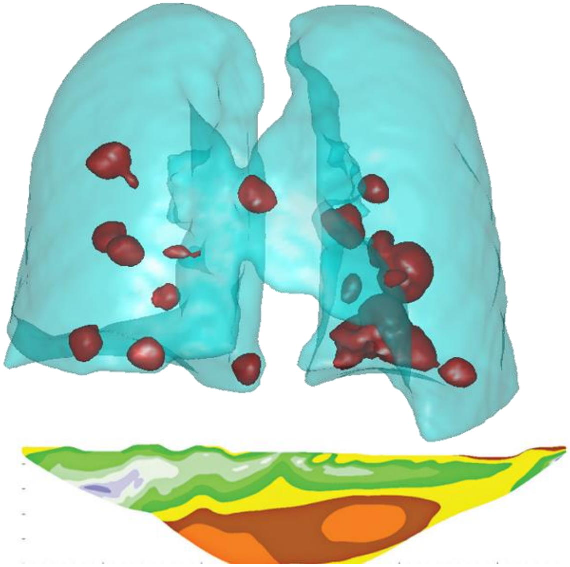
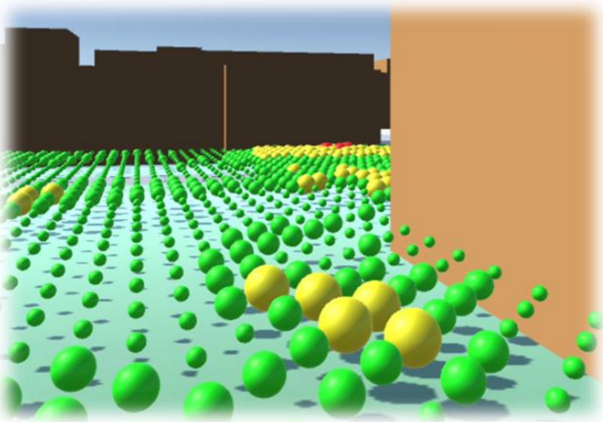
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

An Introduction to Visualization





Beatriz Sousa Santos, University of Aveiro, 2024

Definition

Objectives

History

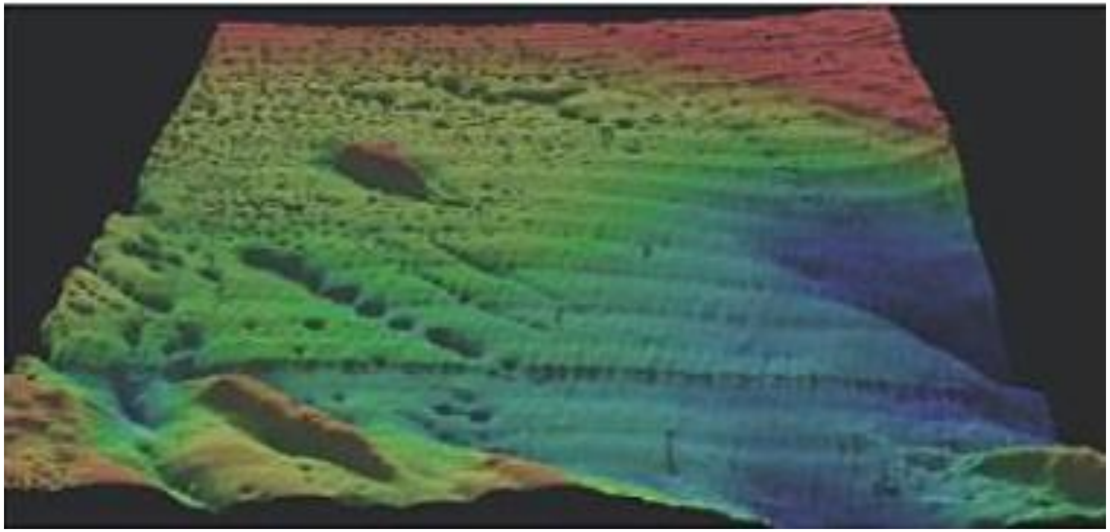
Applications

Model

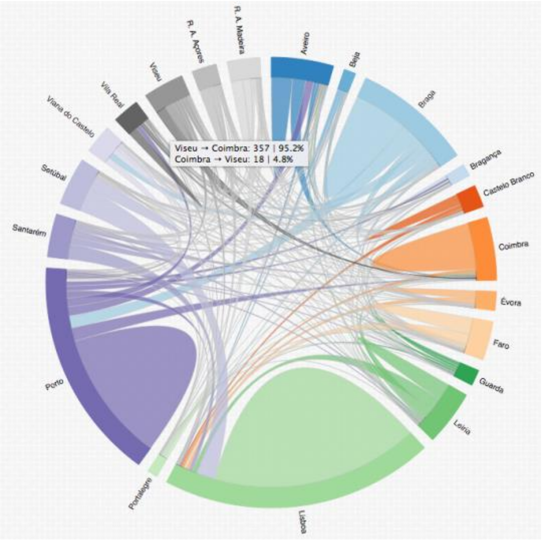
How to obtain and evaluate a Visualization?

What is Visualization?

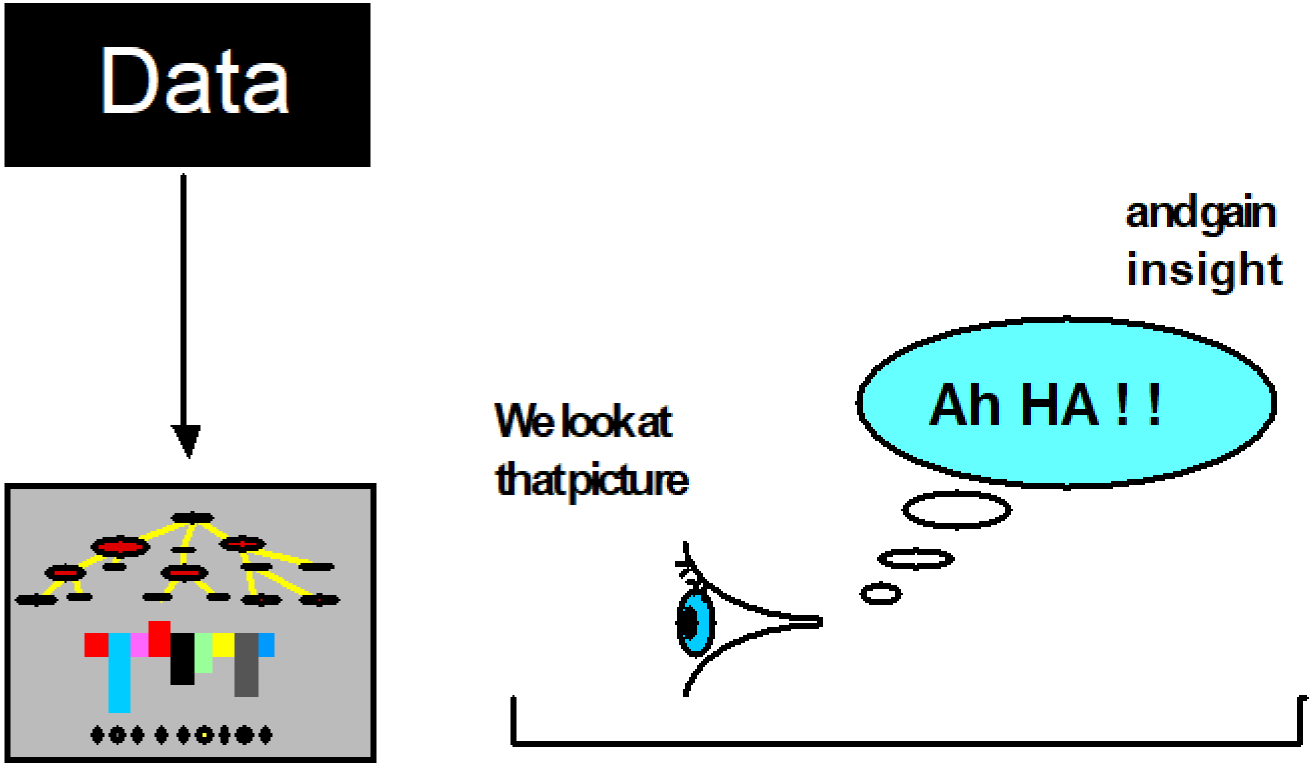
Is the process of exploring, transforming and **representing data** as images to **gain insight into phenomena**



Passamoquoddy Bay
(10^6 measures)
(Ware, 2019)



Portuguese Higher Education
(data from 120 000 candidates)



The process of visualization: graphically encoded data is viewed in order to form a mental model of that data (Spence, 2007)

Human-in-the loop process!

Data and Information Visualization

- In general:

  Data (scientific) Visualization (DV) - Data having an inherent spatial structure

  (e.g., CAT, MR, geophysical, meteorological, fluid dynamics data)

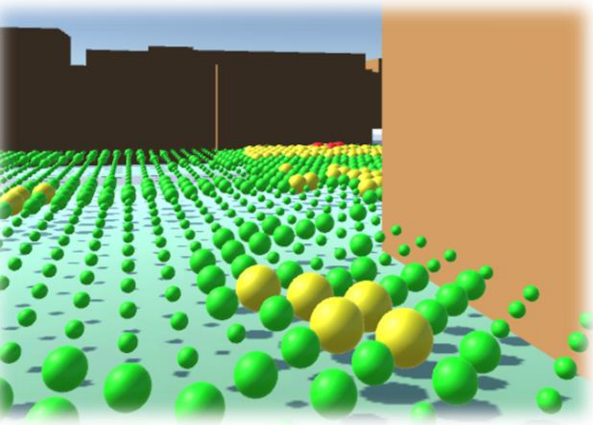
  Information Visualization (IV) – “Abstract” tabular data not having an inherent spatial structure (tabular data)

  (e.g., stock exchange , S/W, Web usage patterns, text)

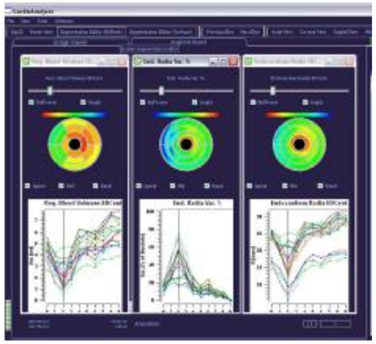
- These designations may be misleading; both DV and IV start with (raw) data and allow to extract information

