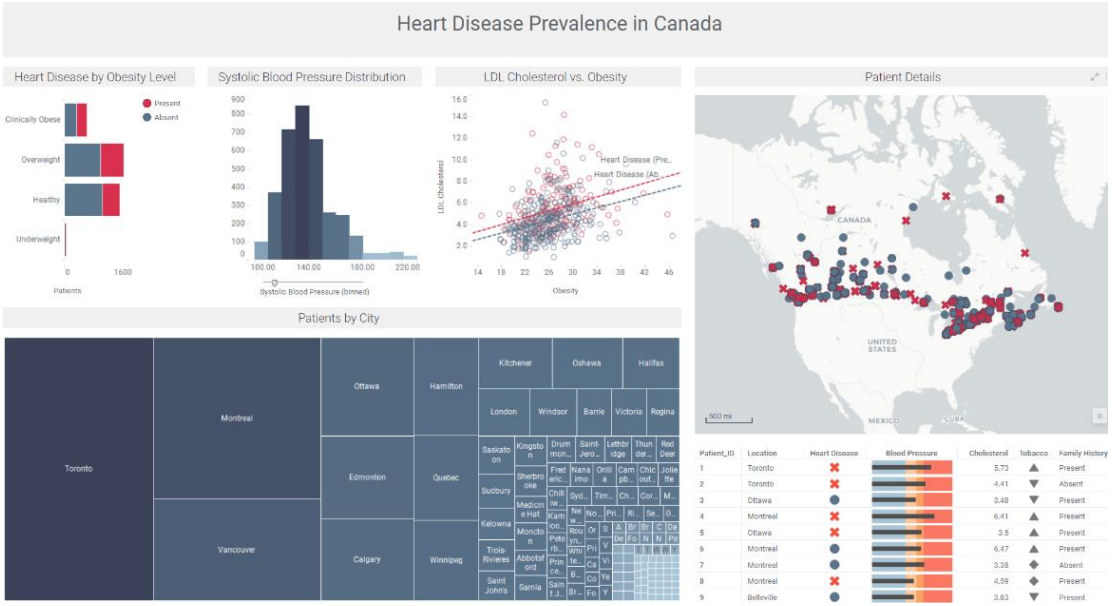
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

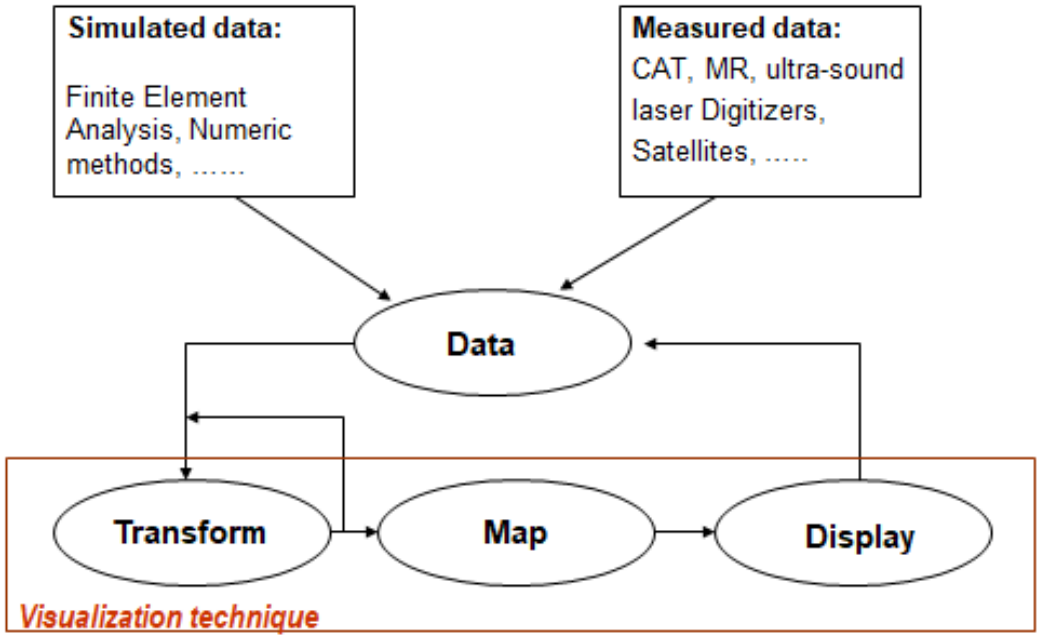
Creating a Visualization



[heart-disease-prevalence]

Beatriz Sousa Santos, 2024

Scientific Visualization reference model

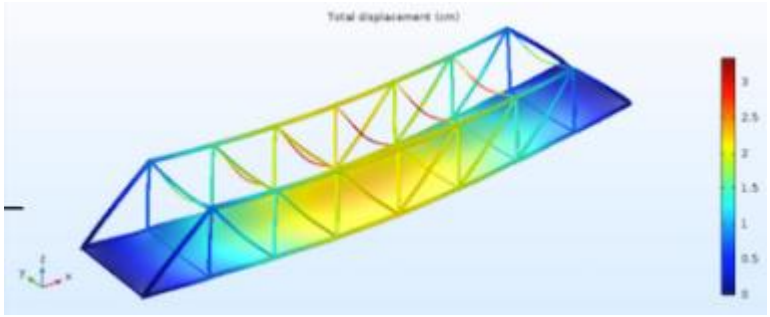


(adapted from Schroeder et al., 2006)

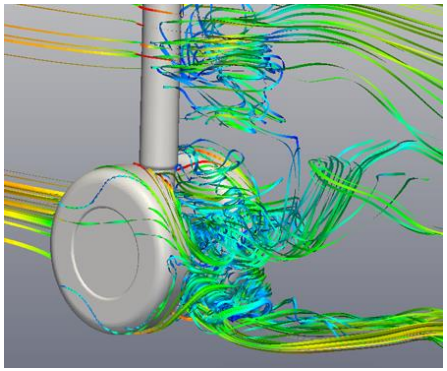
The visualization creator is involved in all phases

The user should get insights from the visualization

Visual mapping

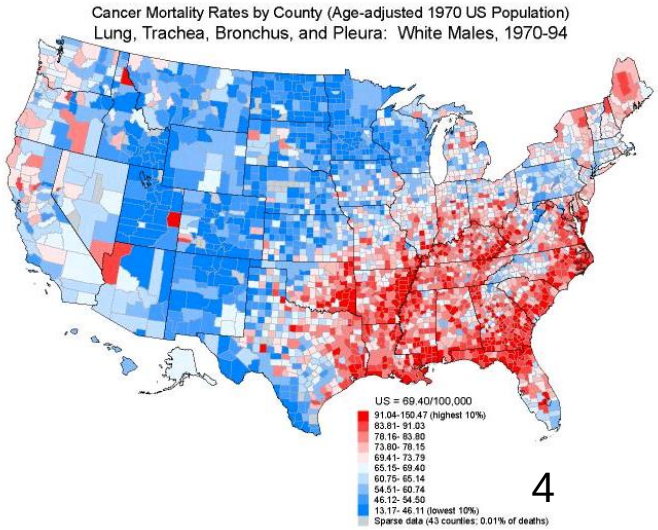


- It is necessary to decide:
  - which visual structures use to **represent** the data
  - their location in the display



- Some types of data can be easily mapped to a spatial location

- Examples:
. data with a topological or geographical structure



- Abstract data don't have an easy correspondence with the dimensions of the physical space around us

Three **structures** must be defined in the **visual mapping/encoding**:

- spatial substrate

- graphical elements

- graphical properties

- **Spatial substrate** - dimensions in physical space where the visual representation is created (can be defined in terms of axes and type of data)

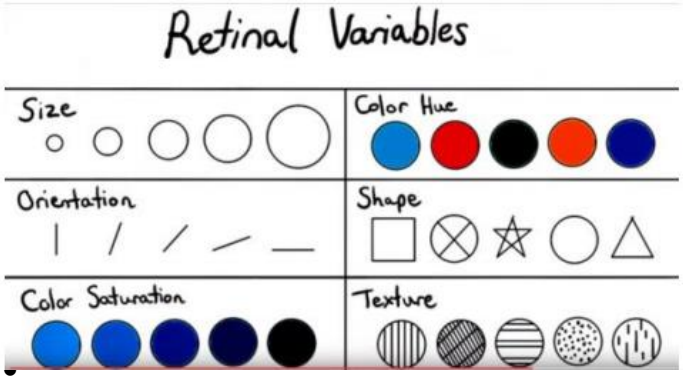
- **Graphical elements** - anything visible appearing in the space
  points, lines, surfaces, volumes

- **Graphical properties** – properties of the graphical elements to which the human retina is very sensitive - **retinal variables:**
  size, orientation, color, texture, and shape

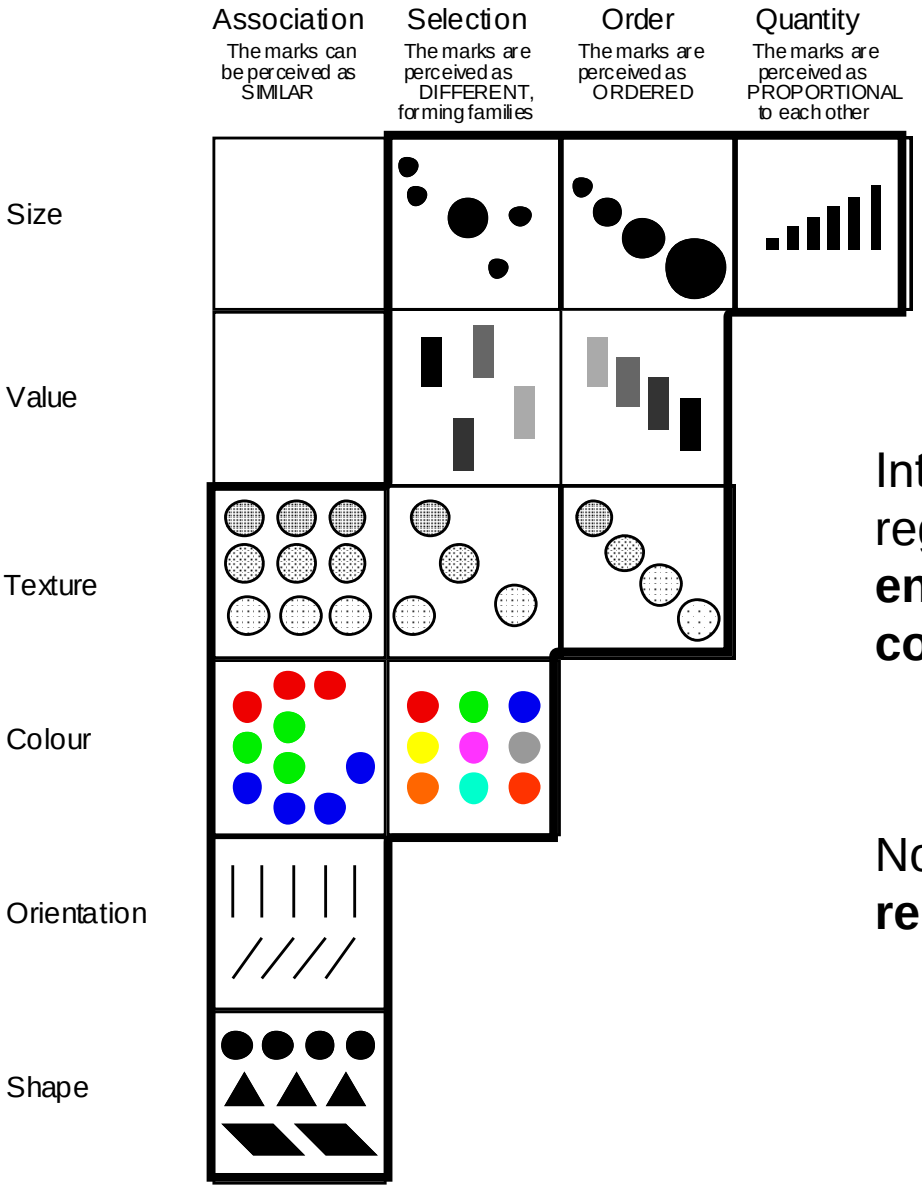
- **Spatial substrate** axes (x, y, …)
  type of data (quantitative, ordinal, categorical)

- **Graphical elements** points
  lines
  surfaces
  volumes

- **Graphical properties** retinal variables:
  size,
  orientation
  color (depends on physiology and culture)
  texture
  shape



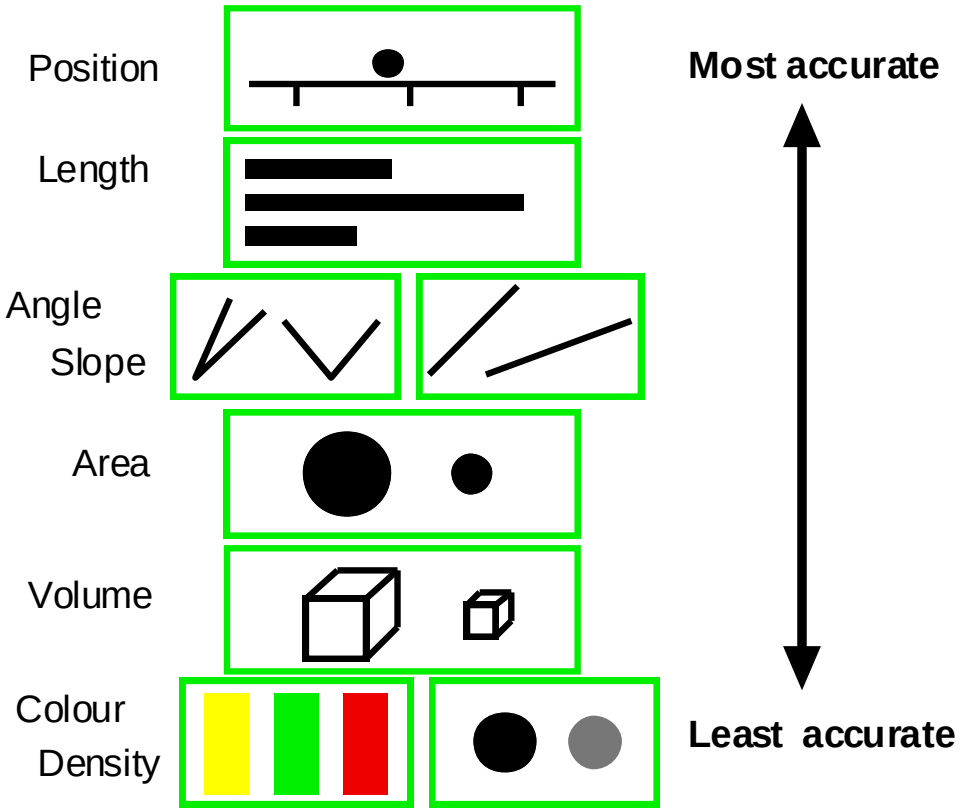
How to select visual encodings?



Interpretation of Bertin's guidance regarding the suitability of various **encoding methods to support common tasks** (Spence, 2007)

Note that **only size is adequate to represent quantity accurately**

How to select visual encodings to accurately represent quantity?



The relative difficulty of **assessing quantitative value** as a function of encoding mechanism, as established by Cleveland and McGill (Spence, 2007)

In a nut shell:
Do you have a lot of data?

