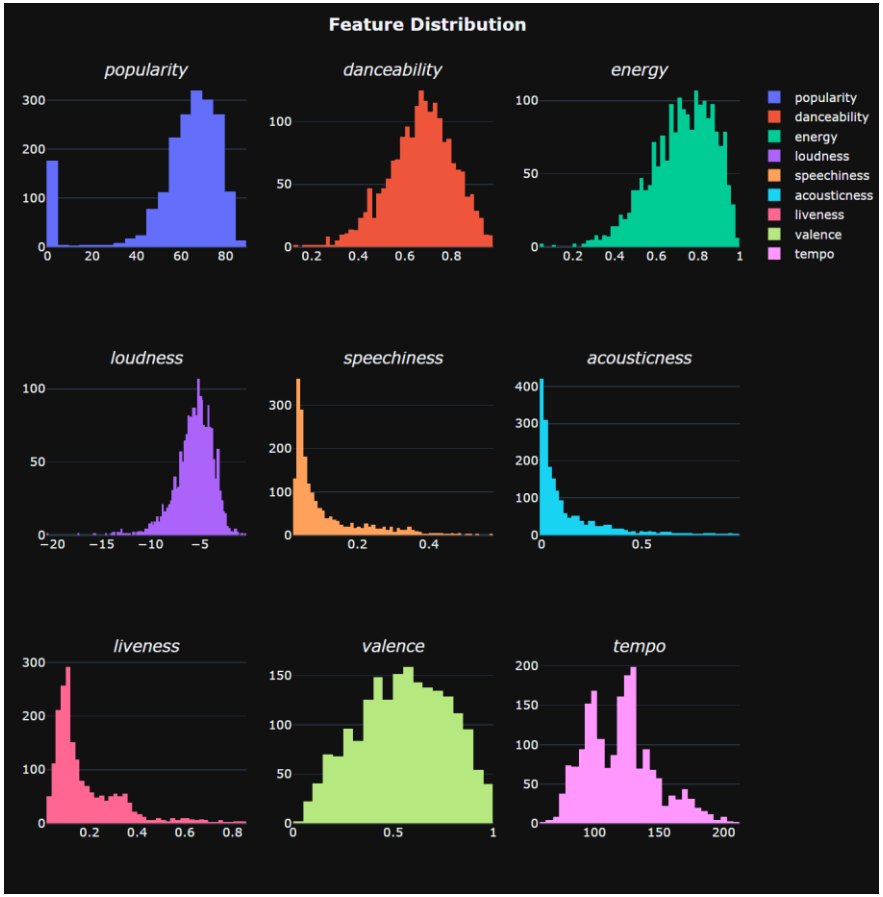
How to choose your visualization

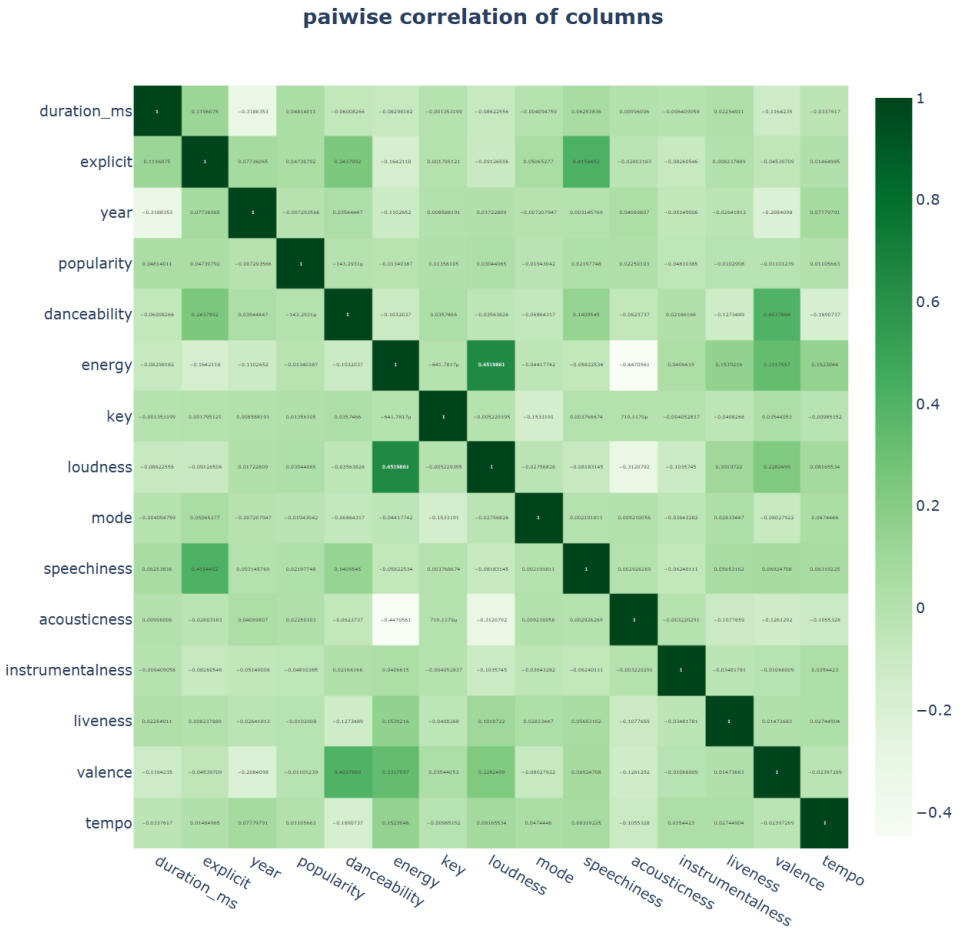


Example: Visualization in a data science project

Spotify Data Visualization

https://www.kaggle.com/code/varunsaikanuri/spotify-data-visualization





Example: Visualization in a data science project

SelfieCity

https://selfiecity.net/ https://selfiecity.net/selfiexploratory/