- Borders between these areas are not well defined …

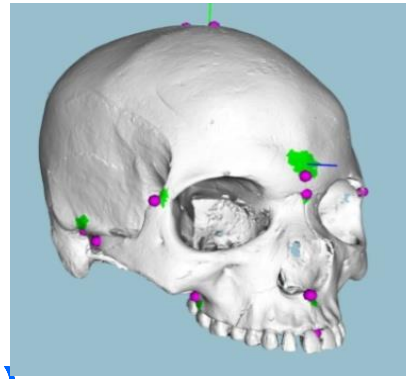
Scientific Visualization **(examples “made in UA”)**



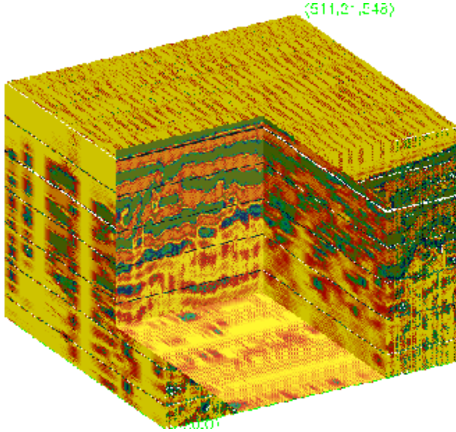
Air pollution **(2022)**



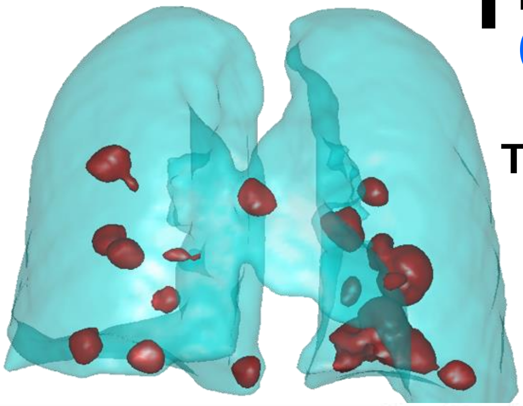
Tomography **(2011)**



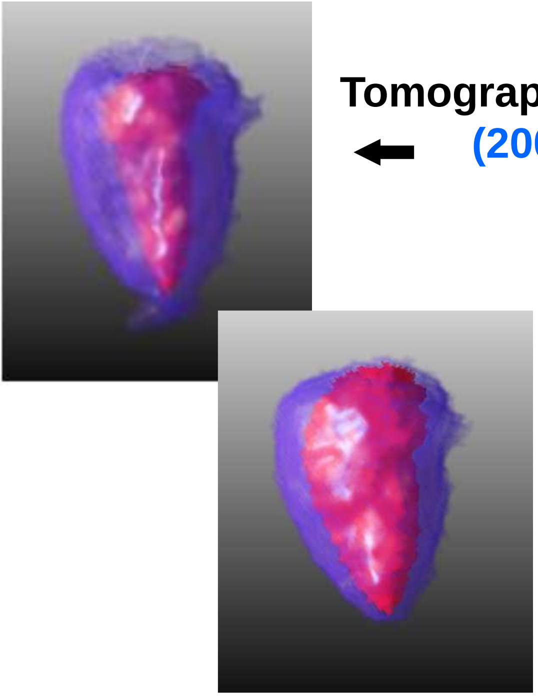
Laser scanner **(2015)**



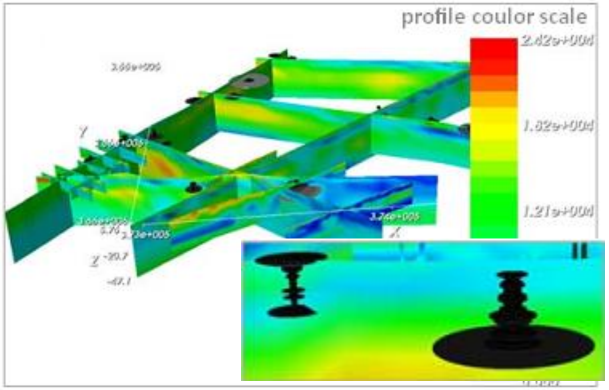
Ground Penetrating Radar **(1999)**



Tomography **(2004)**

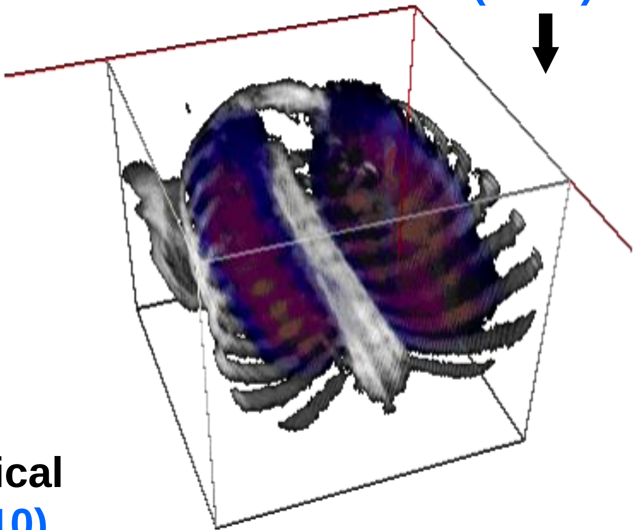


Tomography **(2008)**

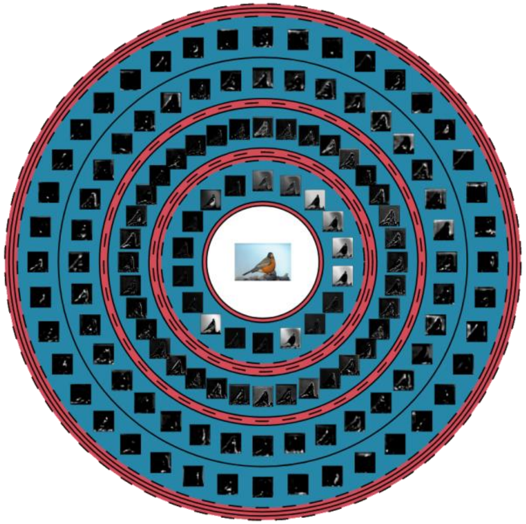


Electrical and mechanical ground resistivity **(2010)**

Tomography and SPECT **(1996)**

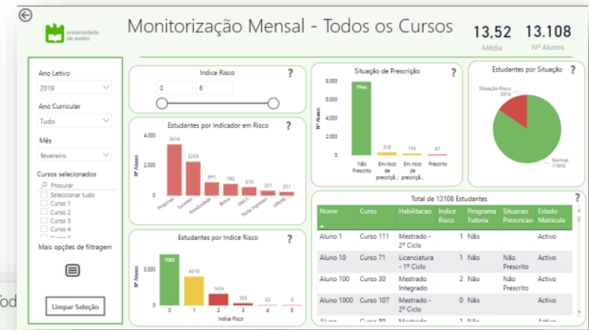


Information Visualization **(examples "made in UA")**

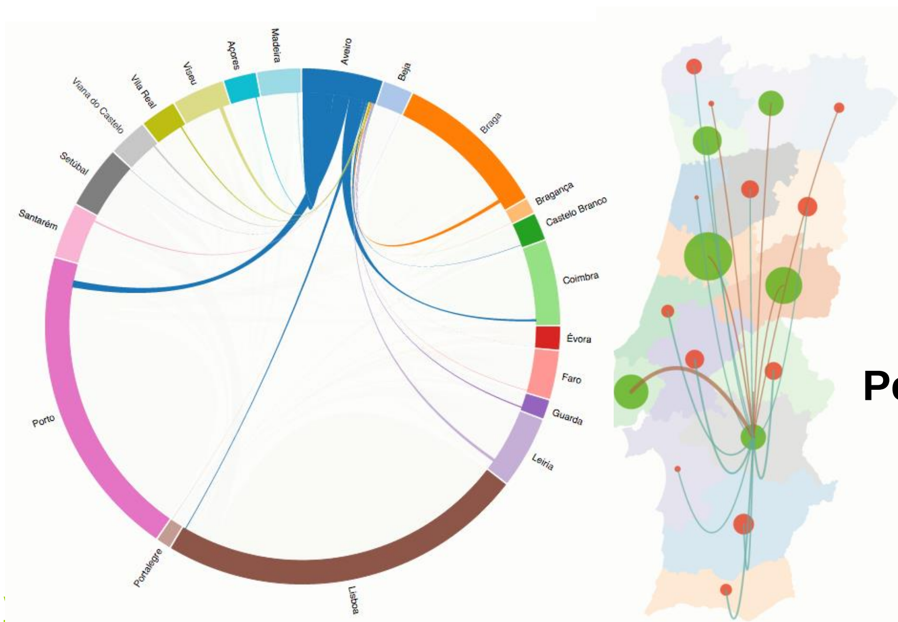


Machine Learning Visualization (XAI)
(UA, 2020)

Academic data
(UA, 2020)

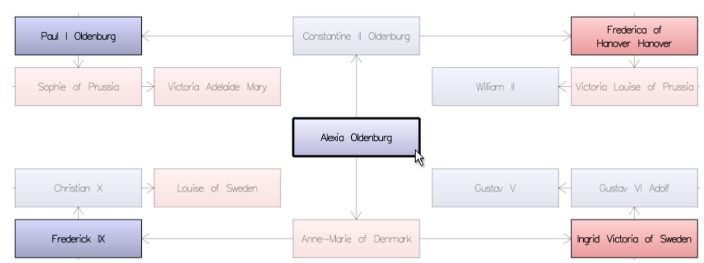


Student Migrations
(UA, 2015)

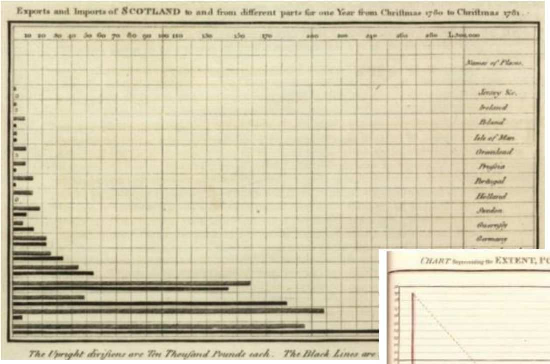


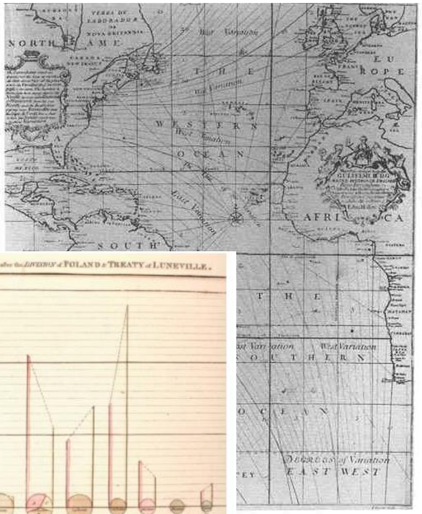
Taxonomy Visualization
(UA, 2021)