- Visualization may be the solution (or part of it)

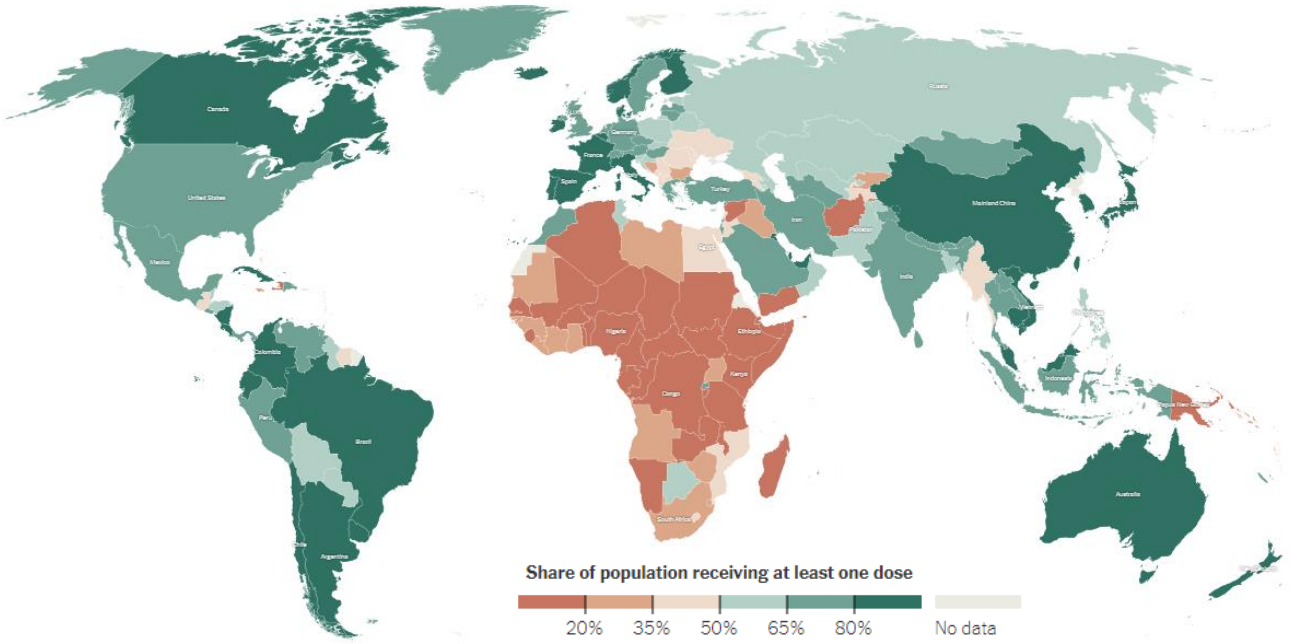
- Creating a Visualization has several phases

- Visual mapping is core

- There are several possible visual encodings/
  visualization techniques

- But,
  How to select techniques ? → next topic

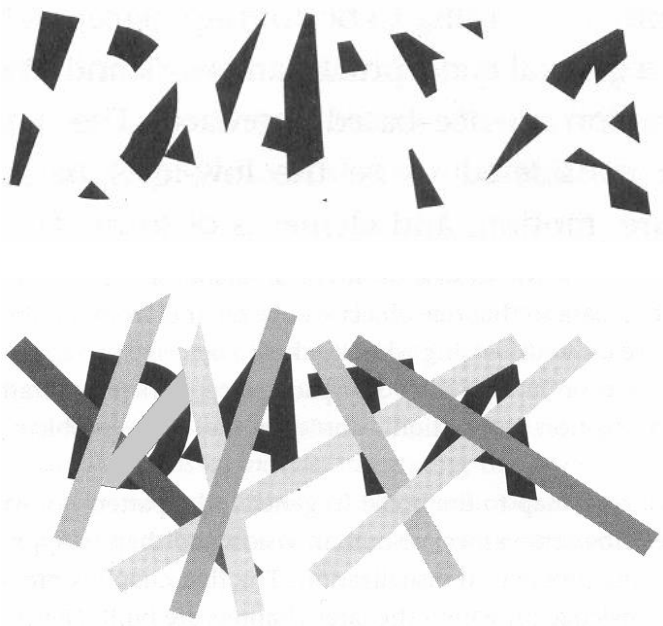
Mapping - Visually encoding value



https://www.nytimes.com/interactive/2021/world/covid-vaccinations-tracker.html

Remember:

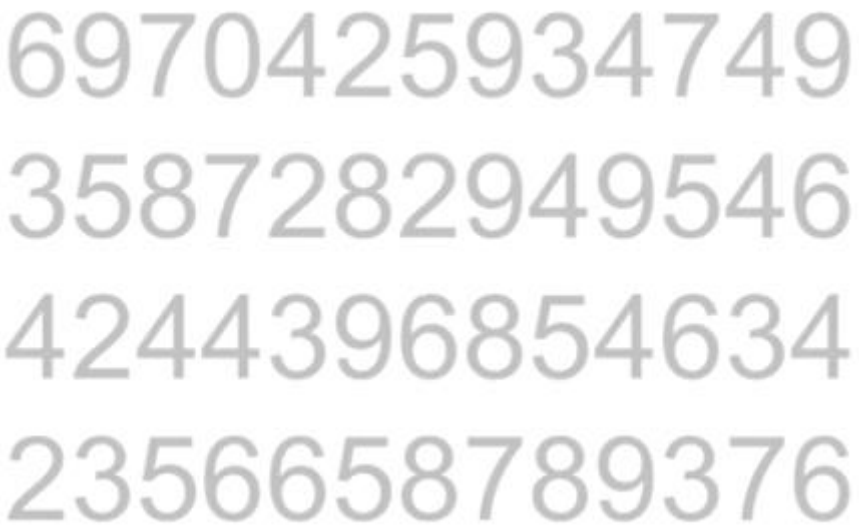
- The Human Visual system is the product of millions of years of evolution



- Although very flexible, it is tuned to data represented in specific ways

- If we understand how its mechanisms work we will be able to produce better results

Pre-attentive attributes can help observers to see before though

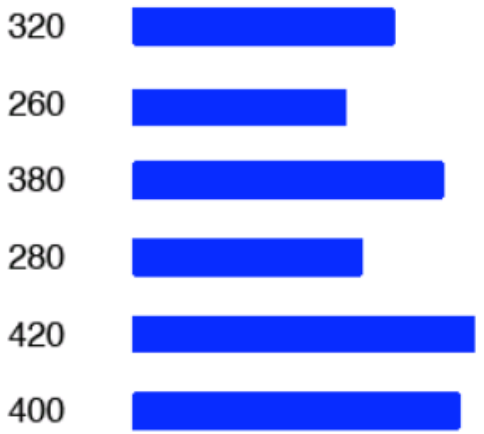


Example: Count the number of 7s

https://www.youtube.com/watch?time_continue=121&v=AiD6etOB6qI

- Some visual attributes as **size**, **proximity** are also quickly processed by visual perception, **before the cognitive processes** come into play

Example:
mapping numerical values
to the length of bars:



(Mazza, 2009)

Procedure to follow to create visual representations of data

1. Define the problem and the **users' questions**
2. Examine the **nature of the data** to represent and **pre-process** the data
3. Determine the **number of attributes**/variables/dimensions
4. Choose the **visual structures to map**

test several ideas …

Important aspects to consider:

nature of the problem
- communicate
- explore
- confirm

nature of the data to represent
- quantitative
- ordinal
- categorical

number of attributes
- univariate
- bivariate
- trivariate
- multivariate

Next: visualization techniques organized according the n. of attributes

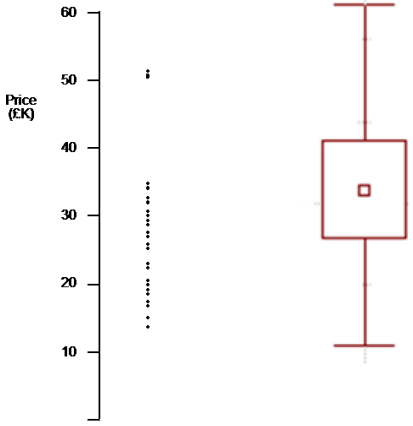
dataset types
- tables
- networks
- spatial or geographical
- fields
- geometry

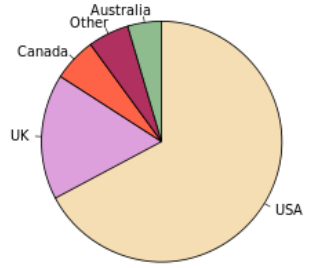
of tabular data

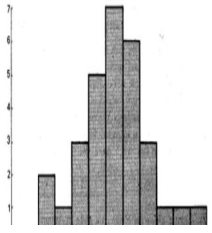
…

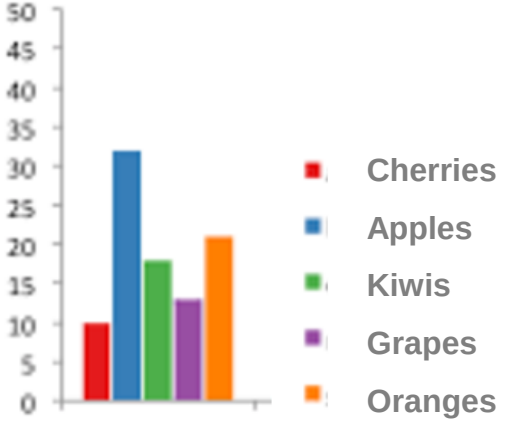
Common Visualization Techniques to visually represent univariate, bivariate data

Univariate data
- dot plot
- box plot
- bar chart
- histogram
- pie chart
- …

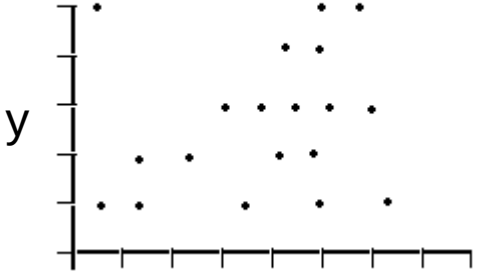


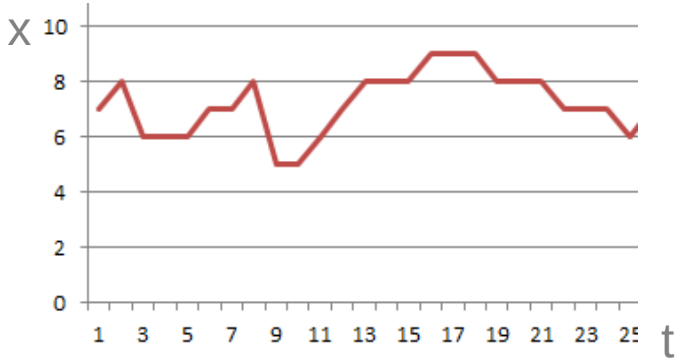






Bivariate data
- scatter plot
- line plot
- time series
- …
- …





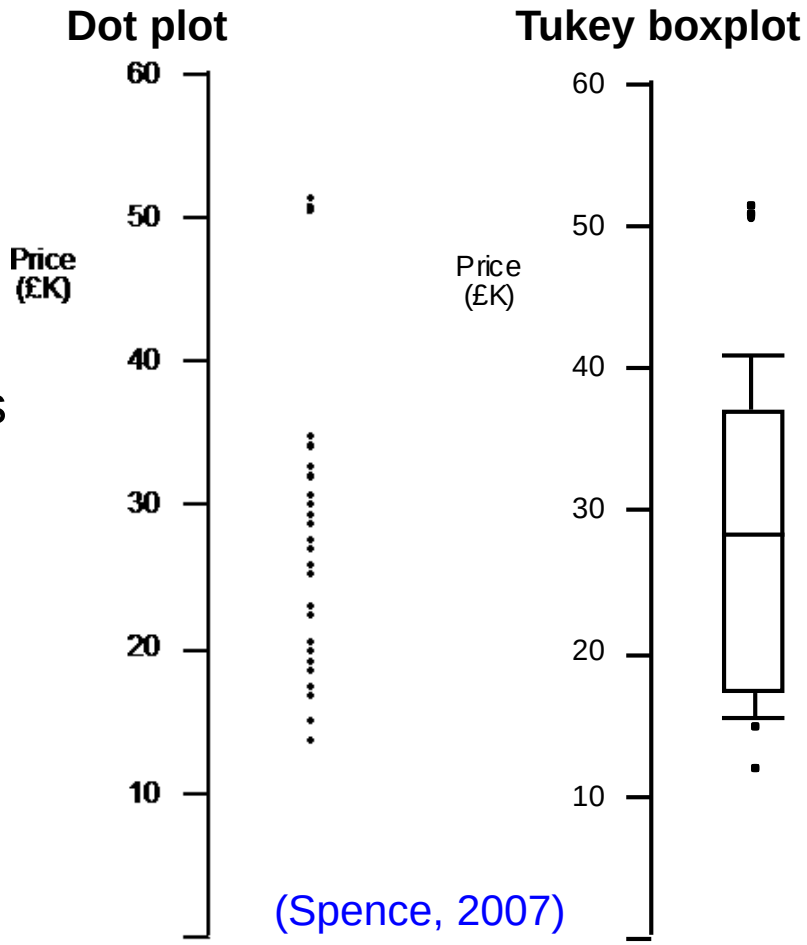
Representing univariate data

- A common situation consists in representing a set of values
- Well established techniques exist
- But new ones can be invented!

  Example: Price for a number of cars
  - dots on a linear scale
  - box plot
  (that will answer many questions:
  median value, outliers,...)

- Including several in the same

Visualization eases comparison



(Spence, 2007)

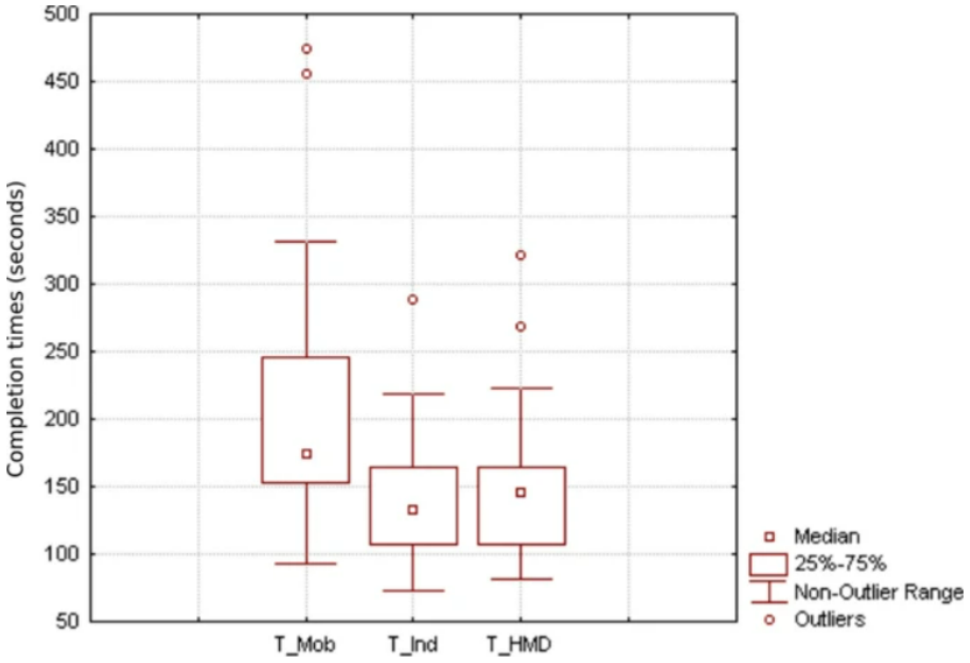
https://www.data-to-viz.com/caveat/boxplot.html

Example:

- Including several box plots in the same Visualization allows comparing:

Comparing 3 augmented reality visualization methods for assembly procedures (times)

https://link.springer.com/article/10.1007/s10055-021-00557-8



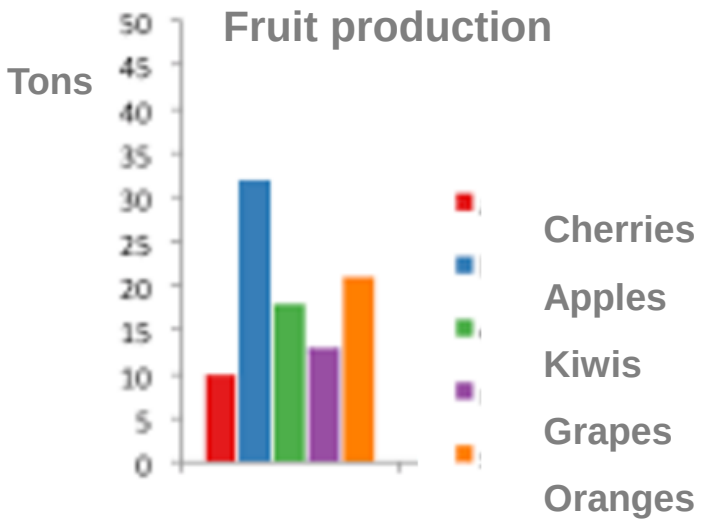
Task performance from the three methods based on time of completion

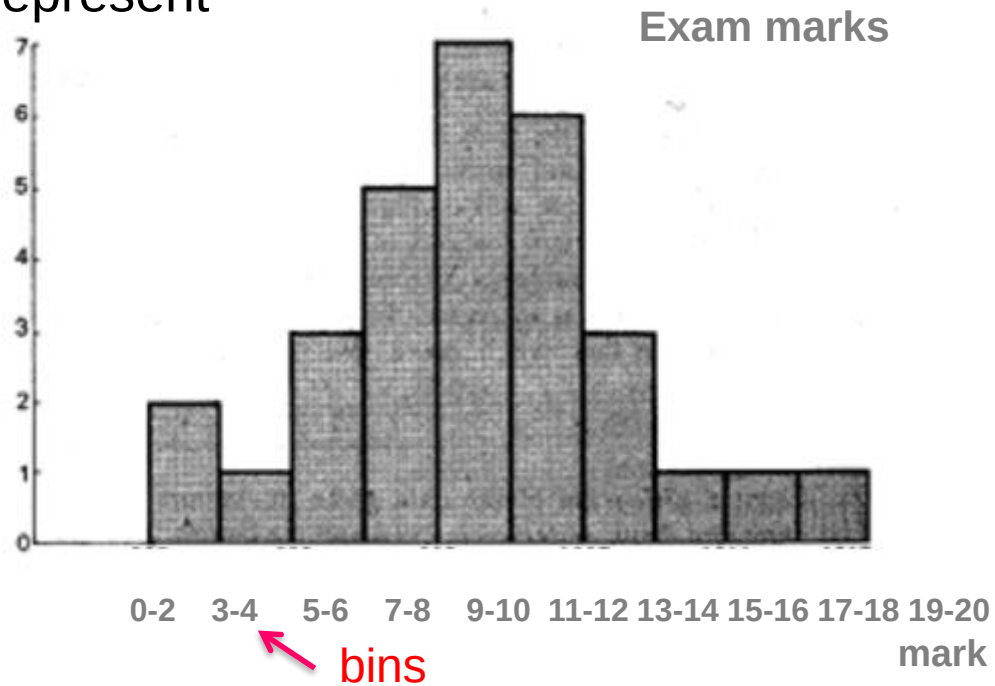
Two common techniques not to be confounded !

Histogram ⇨ represents a distribution of numerical data

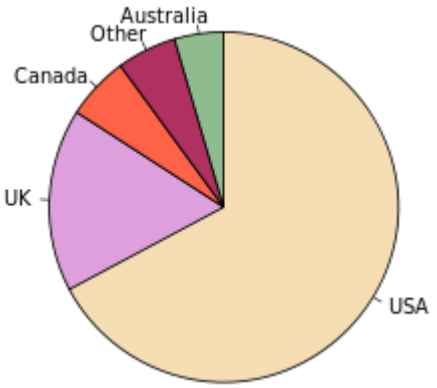
Bar chart ⇨ represents the number of occurrences of a categorical/ ordinal data

Both represent data by rectangular bars (vertical or horizontal) with length proportional to the values they represent





Another simple (and too common) technique



Native English speaking population

- Pie Chart

Represents numerical proportion, **parts of an whole**

The arc length of each slice (its central angle and area), is proportional to the quantity it represents

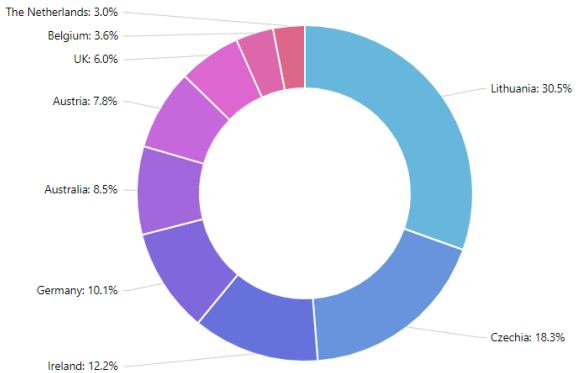
Are much controversial:

many experts recommend avoiding them

http://www.perceptualedge.com/articles/08-21-07.pdf

It is difficult to compare different sections of a pie chart, or to compare data across different pie charts

Variations of pie charts:



- Simple criteria to determine whether a pie chart is acceptable
- Consider it **only if**:
- **The parts make up a meaningful whole**

+ The parts are mutually exclusive

+ There are <6 parts and slices have not very different sizes

If the main purpose is to compare between the parts,
use a different chart!

https://eagereyes.org/techniques/pie-charts

Representing bivariate data

- The **scatterplot** is the conventional representation

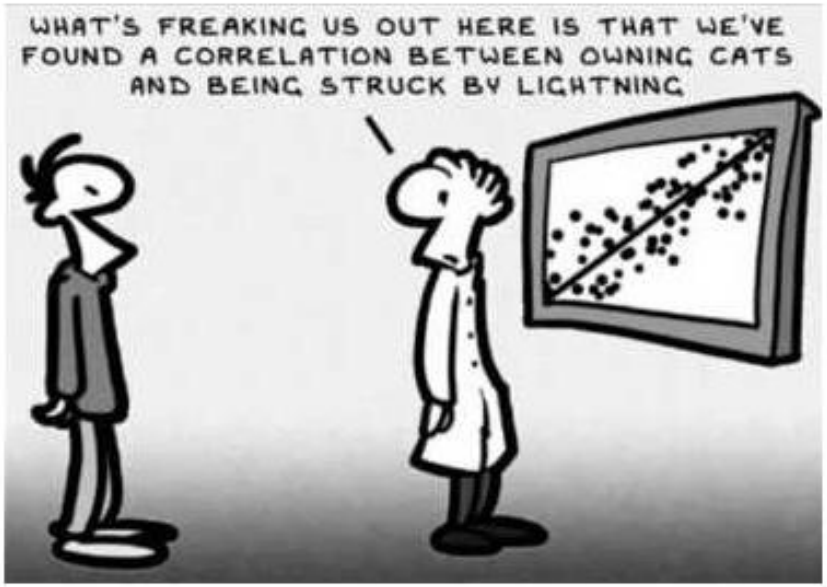
Each observation is represented by a point on a two dimensional space

The axes are associated with these two attributes

This representation affords awareness of:

- **general trends**
- local trade-offs
- outliers

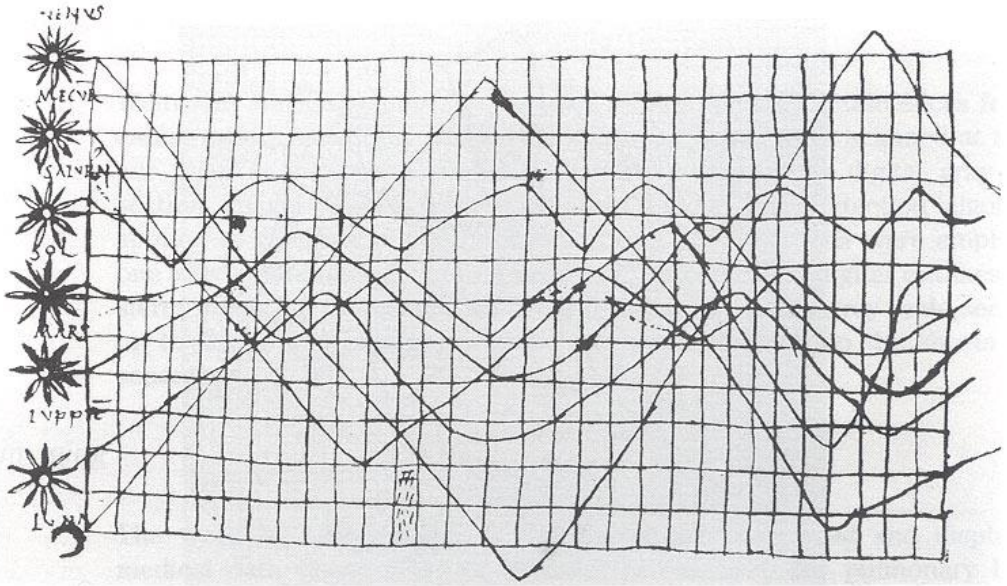
Correlation is not causation



Representing bivariate data

The **line chart**

One of the oldest known and ubiquitous Visualizations



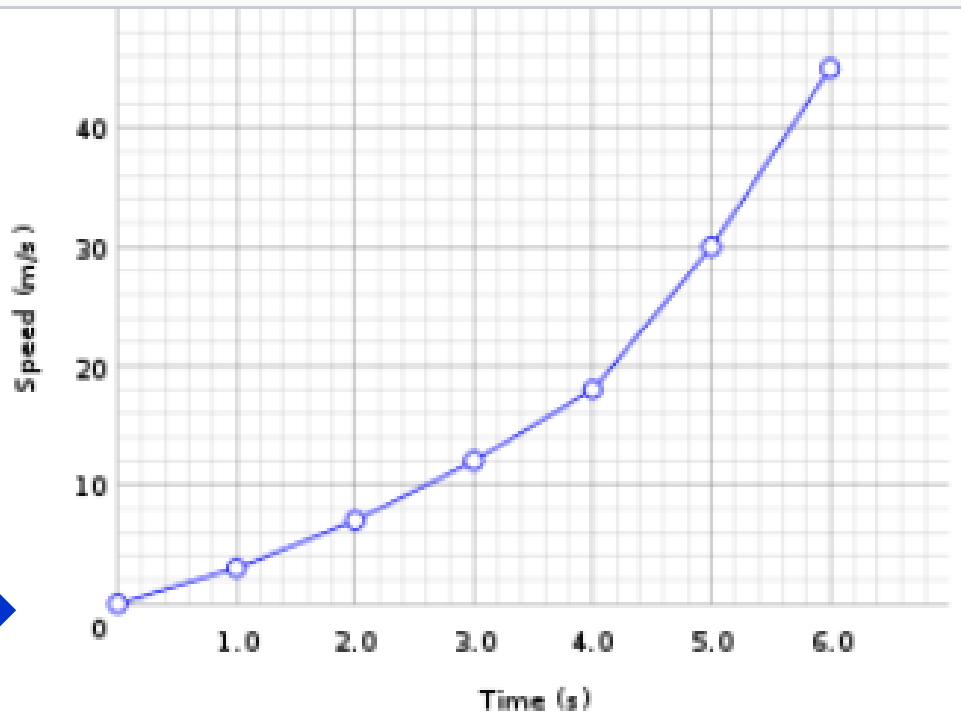
Inclination of orbits along the time - Xth century (Tufte,1983)

- A **line chart** or **line plot** or **line graph** or **curve chart** displays information as a series of data points called 'markers' connected by straight line segments

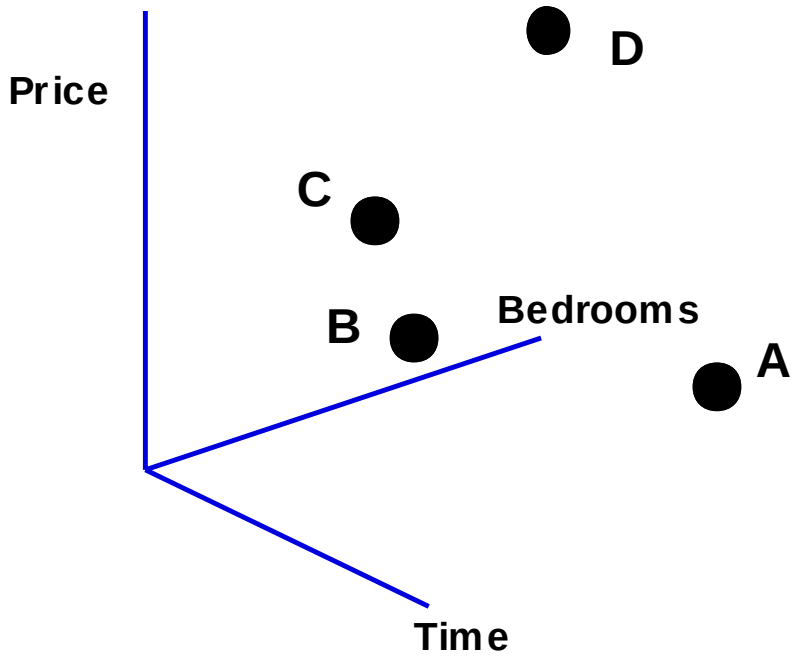
- Basic type of chart common in many fields

- Often used to visualize a trend in data over intervals of time

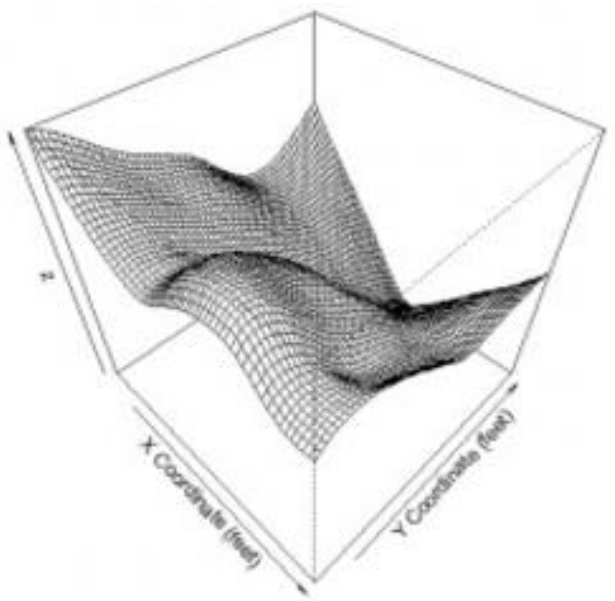
- Can we use a solid line connecting the samples, in this example?