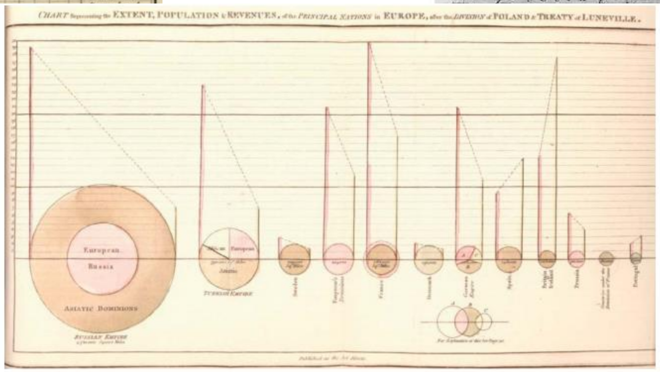
Pedigree trees
(UA, 2011)



Brief History







Brief history

- The usefulness of graphical representations of large amounts of data has been recognized long ago:

XVIII e XIX centuries- use of graphics in statistics and science:

W. Playfair, C. J. Minard

XX century- J. Bertin, E. Tufte

- The use of the computer made Visualization a more practicable discipline:

1987 - Identification of Visualization as an autonomous discipline

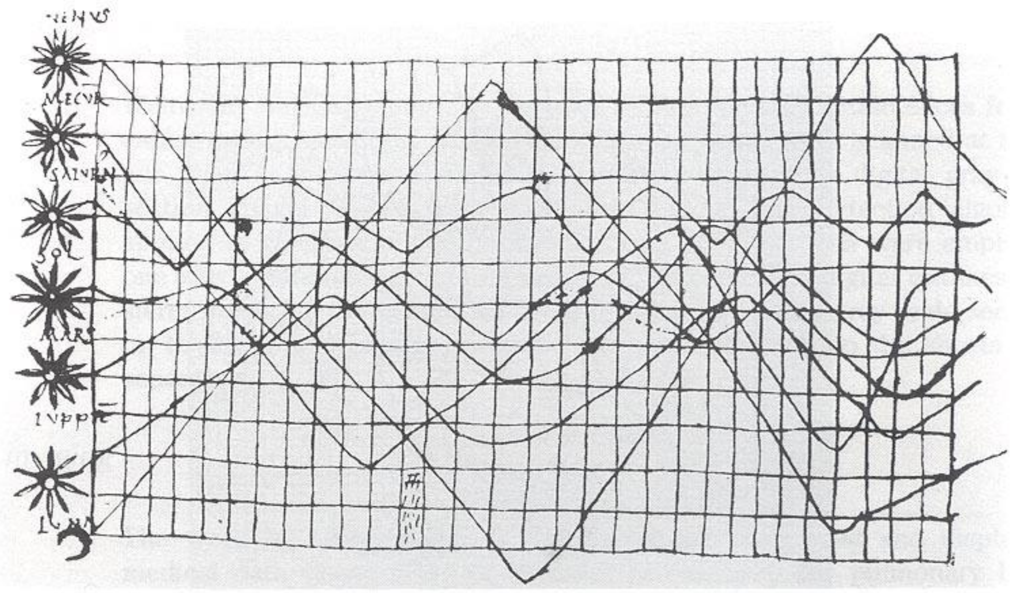
Visualization in Scientific Computing
(McCormick, de Fanti and Brown – 1987)

Brief history

- Plenty of Visualization examples of the “pre-computer age”:
    - Inclination of planetary orbits – Xth century
    - Import/ export (Playfair) – XVIIIth century
    - Magnetic declination (Halley) – XVIIIth century
    - Russia campaign of Napoleon (Minard) –XIXth century
    - Cholera out-brake in London (Dr. Snow) – XIXth century

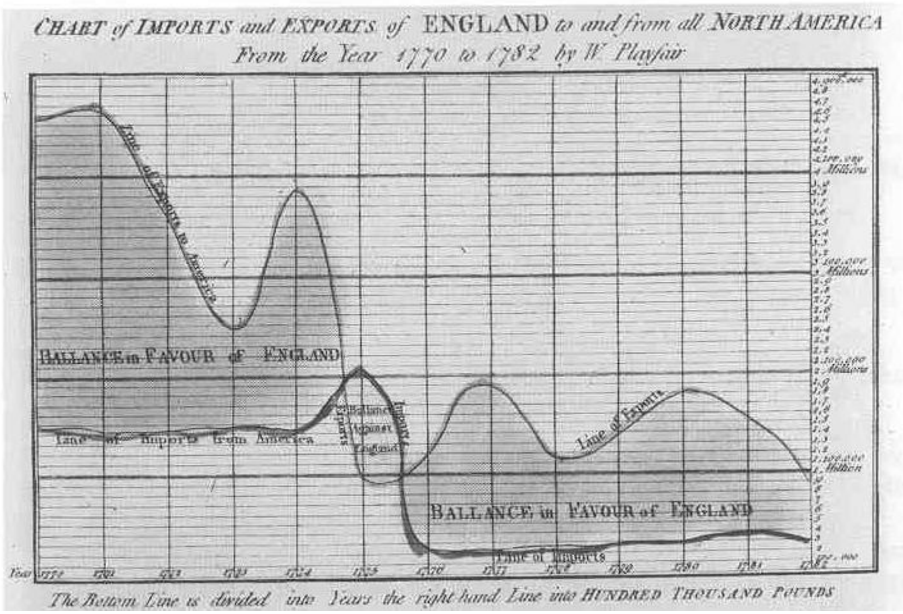
“Pre-computer” Visualization:

One of the oldest known Visualizations



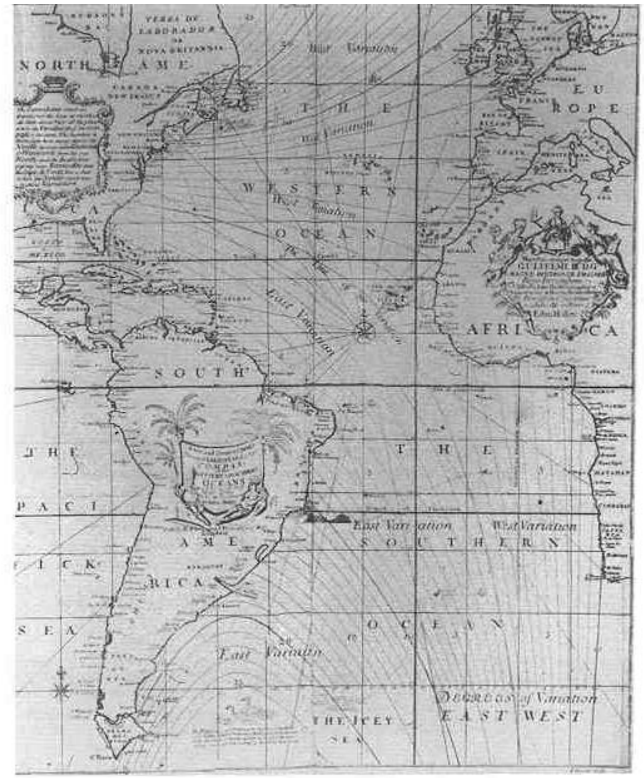
Inclination of orbits along the time - Xth century (Tufte,1983)

One of the first Visualizations used in “business”



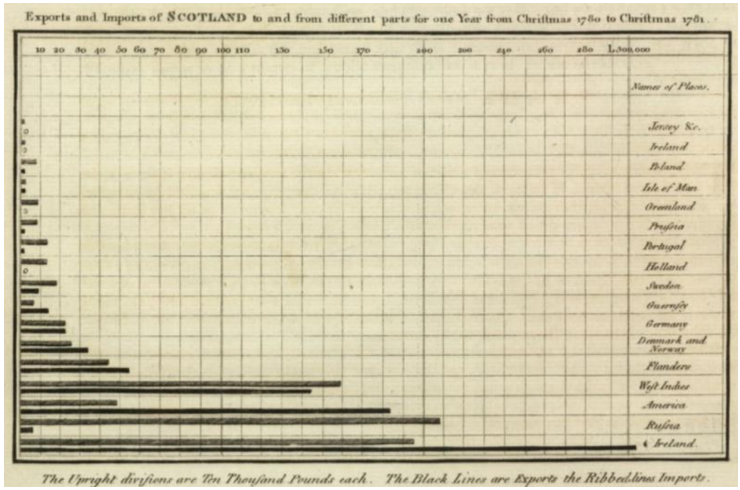
Import/export during the period from1770 to1782 by William Playfair (Tufte, 1983)

One of the first visualizations using contours (isolines)



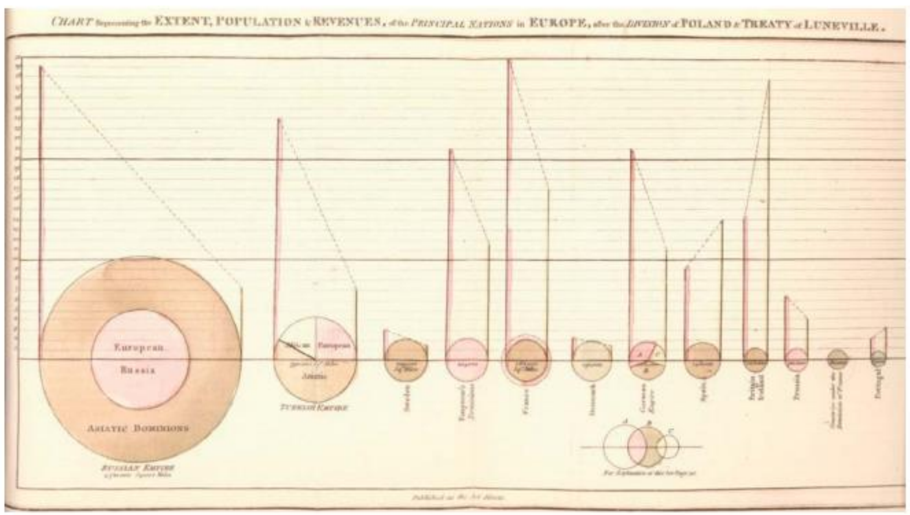
Magnetic declination 1701 Edmund Halley (Tufte,1983)