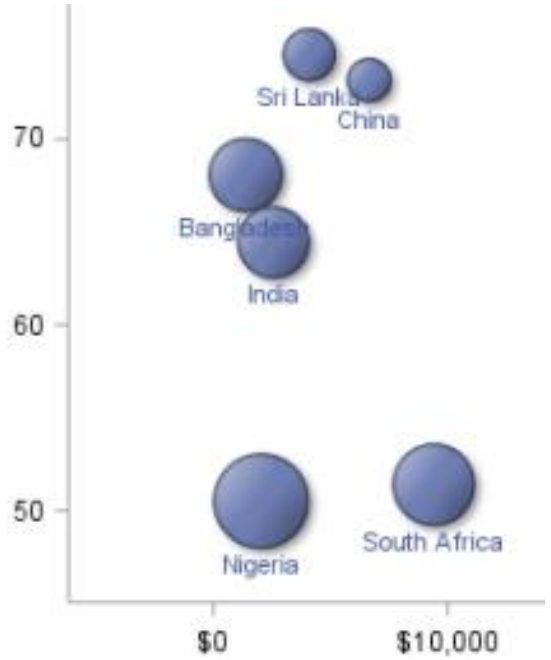


Common Visualization Techniques to represent trivariate data



Trivariate data
- surface plot
- contour plot
- 3D representation
- bubble plot/chart
- …



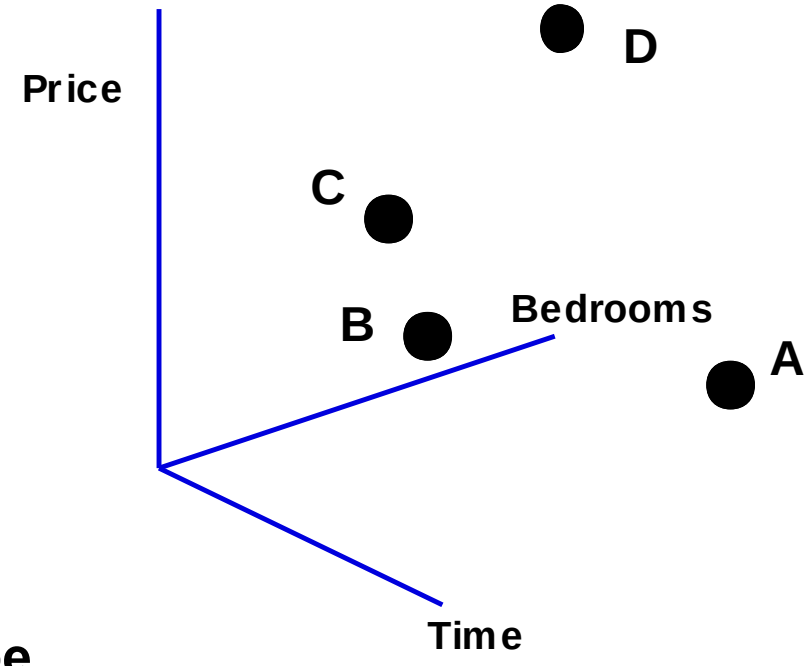


Representing Trivariate data

- Since we live in a 3D world, representing trivariate data as points in a 3D space and displaying a 2D view is natural

- However, these representations of abstract data can be ambiguous

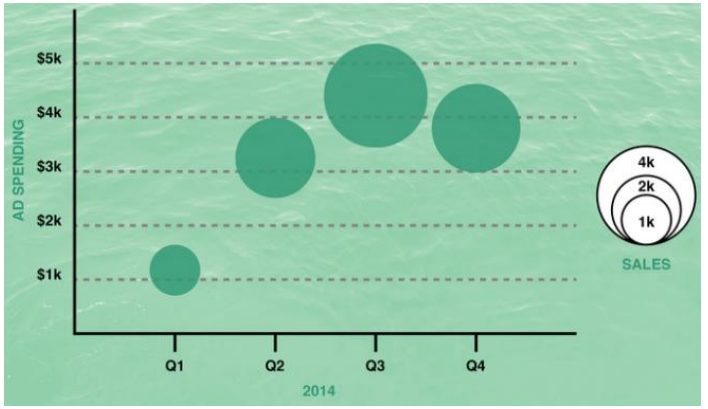
- This can be solved by interaction, allowing the user to reorient the representation



"**for 3D to be useful, you' ve got to be able to move it**" (Spence, 2007)

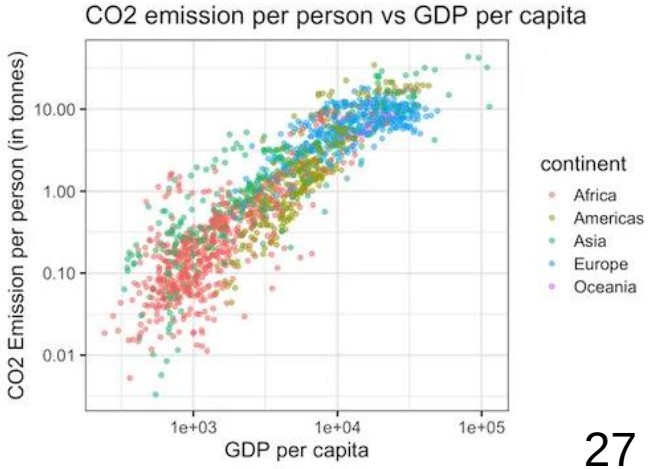
Other Simple (and common) representations of trivariate data

- In a **bubble chart** data are represented as a disk that expresses two of the values through the disk's *xy* location and the third through its size (radius or area?)



- Mapping the variable to circle size must be done carefully. The interpretation may be ambiguous

- Representing one more dimension through color in a scatter plot



https://visage.co/data-visualization-101-bubble-charts/

Important aspects to consider:

nature of the problem
- communicate
- explore
- confirm

nature of the data to represent
- quantitative
- ordinal
- categorical

number of attributes
- univariate
- bivariate
- trivariate
- multivariate

Next: visualization techniques organized according the n. of attributes

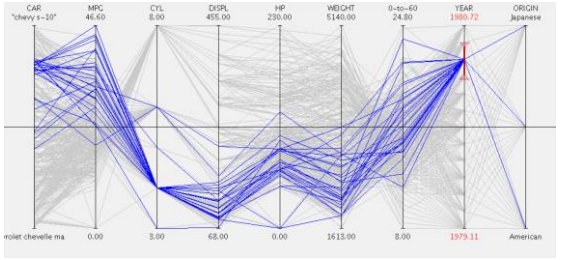
dataset types
- tables
- networks
- spatial or geographical
- fields
- geometry

of tabular data

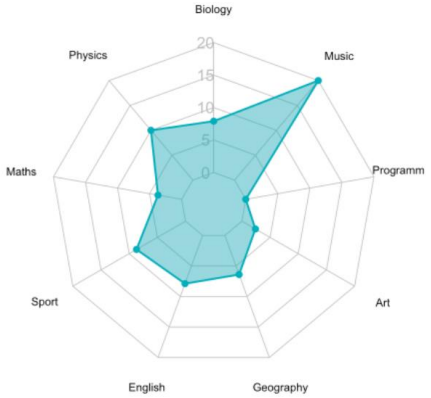
…

Techniques for Multivariate (or Hypervariate) data

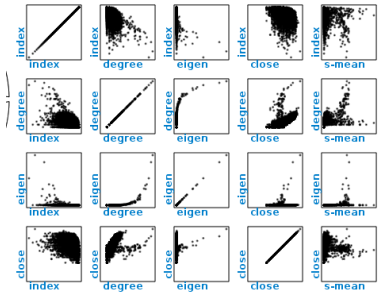
- Coordinate plots
  - parallel coordinate plots



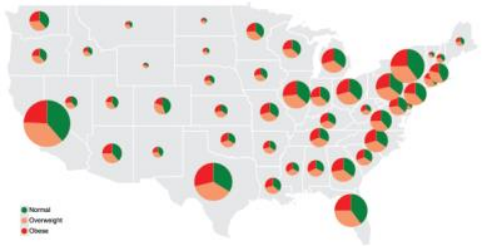
  - star (radar/spider) plots



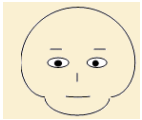
- Scatterplot Matrix



- Maps

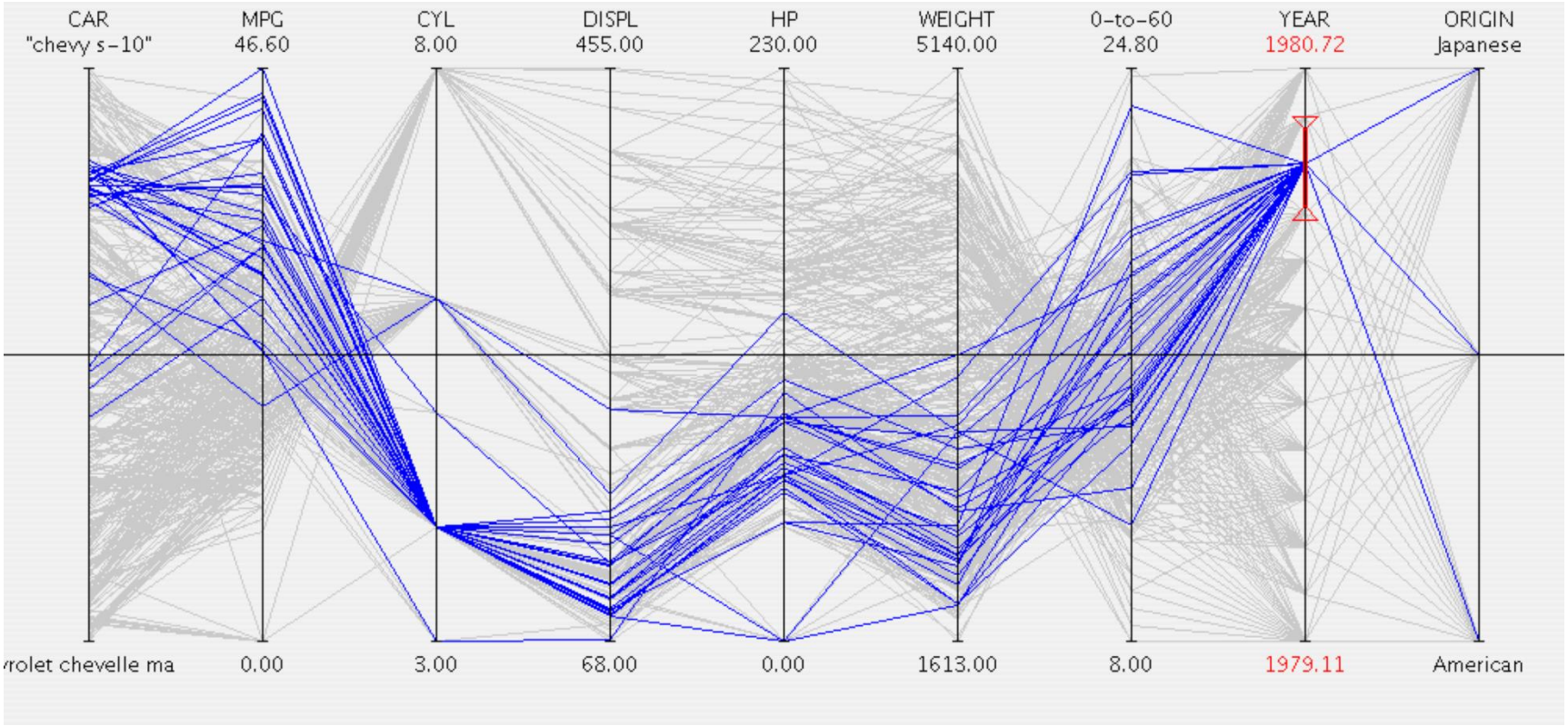


- Icons/glyphs



- **Parallel coordinates plots** are one of the most popular techniques for hypervariate data

- They have a very simple basis

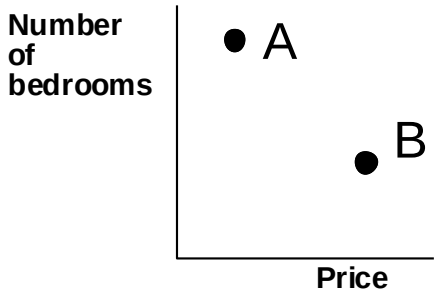


(Dataset with cars to sell)

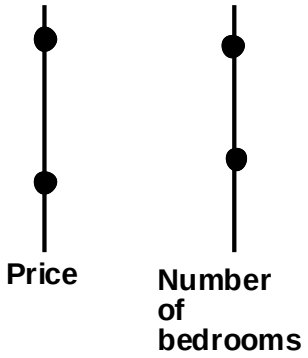
(Spence, 2007)

Consider a simple case of bivariate data

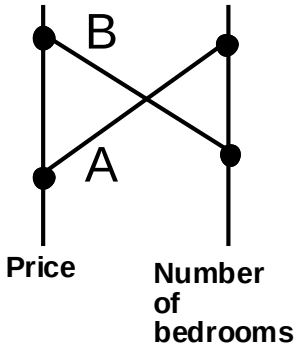
(data concerning houses to sell)



1- A scatterplot represents the price and number of bedrooms associated with two houses



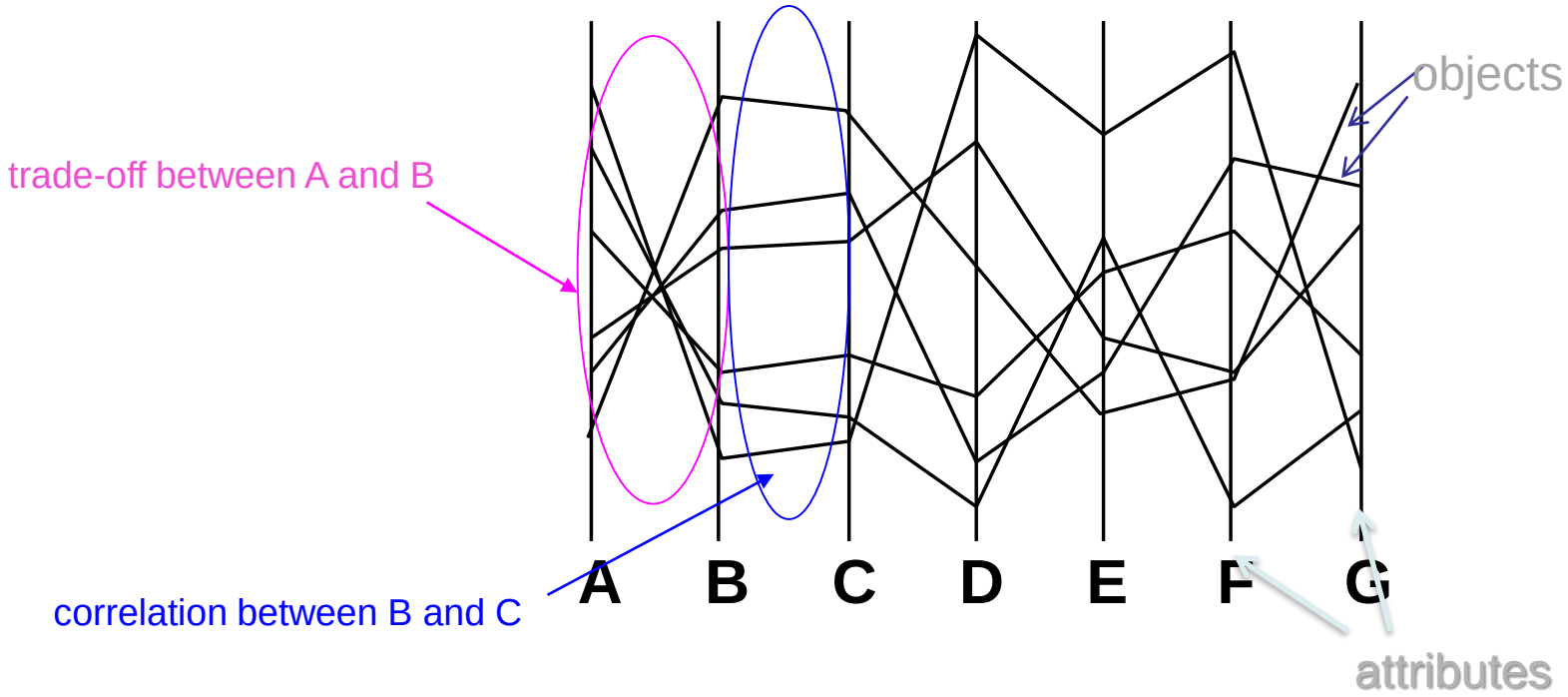
2- the axes are detached and made parallel; each house is represented by a point on each axis



3- To avoid ambiguity the pair of points representing a house are joined and labeled

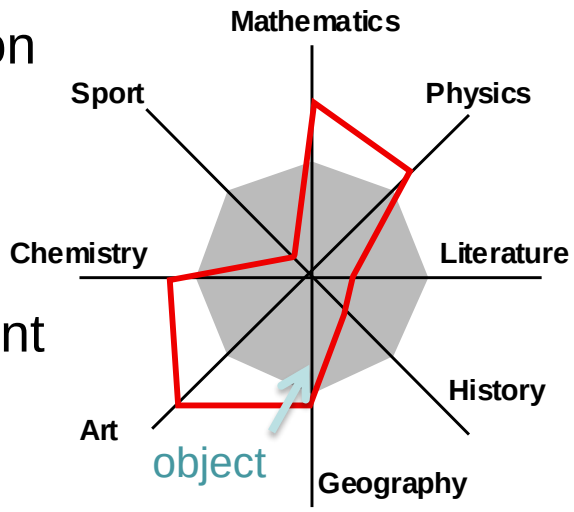
- For objects characterized by many attributes the parallel coordinate plots offer many advantages

A example for six objects, each characterized by seven attributes:



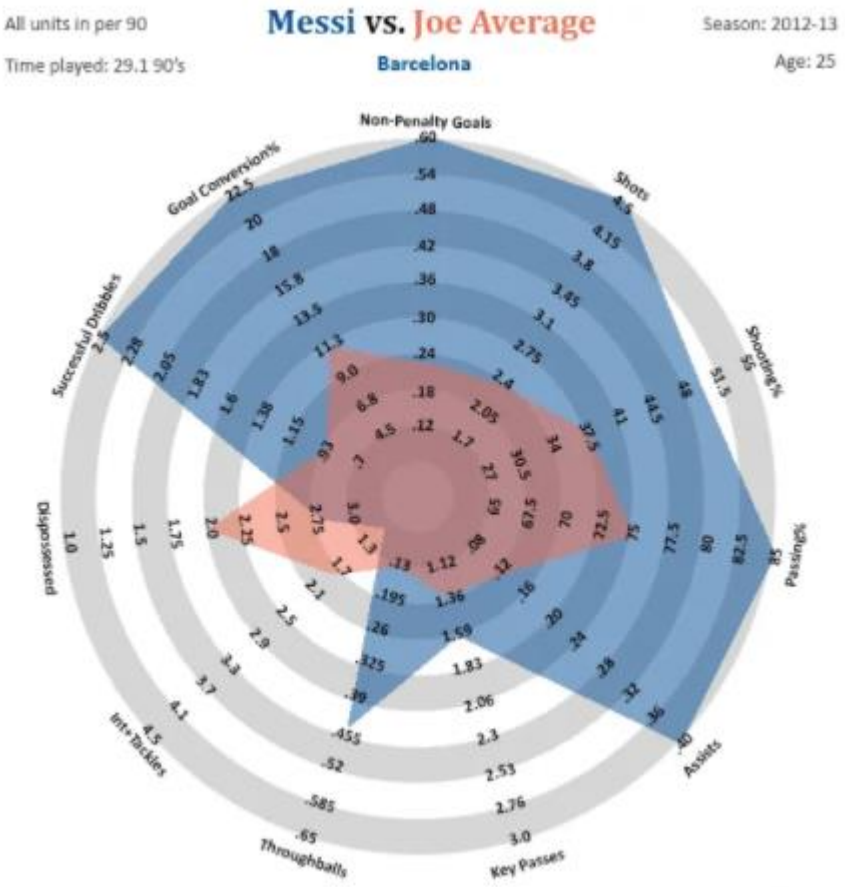
The trade-off between A and B, and the correlation between B and C, are immediately apparent. The trade-off between B and E, and the correlation between C and G, are not.

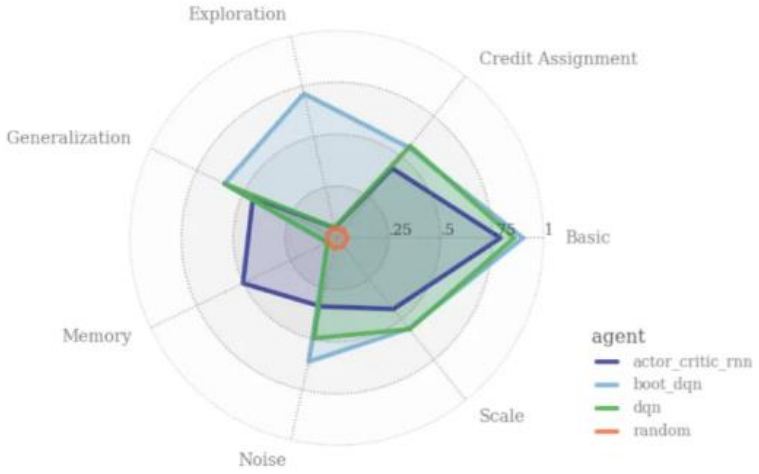
- **Star plots** have many features in common with parallel coordinate plots



(Spence, 2007)

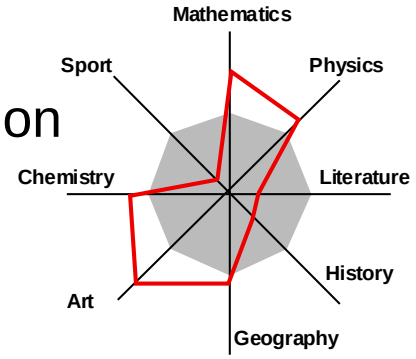
- An attribute value is represented by a point on a coordinate axis
- Attribute axes radiate from a common origin
- For a given object, points are joined by straight lines
- Other useful information such as average values or thresholds can be encoded





https://syncedreview.com/2019/08/16/deepmind-bsuite-evaluates-reinforcement-learning-agents/

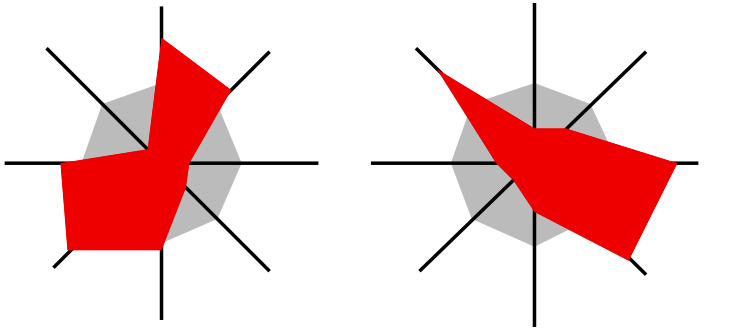
Properties of star plots:



- Their shape can provide a reasonably rapid appreciation of the attributes of the objects

- They offer **object visibility** and are suitable to compare objects

(by visibility it is meant the ability to gain insight pre-attentively; without a great cognitive effort)



Bob's performance Tony's performance

(Spence, 2007)

- The **scatterplot matrix** (SPLOM) is applicable to higher n. of variables

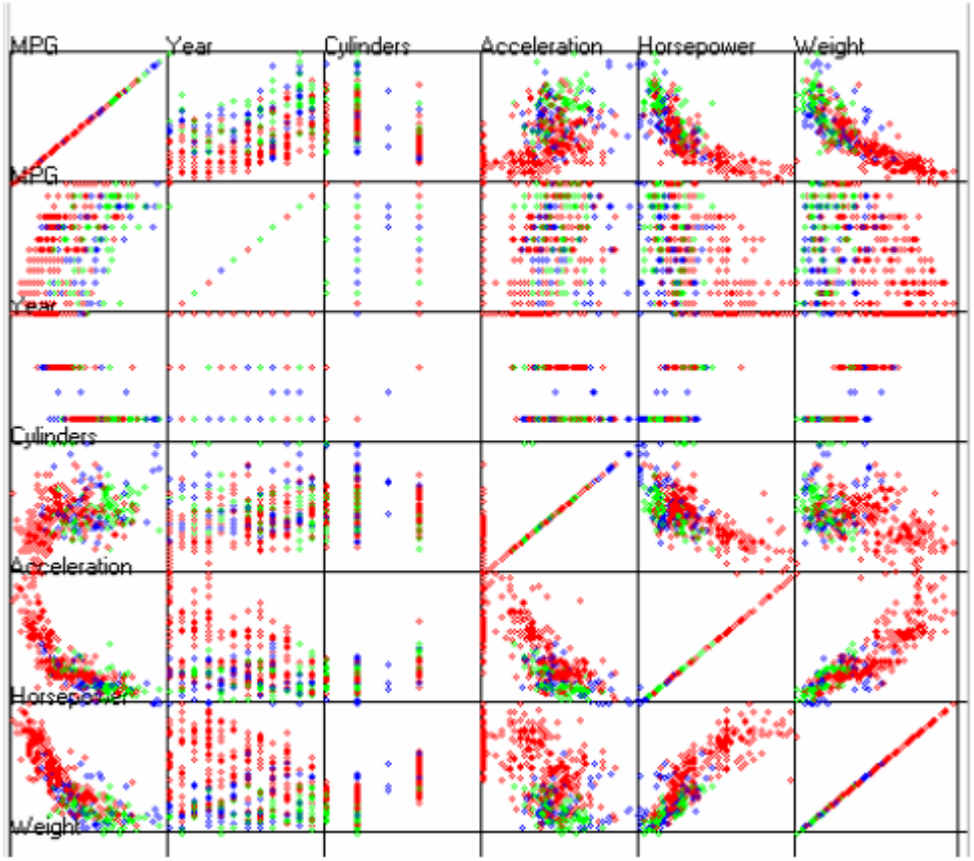
- However, as the number of attributes increases, the number of different pairs of attributes increases rapidly:

  – 2 variables-> 1 scatterplot

  – 3 variables -> 3 scatterplots

  – 4 variables -> 6 scatterplots

We may try to reduce the number of dimensions keeping the more relevant: **Dimensionality reduction!**

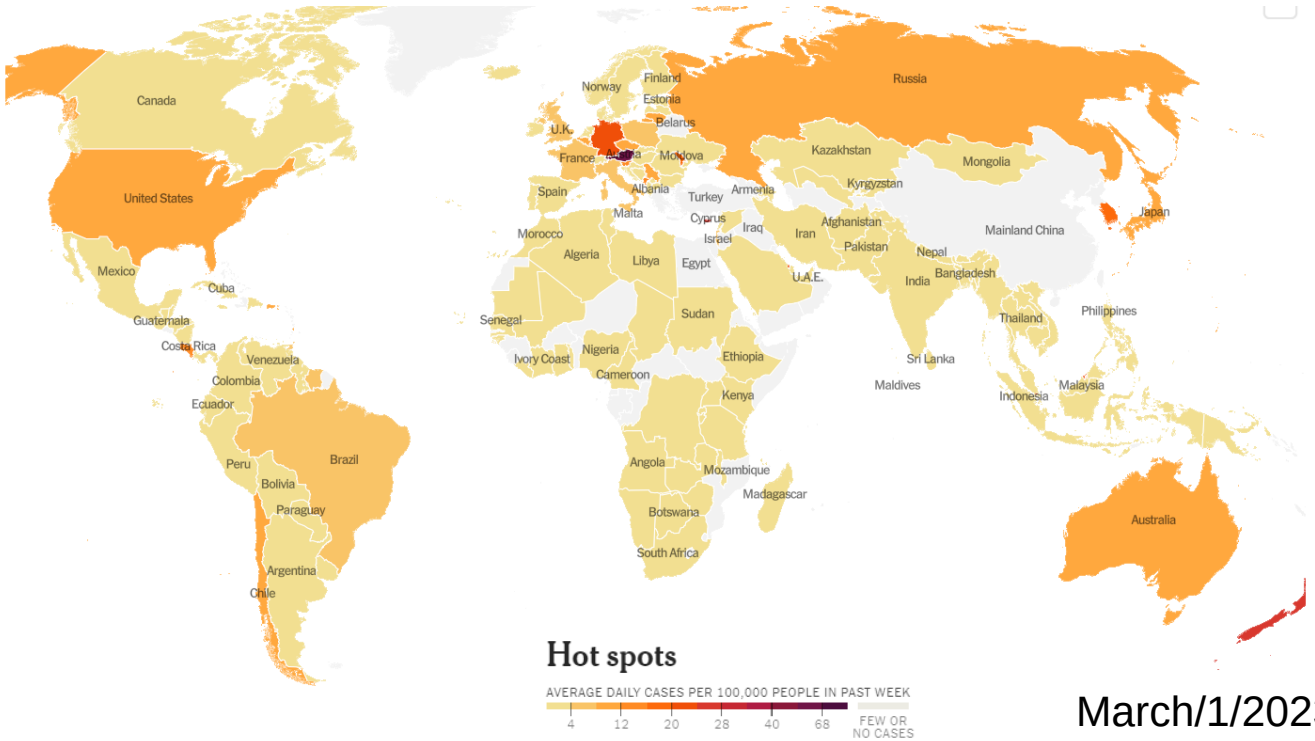


Scatterplot matrix for 6 attributes of a car dataset

Simple representations of attributes on a map

Choropleth maps - A standard approach to communicating aggregated data by geographical areas using color encoding of the geographic area

They require some care: what are the possible issues?