“Ancestors” of simple representations of univariate data

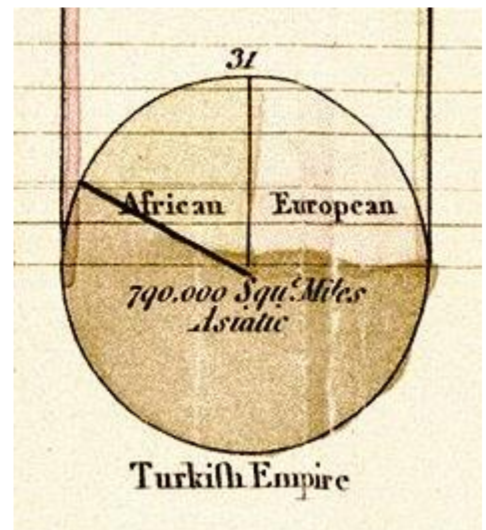


Exports and Imports of Scotland to and from different parts for one
W. Playfair’s *The Commercial and Political Atlas, 1871*

https://en.wikipedia.org/wiki/William_Playfair

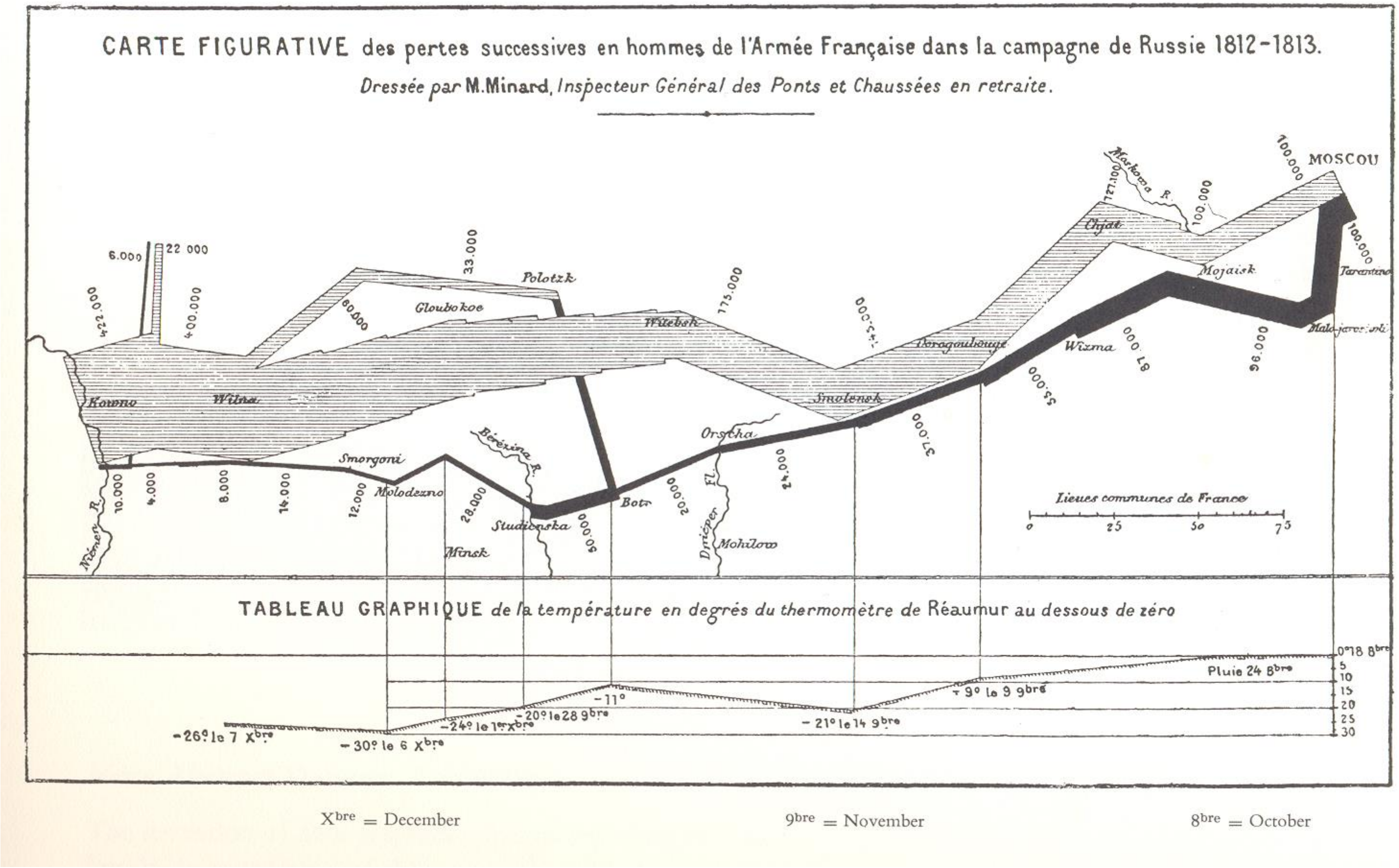


W. Playfair, *Statistical Breviary*, 1801



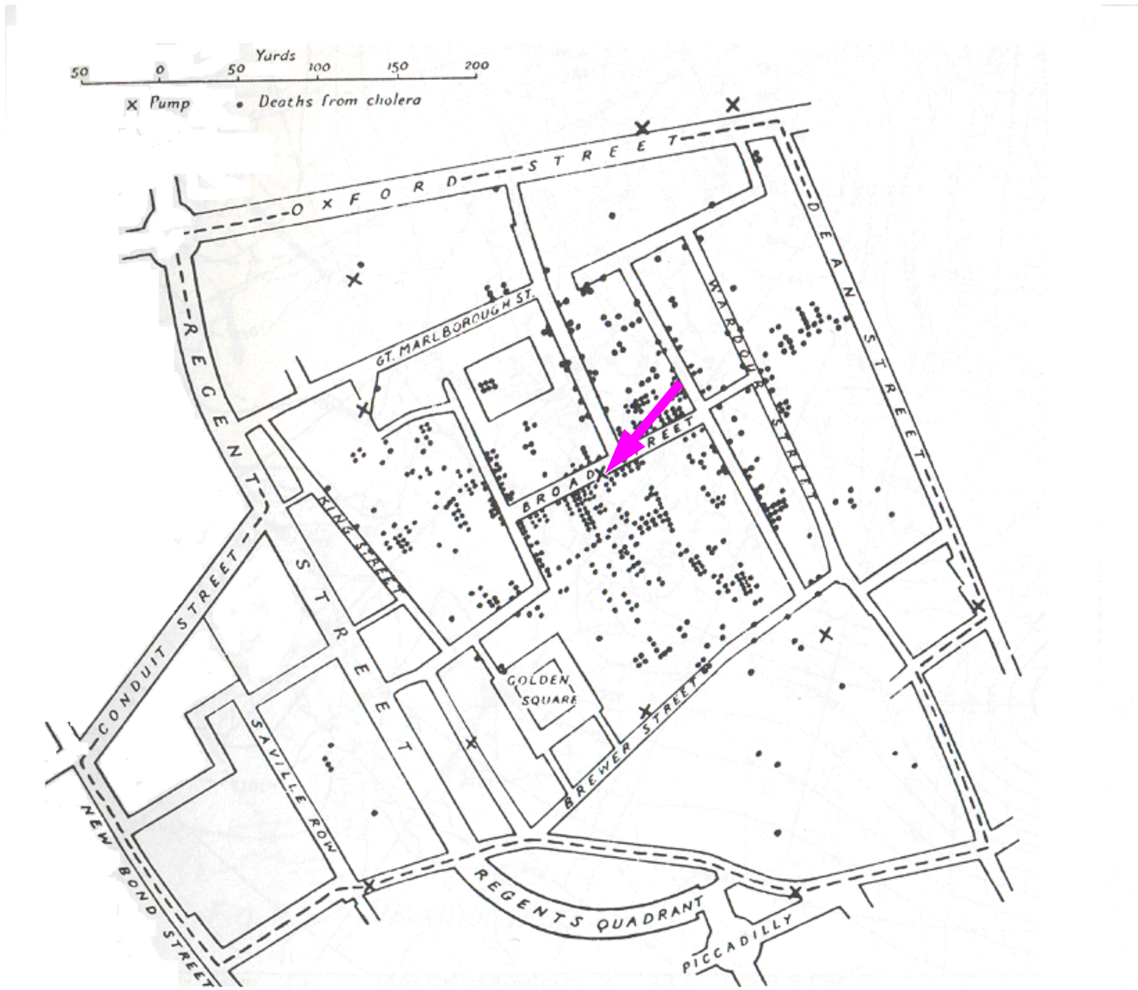
Multidimensional Visualization

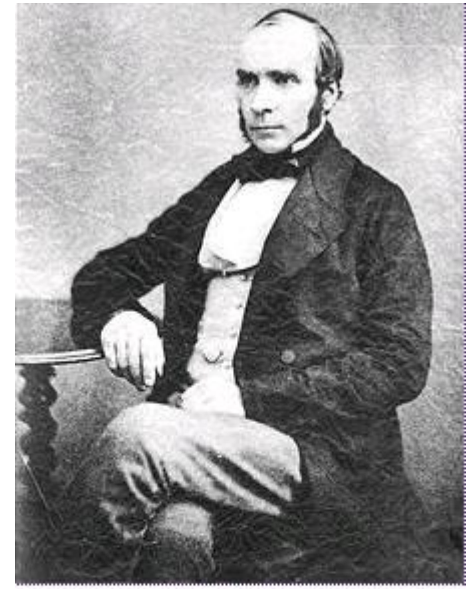
6 dimensions: place (2), n. of men and direction of the army, date, temperature



Russia campaign of Napoleon 1861 by Charles Minard (Tufte,1983)