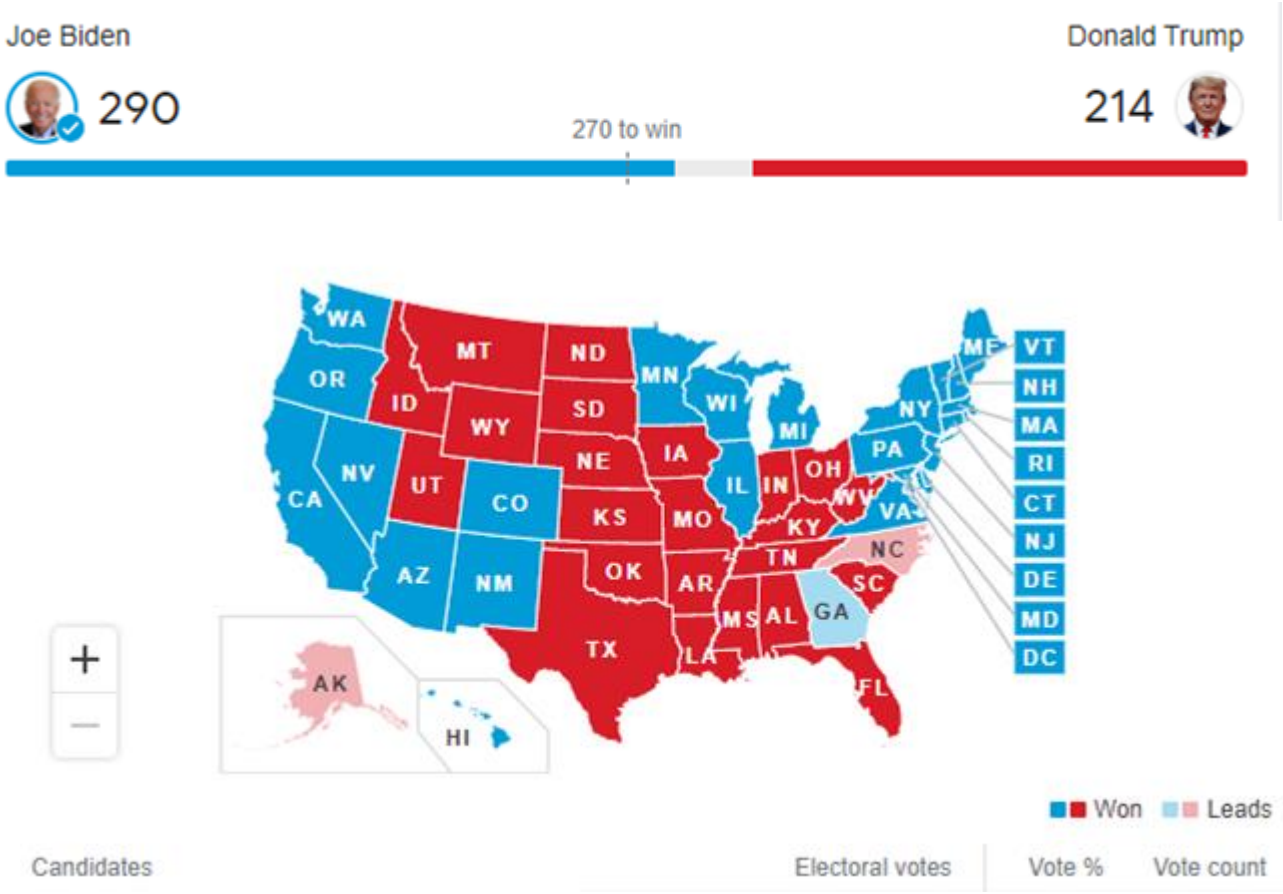


March/1/2023

https://www.nytimes.com/interactive/2020/world/coronavirus-maps.html

Visualizations of the US 2020 Election

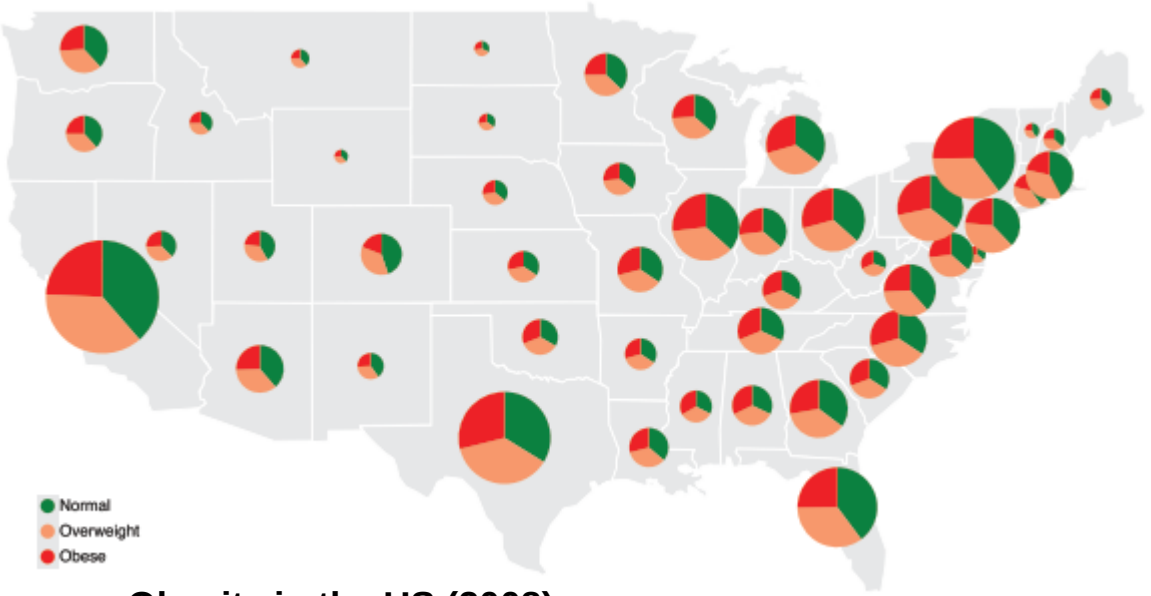
(choropleth + bar)
the bar helps better understand the ratio of votes
(and the number provides the maximum accuracy)



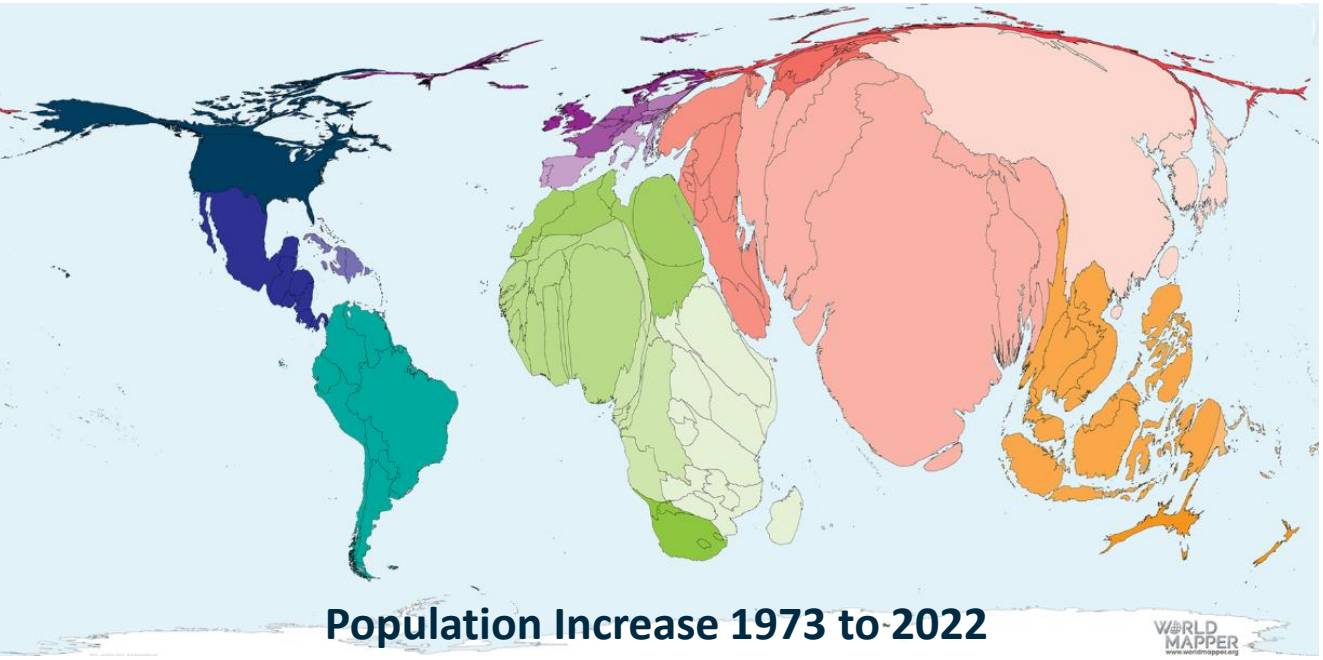
Simple representations of attributes on a map

- **Graduated Symbol Maps** are an alternative to the choropleth map;
- Symbols are placed over an underlying map; may show more atrributes
- Avoid confounding geographic area with data values

What is missing in this visualization?



Obesity in the US (2008)
(Heer et al., 2010)

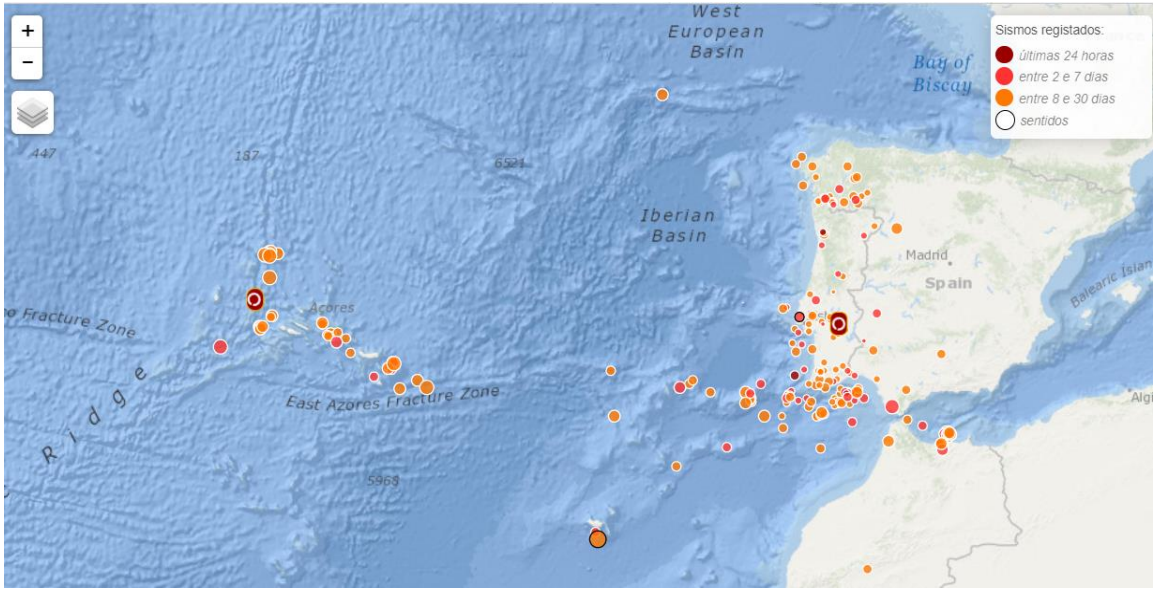


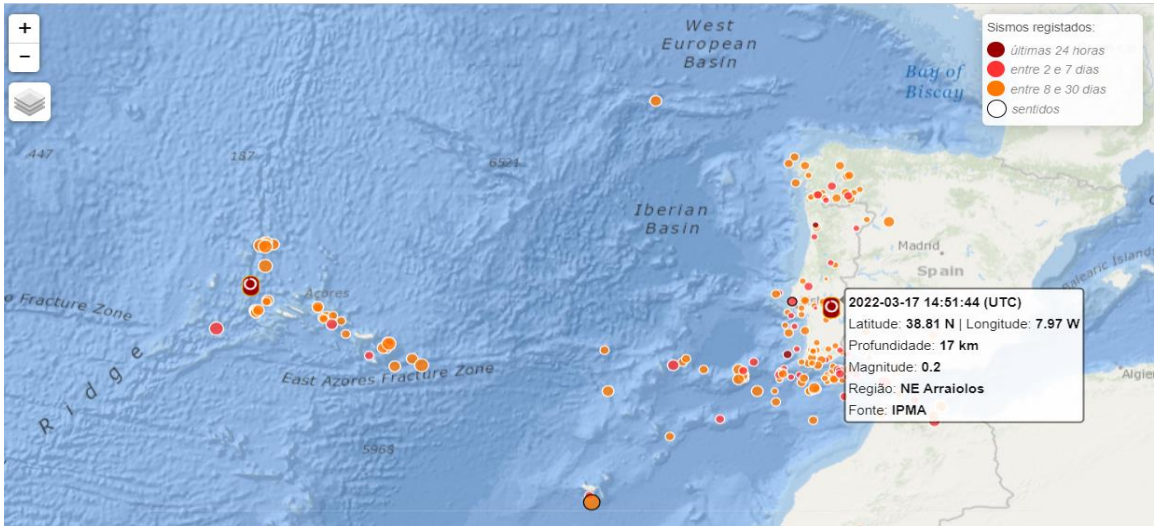
Cartograms:
Using distortion to represent a variable

https://worldmapper.org/

Seismic activity:

Is something missing in this visualization?

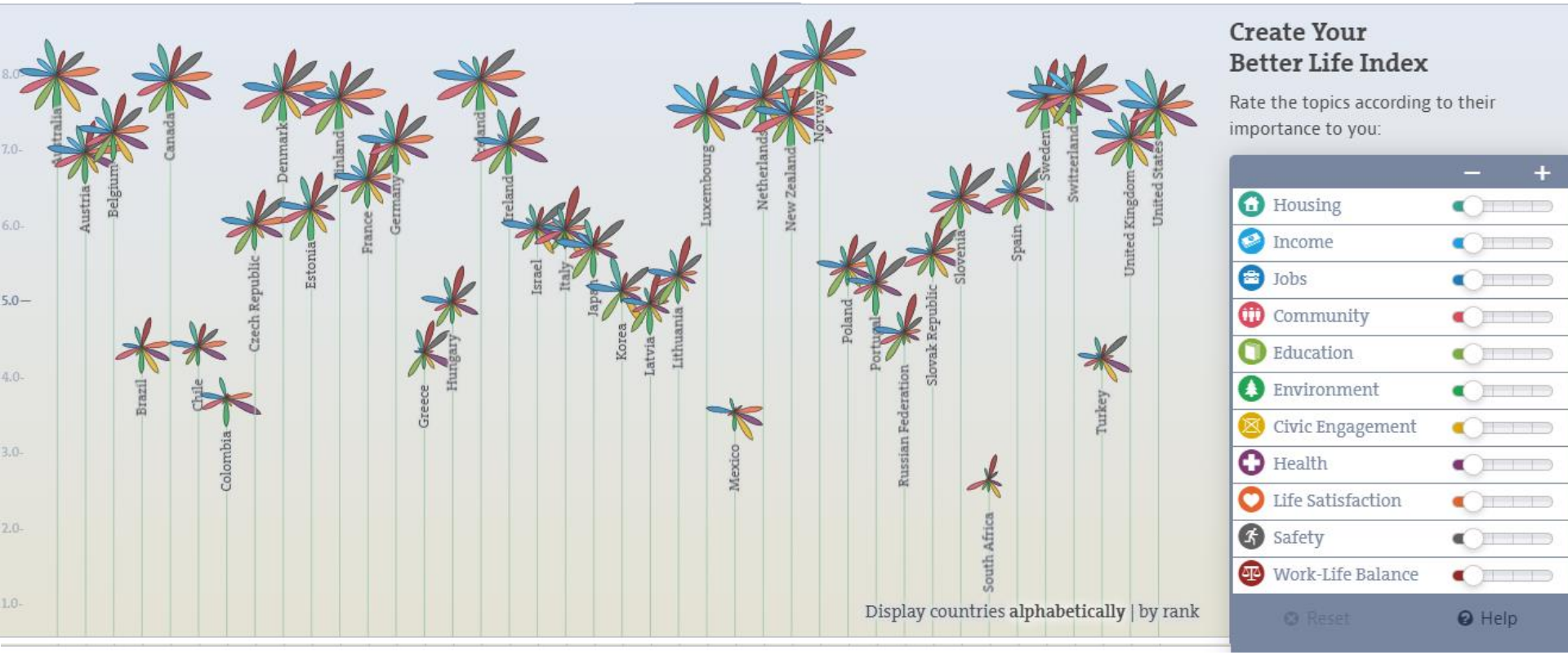




https://www.ipma.pt/pt/geofisica/sismicidade/index.jsp

Glyph chart example

The physical properties of the shape represent different categorical variables sized according to the associated quantitative value and distinguished through color