Visualization in scientific discovery

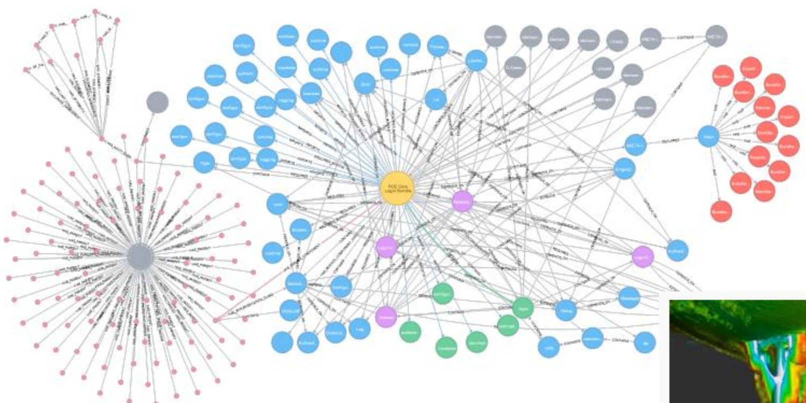


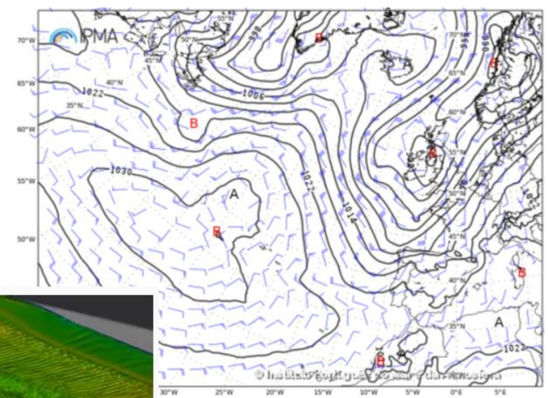


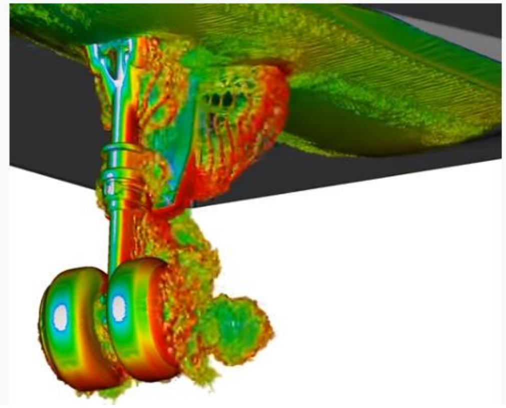
Dr. John Snow

Discovering the cause of the London cholera out brake, 1853-54
(Wikipedia)

Applications







Applications of Scientific Visualization

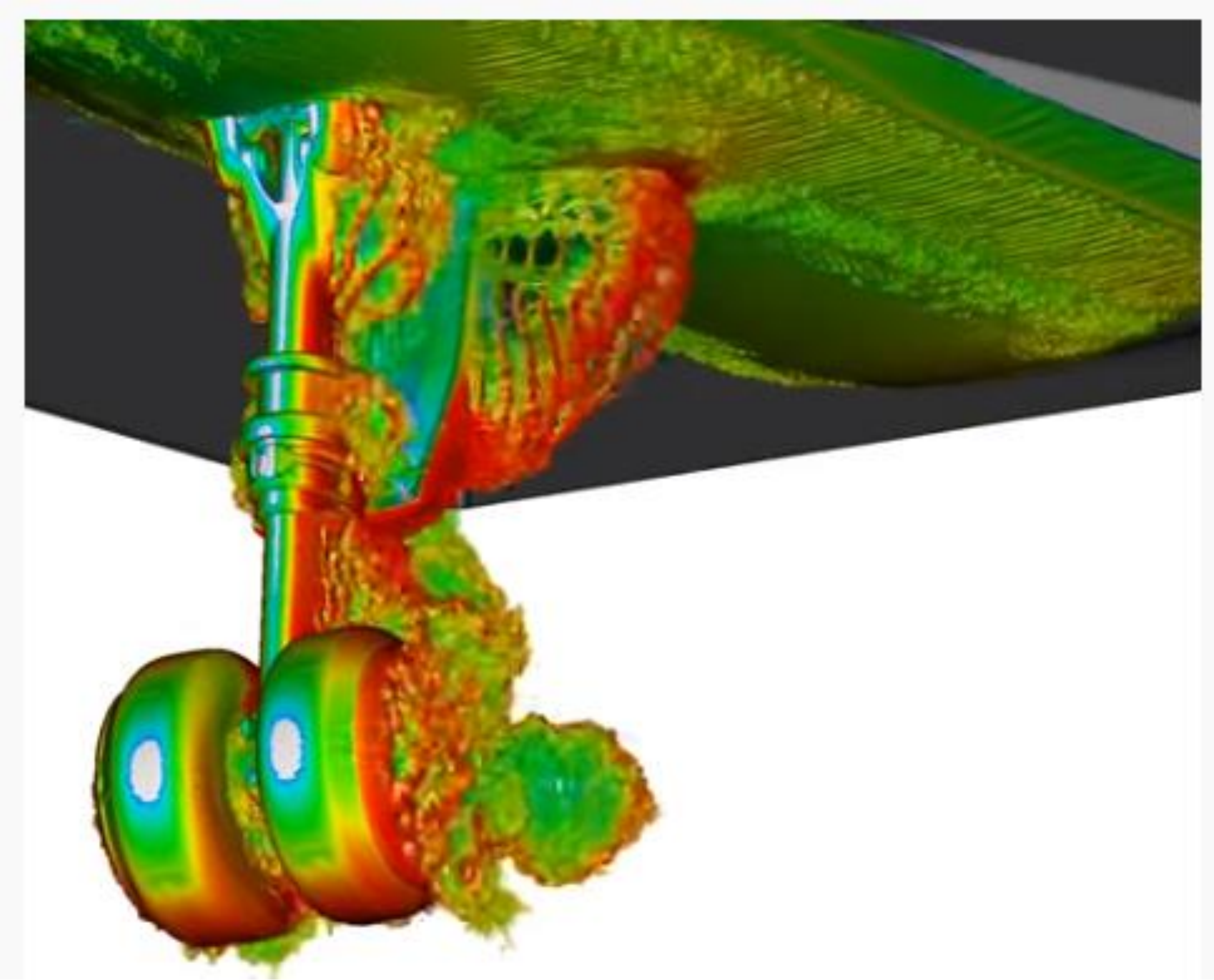
- **Scientific Visualization** is currently used in many scientific areas:
  - All engineering fields …
  - Medicine
  - Meteorology, climatology, oceanography
  - Fluid dynamics
  - Cosmology
  - etc., etc.

  - Let us see some examples …

  - Can you think of an area where data visualization cannot be applied?

Fluid mechanics visualization

NASA/Boeing CFD visualization of vortices responsible for the noise created by the 777's noise landing



https://www.youtube.com/watch?v=F9EFx7aQuhw

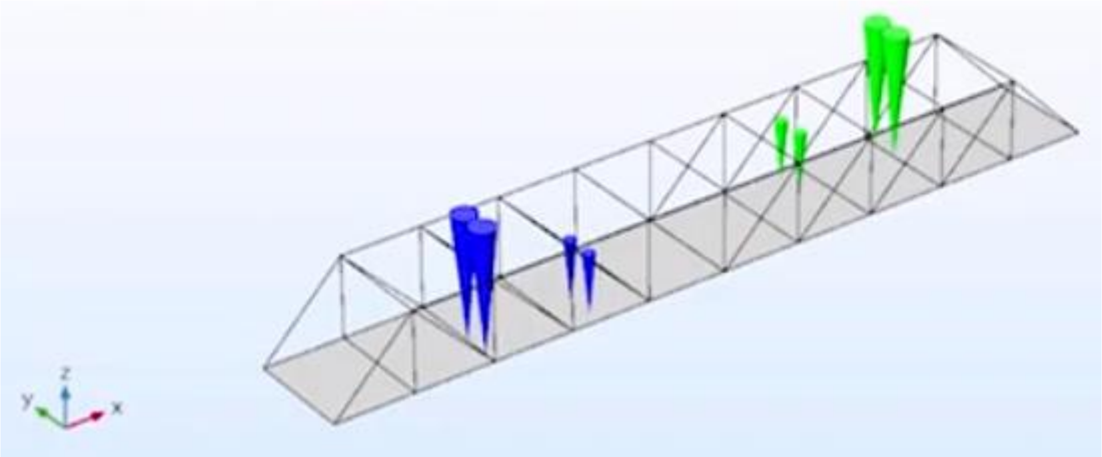
Visualization and Virtual Reality at the Automotive Industry

90% of the new Maserati M20 was digitally developed

Tested in a VR simulator, improving results, reducing time and cost of development

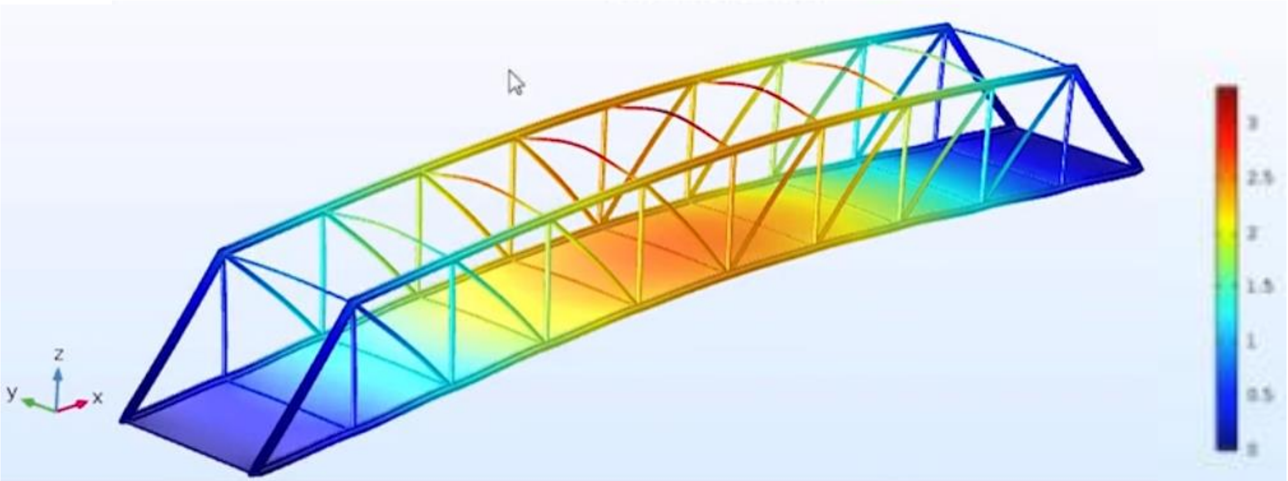
https://www.youtube.com/watch?v=mICaOrJ9oAk