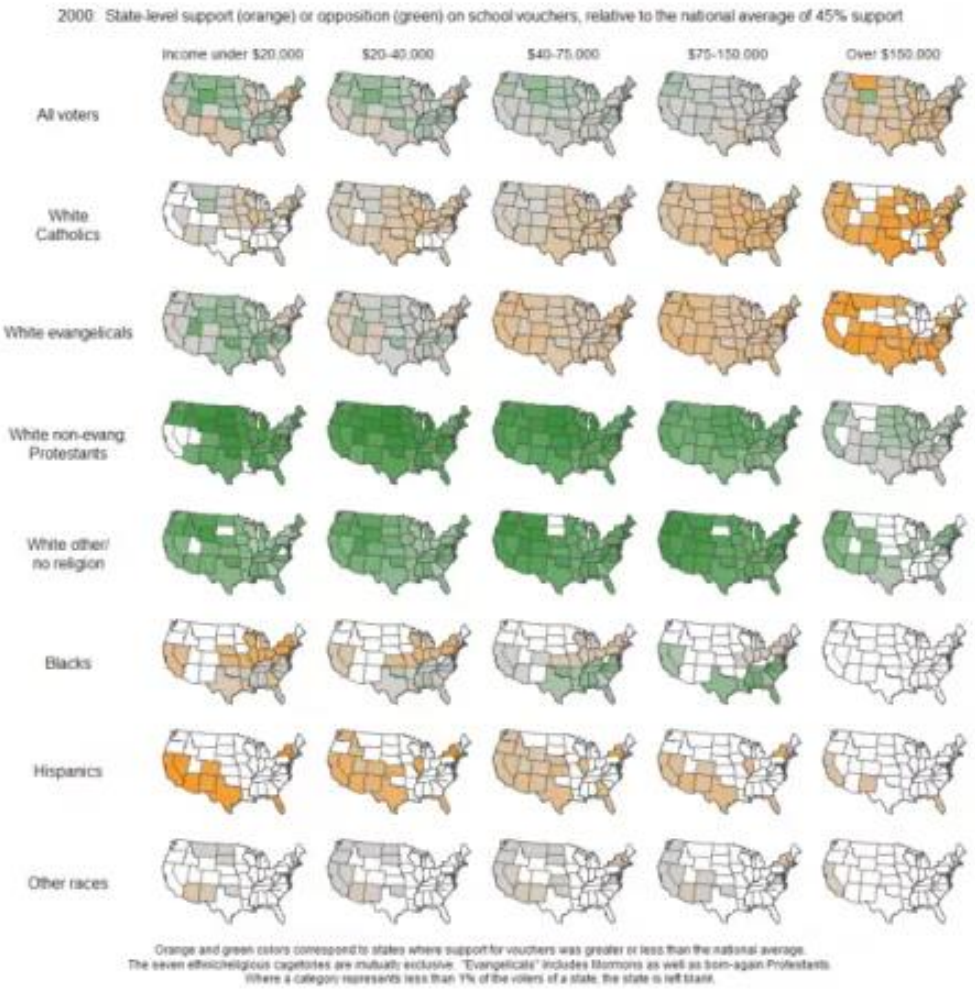
(Kirk, 2012)

http://oecdbetterlifeindex.org

Small multiples:

arrangement approach that facilitates efficient and effective comparisons

(Kirk, 2012)



Dashboards

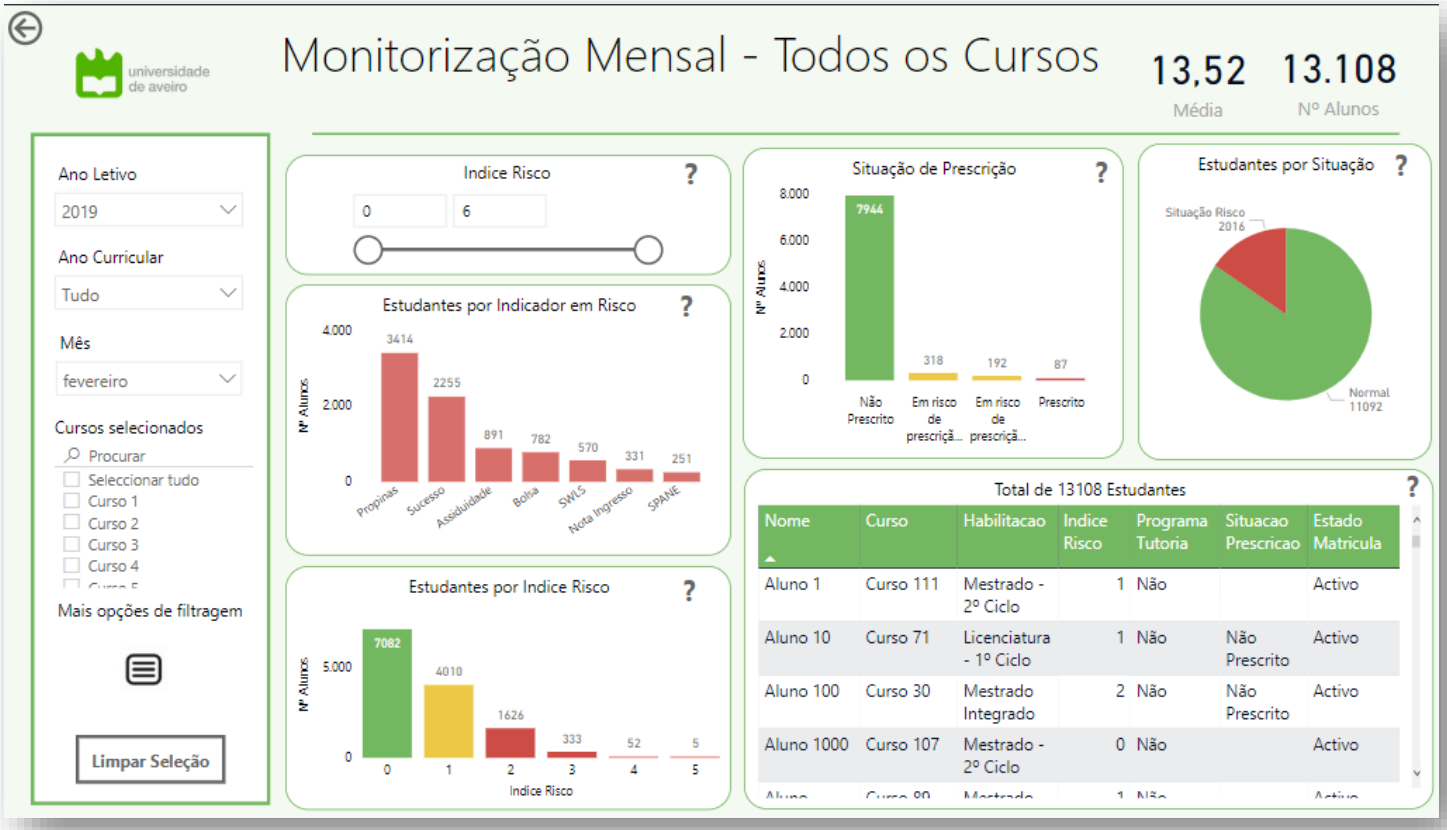
Visual display summarizing a dataset providing information at-a-glance (e.g. KPIs)

" A dashboard is a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance. " (Few, 2004)

https://www.nngroup.com/articles/dashboards-preattentive/

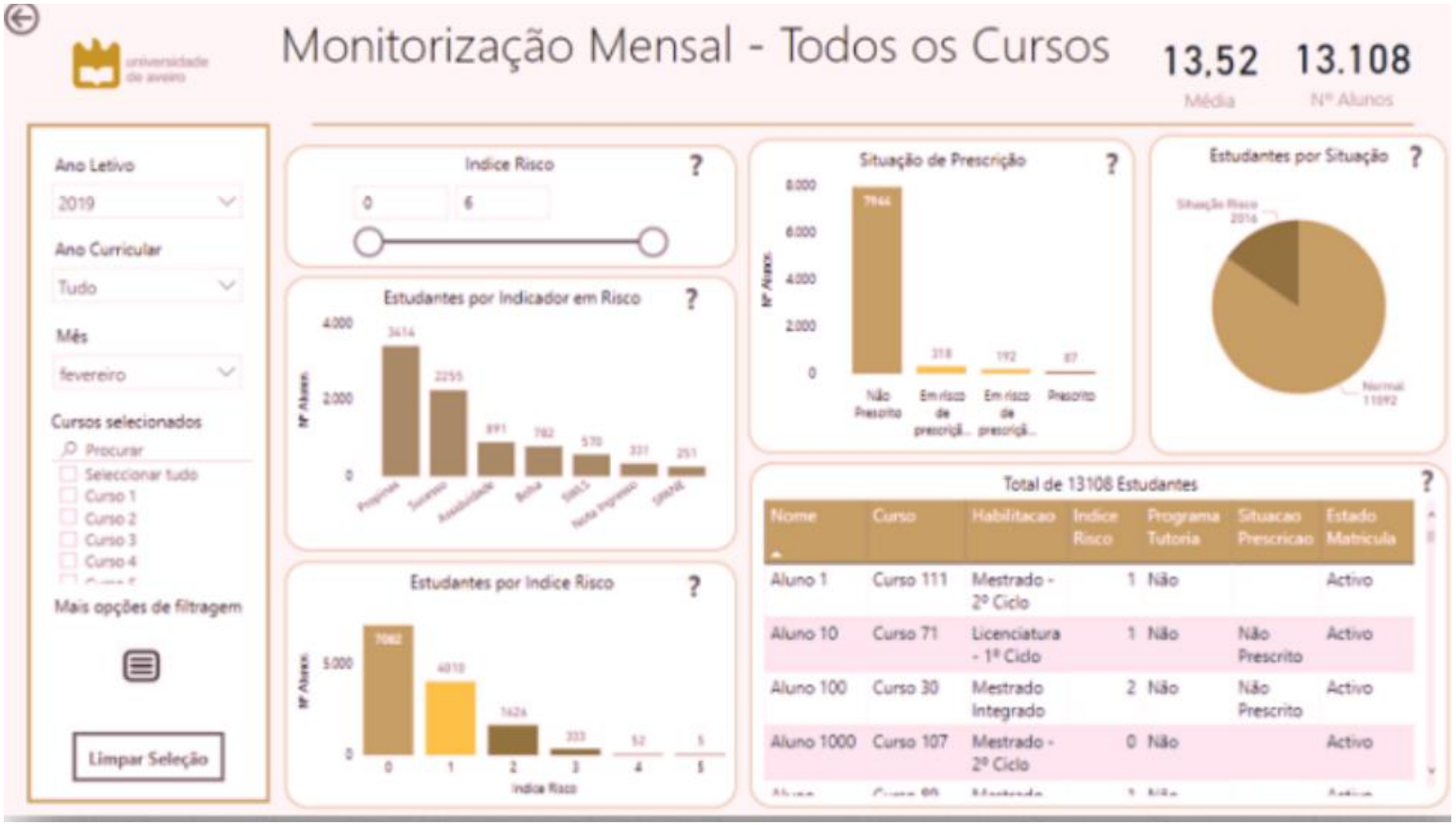
Prototype: "Portal dos indicadores, UA"

Any issues about the color?



Testing readability to color-blind users:

As seen by someone with deuteranopia (red-green blindness) https://www.color-blindness.com/coblis-color-blindness-simulator/)



nature of the problem
- communicate
- explore
- confirm

nature of the data to represent
- quantitative
- ordinal
- categorical

number of attributes
- univariate
- bivariate
- trivariate
- multivariate

visualization techniques organized according the n. of attributes

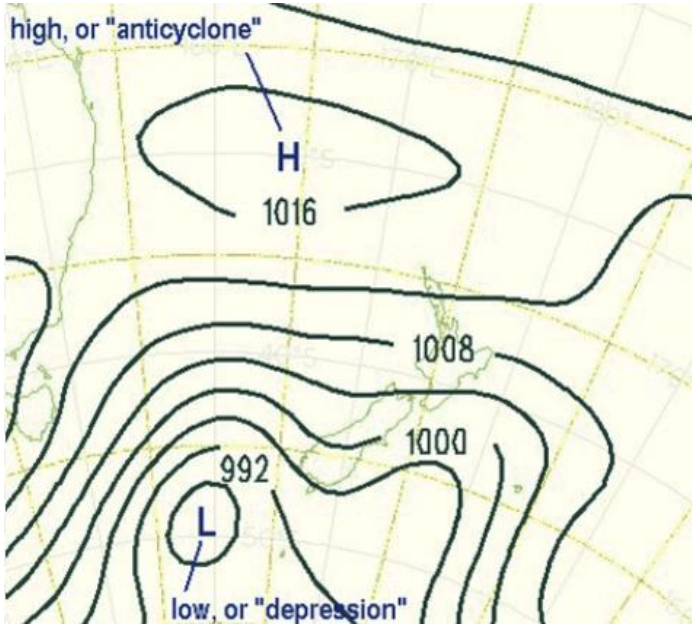
dataset types
- tables
- networks
- spatial or geographical
- fields
- geometry

Next: of field data

…

Representations of a scalar in a 2D field

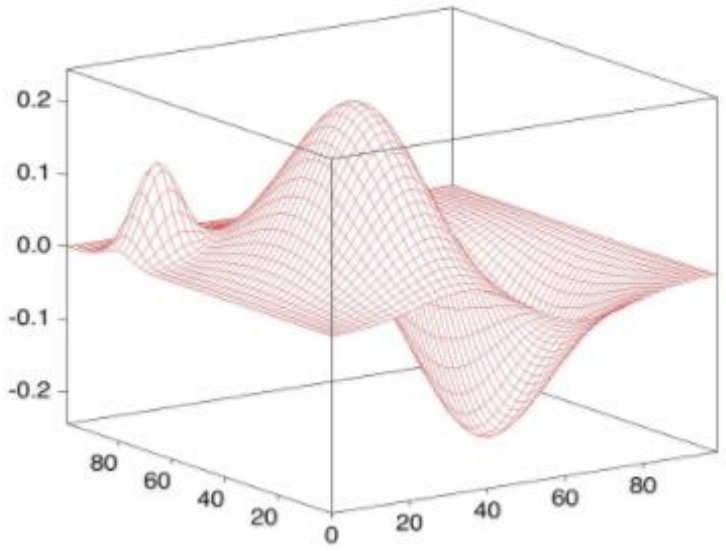
- Contour plots
- **contour line** (also **isoline**, **isopleth**, or **equipotential curve**) of a function of two variables is a curve along which the function has a constant value, so that the curve joins points of equal value.
- Typical in meteorological charts (isobars and isothermal curves)
- and maps (to represent altitude or depth)

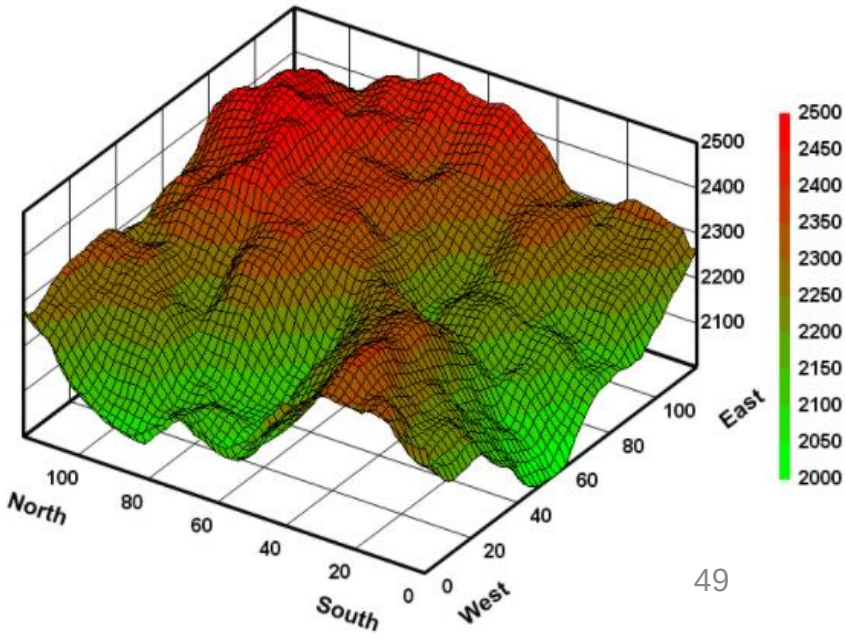


Representations of a 3D scalar function

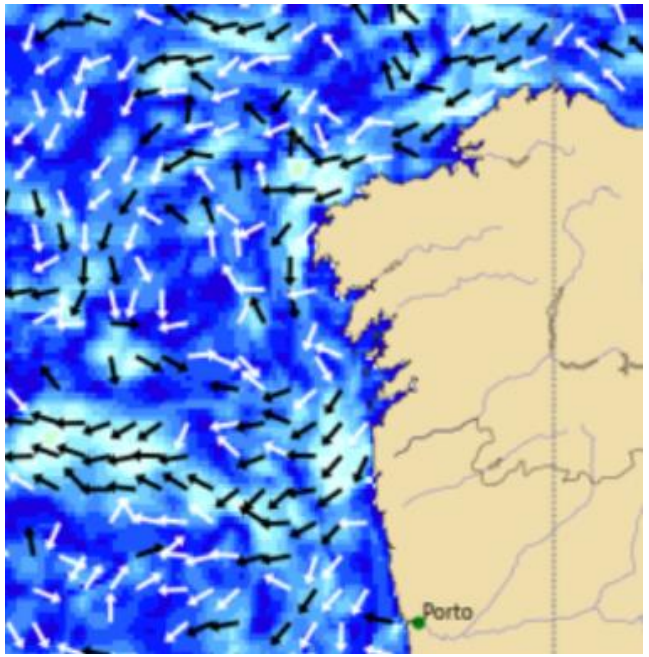
- Surface plots
- May be combined with color