Civil engineering visualization



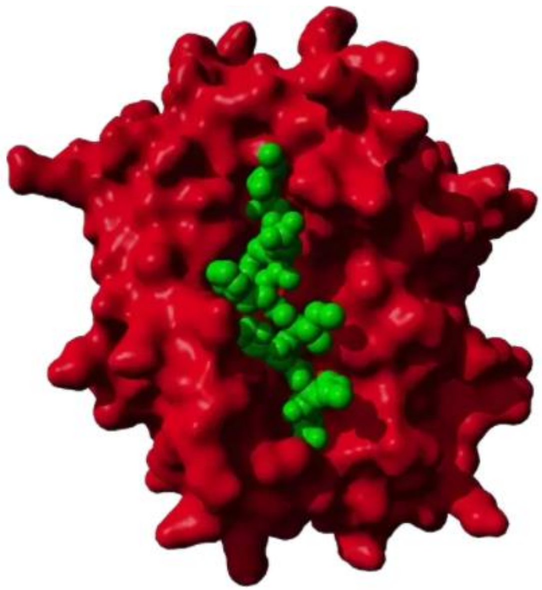
Bridge project:

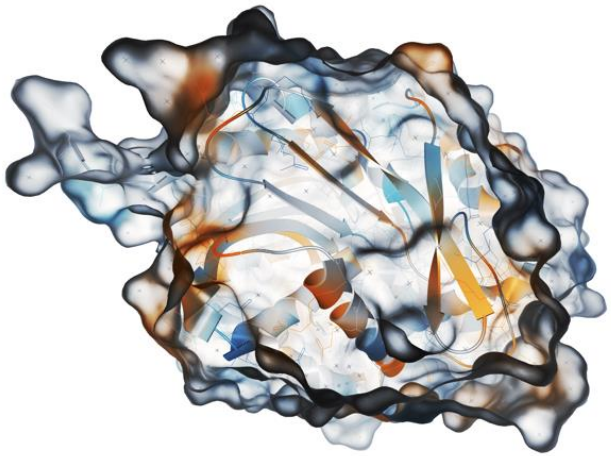
Visualizing Displacement, Force and Moment in Beams, Stress in Beams, and Stress in Roadway

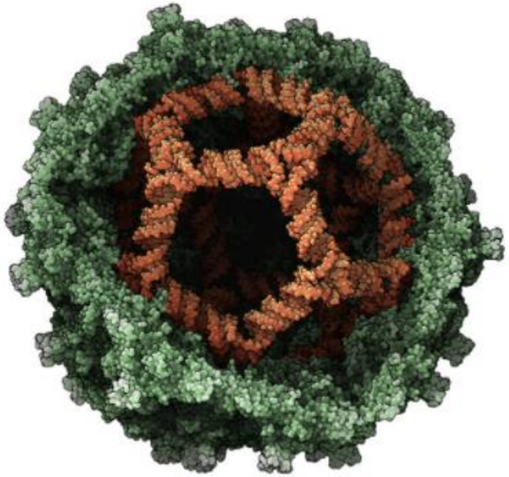


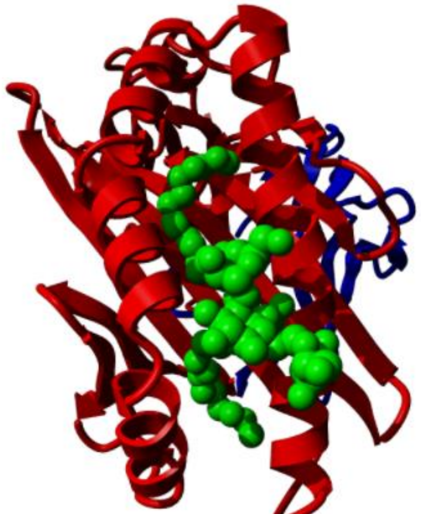
https://www.comsol.com/blogs/efficiently-analyze-civil-engineering-designs-using-an-app

Molecule visualization





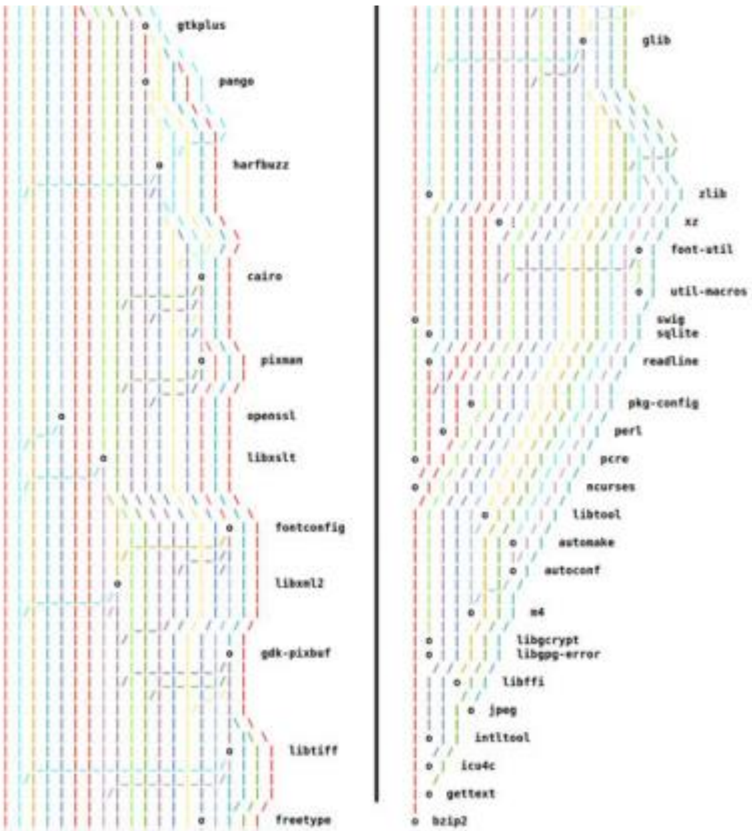




Design:
Drugs
Proteins
Materials
Nanosystems

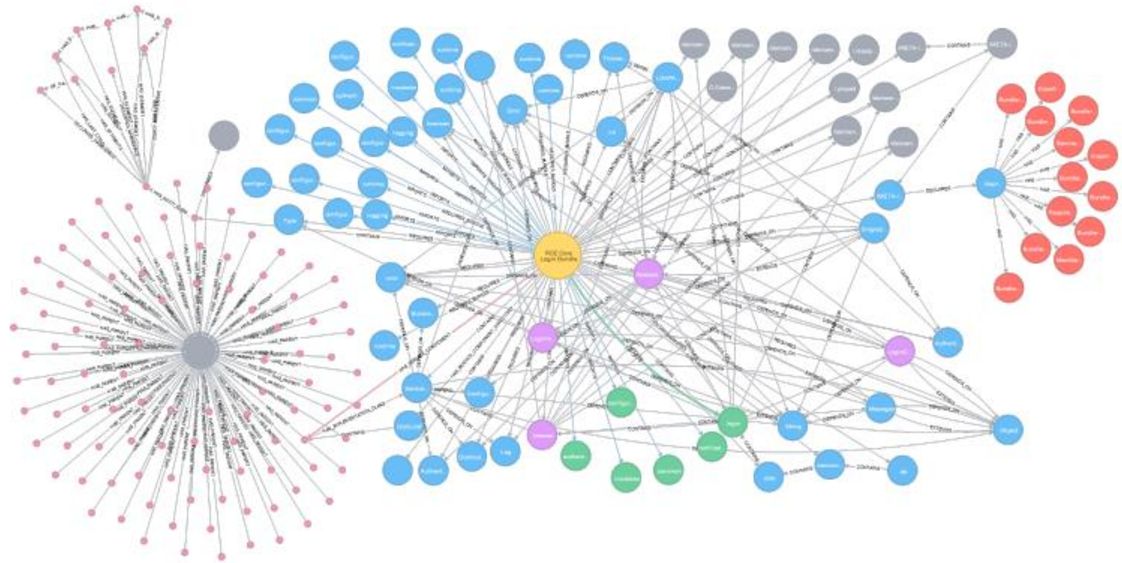
https://www.samson-connect.net/

Software visualization

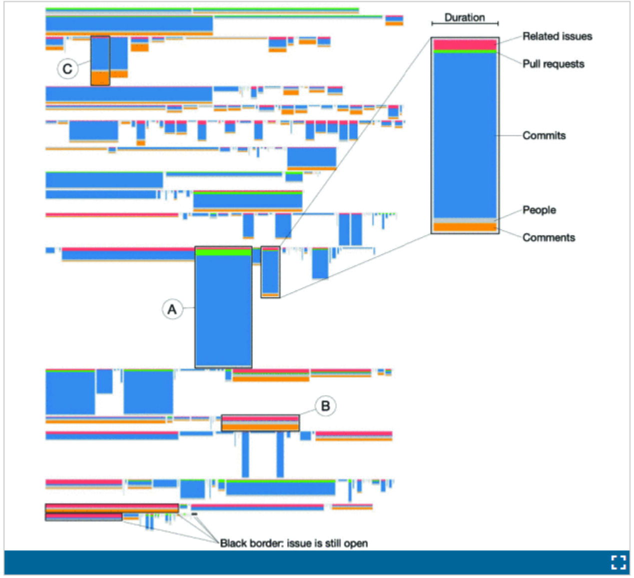


git-style package dependency graph of dia (also shown in Fig. 1). The freetype node has been duplicated to show alignment between the two halves.

https://ieeexplore.ieee.org/document/8419271



https://ieeexplore.ieee.org/document/8742198

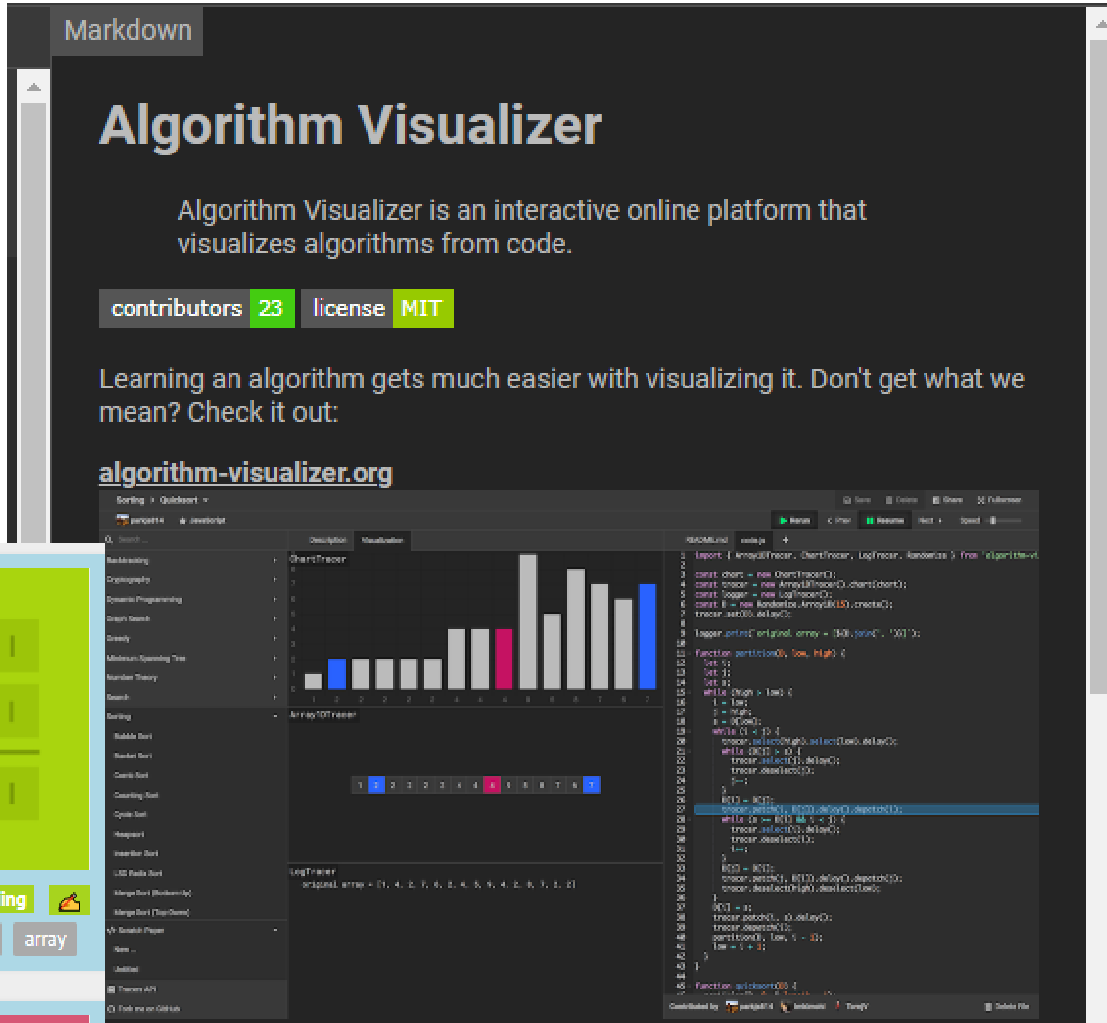


https://ieeexplore.ieee.org/document/9604892

Algorithm visualization

- Beyond mathematical and empirical analyses of algorithms

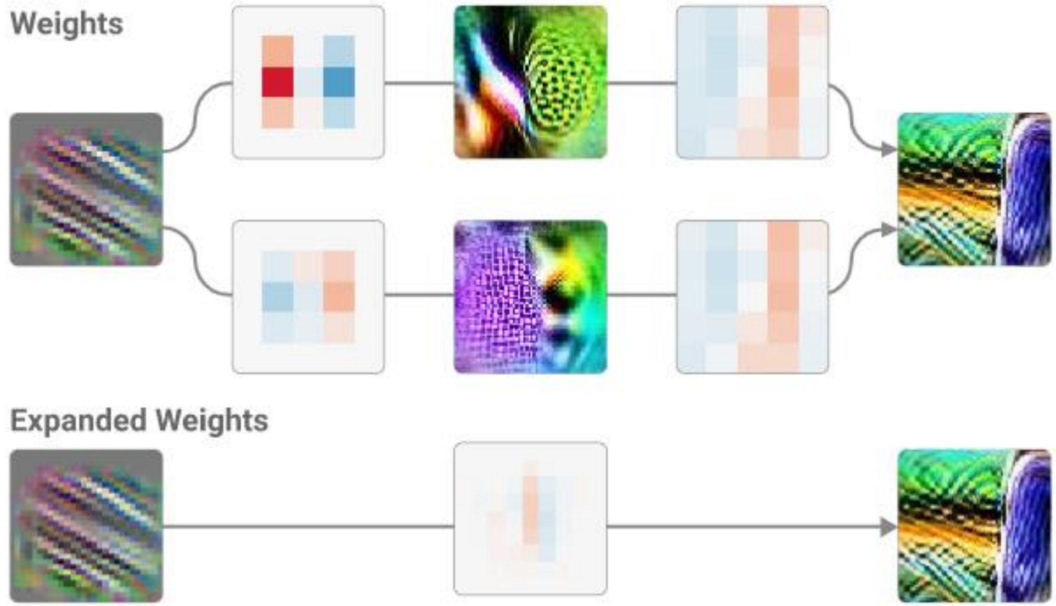
https://visualgo.net/en

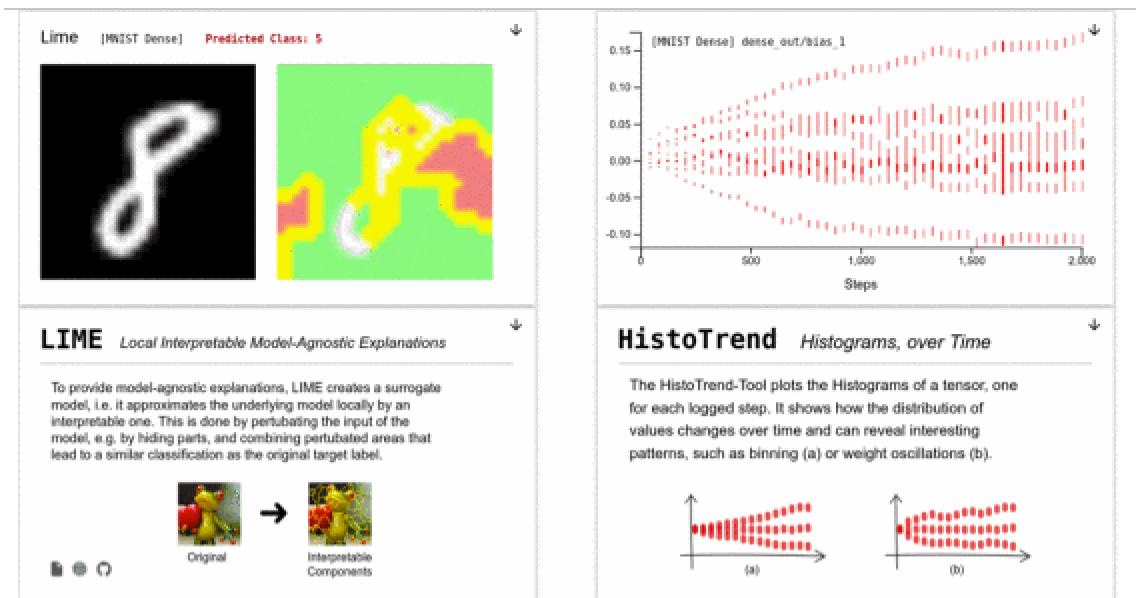


https://algorithm-visualizer.org/

Machine Learning visualization

- To help understand the “inner workings” of neural networks and other AI methods





(a) LIME (high-abstraction explainer) (b) HistoTrend (low-abstraction explainer)

https://distill.pub/2020/circuits/visualizing-weights/

https://ieeexplore.ieee.org/document/8807299

Medicine
(education)

- Human anatomy

- using volume rendering

- VOXELman (University of Hamburg)

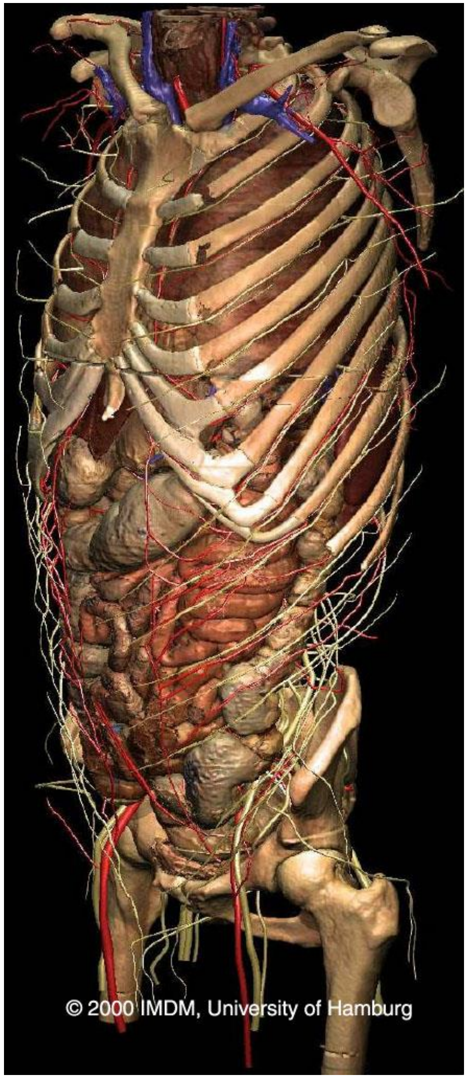
- Visible Human project
  (National Library of Medicine-USA)

https://www.visiblebody.com/

http://www.voxel-man.de/3d-navigator/inner_organs/

http://www.nlm.nih.gov/research/visible/visible_human.html

https://www.nlm.nih.gov/research/visible/applications.html



Medicine
(e.g. surgery training)

VOXELman,
University of Hamburg

- Temporal bone surgery

- Movement of the drill is controlled with a force feedback device

https://www.voxel-man.com/simulators/tempo/

https://www.youtube.com/watch?v=CUOm6fxCJqI

Combining imaging from MRIs, CT scans and angiograms to create a three-dimensional model that physicians and patients can see and manipulate — just like a virtual reality game – Stanford Medicine

https://medicalgiving.stanford.edu/news/virtual-reality-system-helps-surgeons-reassures-patients.html
https://www.statnews.com/2019/08/16/virtual-reality-improve-surgeon-training/

Dentistry (e.g. training)