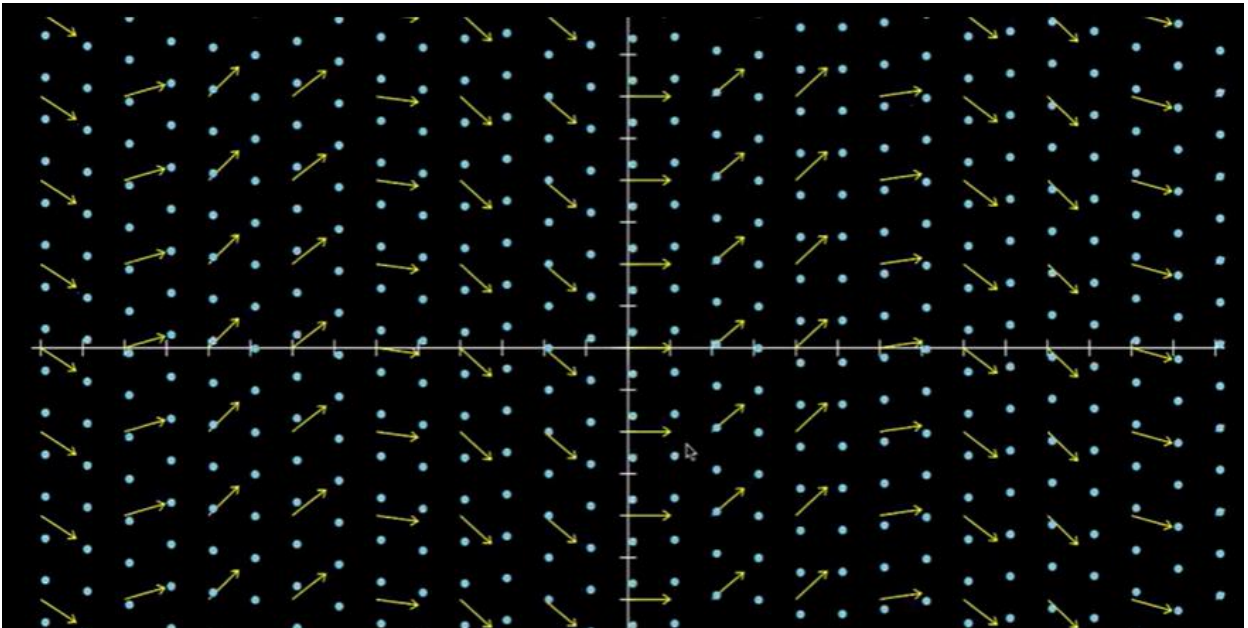
(preferably in a redundant way and carefully selecting the scale)





Representing vectors in a 2D field



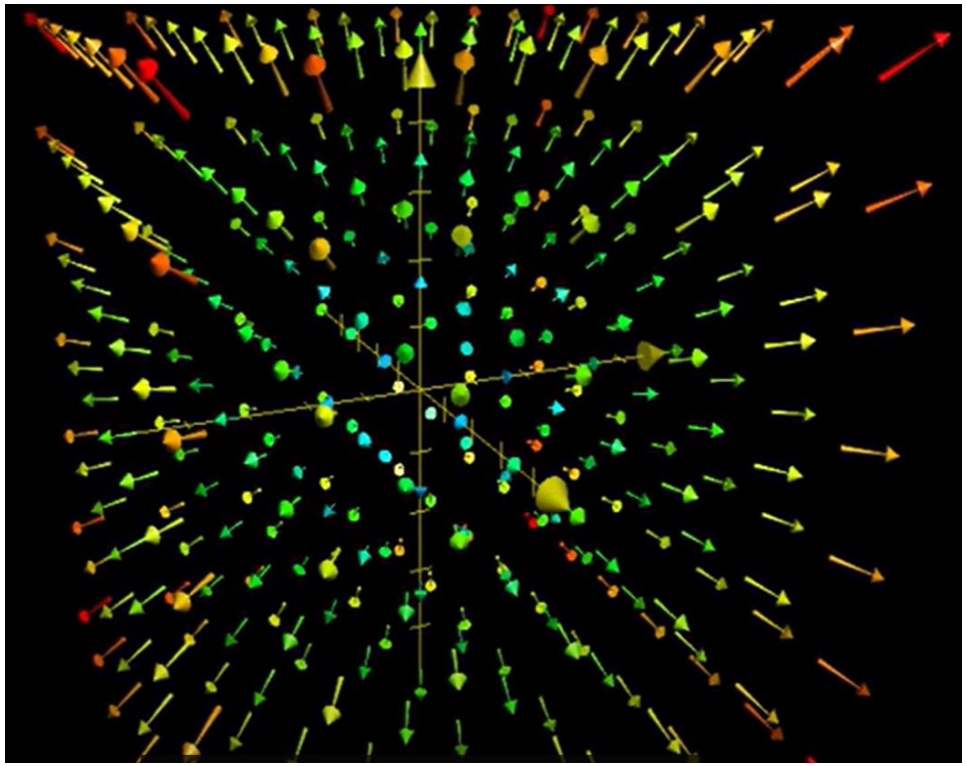


https://www.ipma.pt/pt/maritima/currents/

https://www.khanacademy.org/math/multivariable-calculus/thinking-about-multivariable-function/visualizing-vector-valued-functions/v/fluid-flow-and-vector-fields

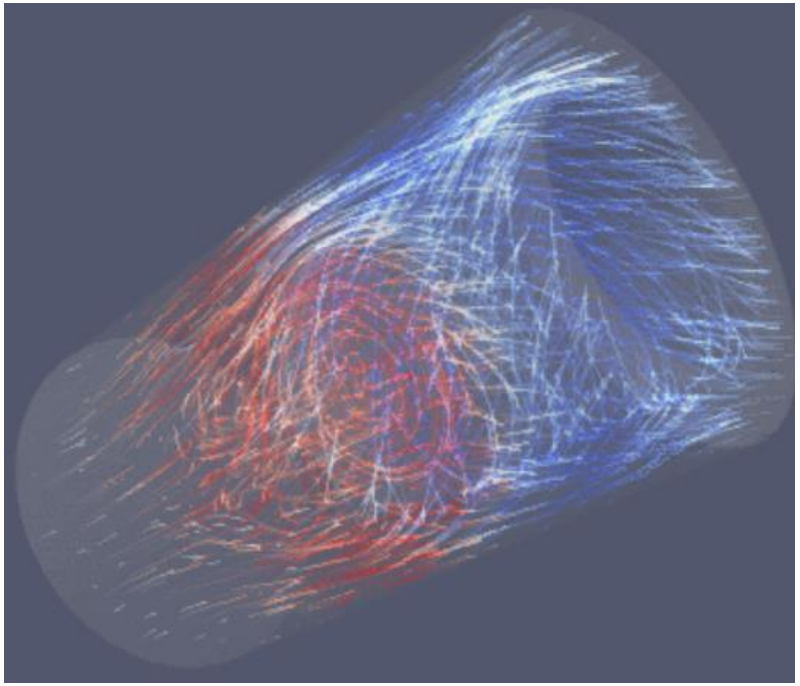
Representations of vectors in a 3D field

Vector data visualization: in 3D space a vector variable is visualized



3d vector field example (video) | Khan Academy

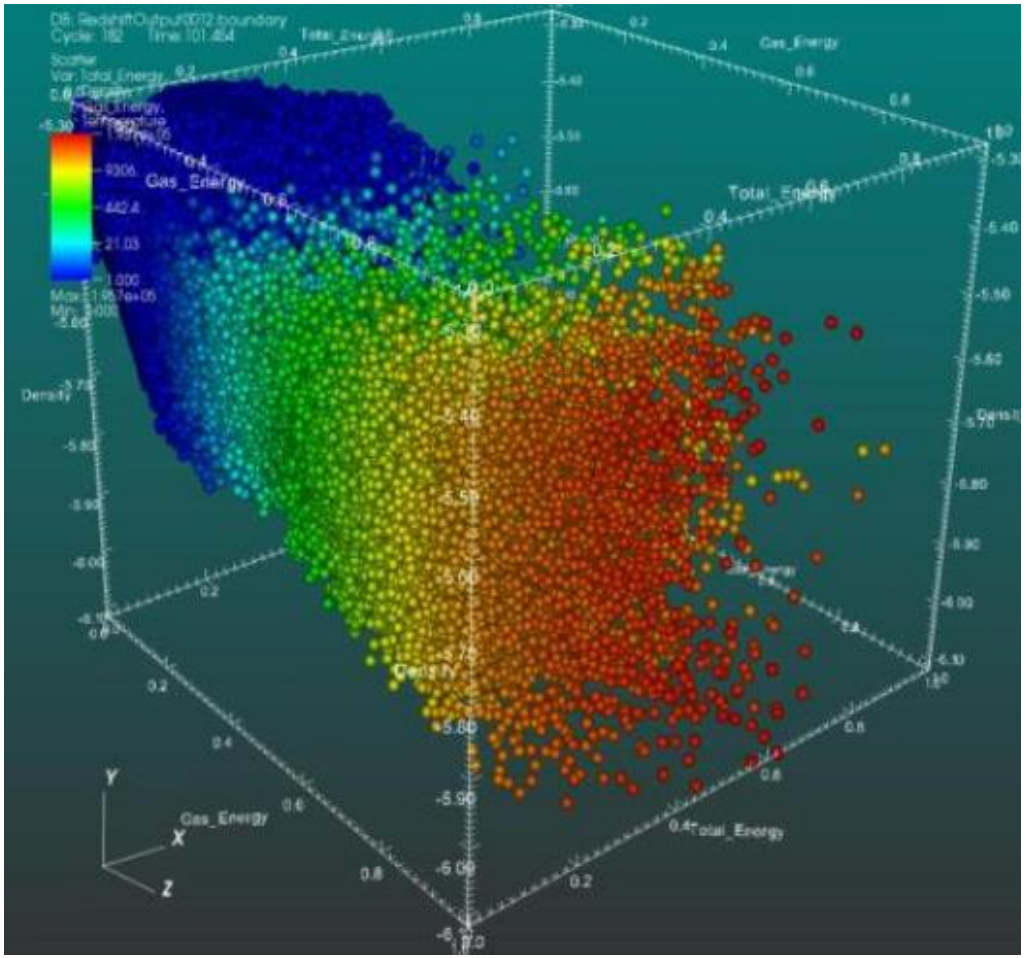
Stream Lines are another interesting representation



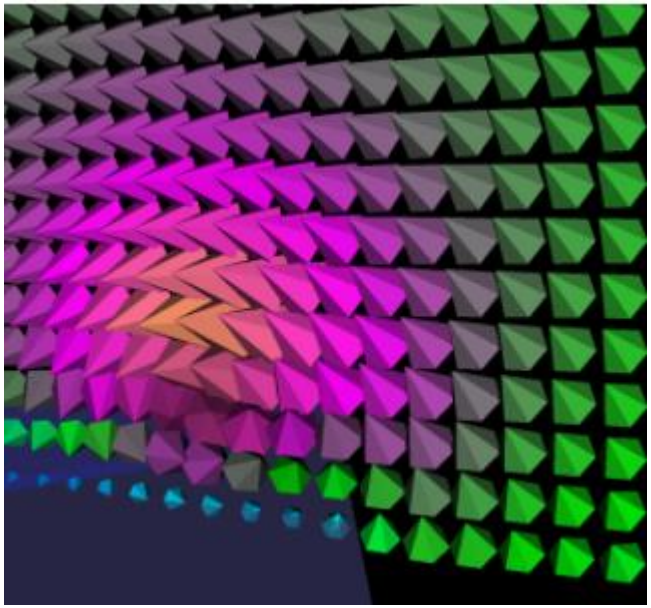
New Animated Stream Lines Representation for ParaView 5.3 (kitware.com)

Glyphs

Four-dimensional data visualization: in 3D space a fourth scalar variable is visualized using colored glyphs

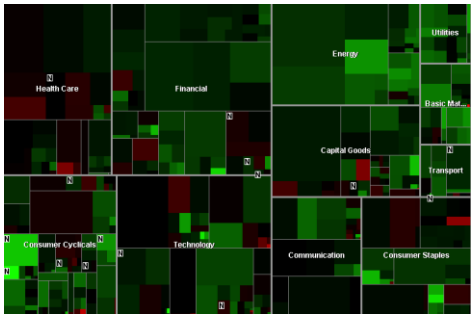


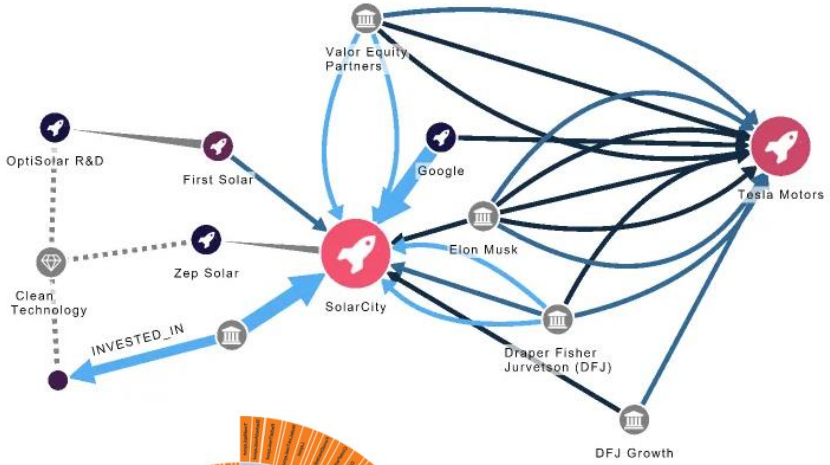
Glyphs for Visualizing a 3D Vector Field

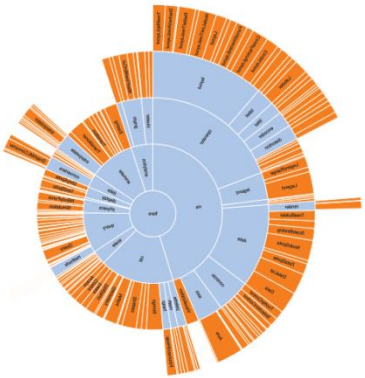


(Wikipedia/Glyph)

- These are only some of the visualization techniques to represent a value
- There are a lot more …
- And we may want to visually represent beyond value: relation
  - Networks
  - Hierarchical data (trees)







https://plotly.com/python/sunburst-charts/

Understanding and Using Tree Maps | Tableau

Bibliography

- Spence, R., *Information Visualization, Design for Interaction*, 2nd ed., Prentice Hall, 2007
- Kirk, A*., Data Visualisation: A Handbook for Data Driven Design*, 2nd. Ed., Sage, 2019
- Mazza, R., Introduction to Information Visualization, Springer, 2009
- Ware, C., *Information Visualization, Perception to Design*, 2nd ed.,Morgan Kaufmann,2004
- Tufte, E., *The Visual Display of Quantitative Information*, 2nd ed., Graphics Press, 2001
- Heer, J., Bostock, M., & Ogievetsky, V. A tour through the visualization zoo. *Communications of the ACM*, vol. 8, n.1, 2010 https://doi.org/10.1145/1743546.1743567