Stereoscopic display + glasses

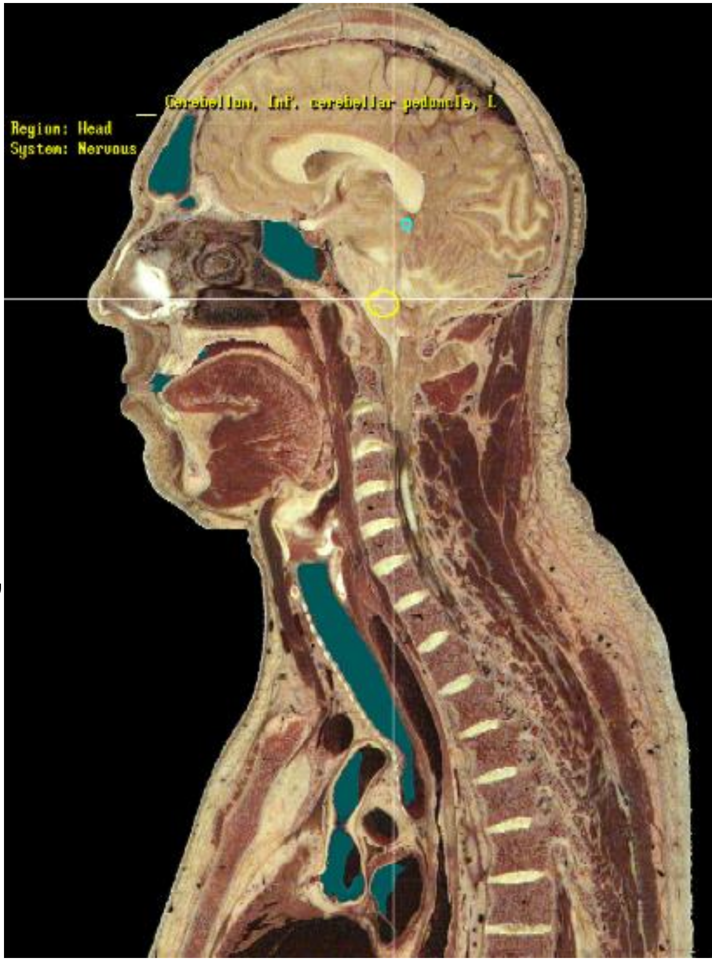
Interaction devices:
- two force feedback devices
- foot pedal

https://www.voxel-man.com/simulators/dental/

https://www.youtube.com/watch?v=CB_vdW6K42o

An example of Scientific Visualization: The visible Human Project

(1994,1995)



The data sets were designed to serve as
(1) a reference for the study of human anatomy,
(2) public-domain data for testing medical imaging algorithms,
(3) a test bed and model for the construction of network-accessible image libraries.

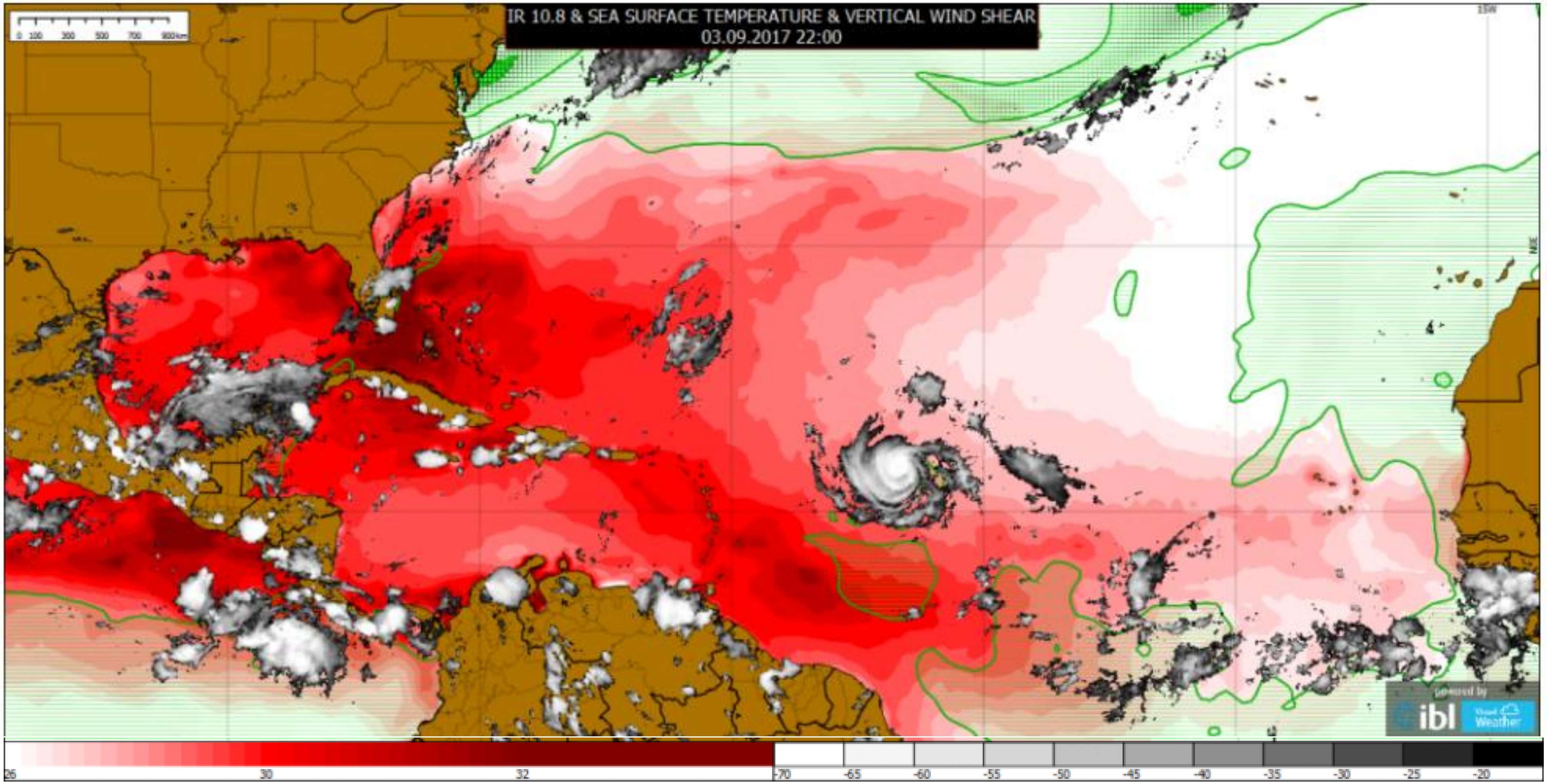
Have been applied to a wide range of educational, diagnostic, treatment planning, virtual reality, artistic, mathematical, and industrial uses.

About 4,000 licensees from 66 countries

As of 2019, a license is no longer required to access the VHP datasets.

https://www.nlm.nih.gov/research/visible/applications.html

Meteorology and oceanography

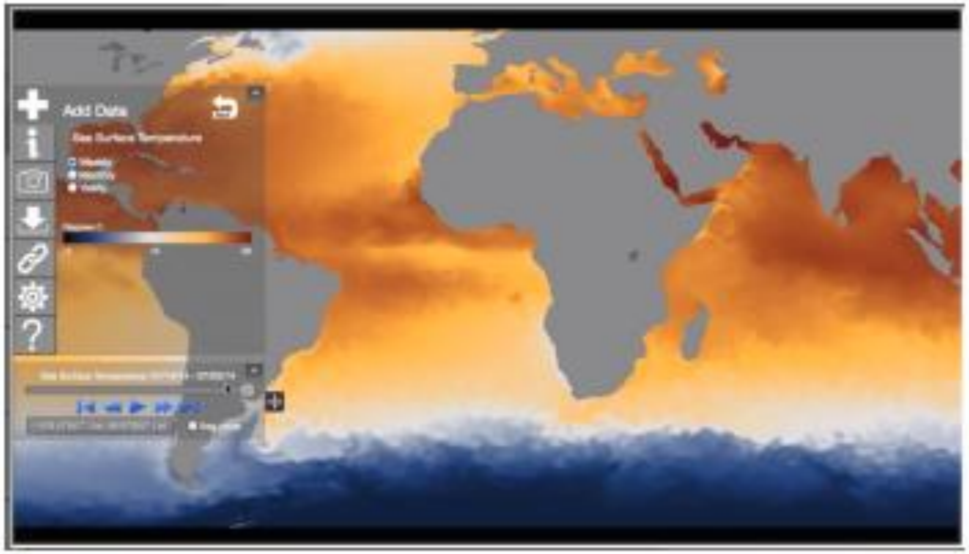


https://www.iblsoft.com/products/visualweather/

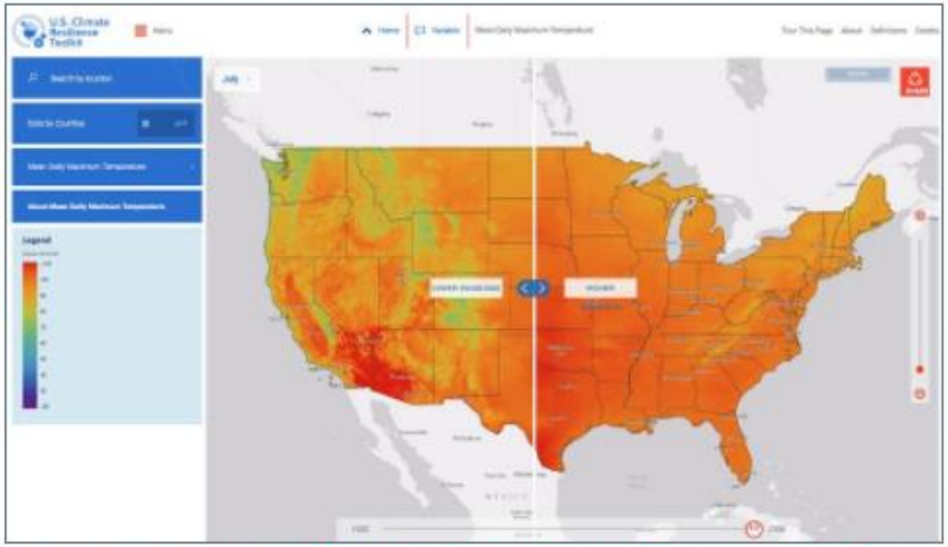
Climate research
(by NOAA)

•The Climate Explorer offers graphs, maps, and data of observed and projected temperature, precipitation, and related climate variables for every county in the contiguous US

• The tool shows projected conditions for two possible futures:
  – one in which humans make a moderate attempt to reduce global emissions of heat-trapping gases,
  – one in which we go on conducting business as usual.



https://www.climate.gov/maps-data/primer/visualizing-climate-data

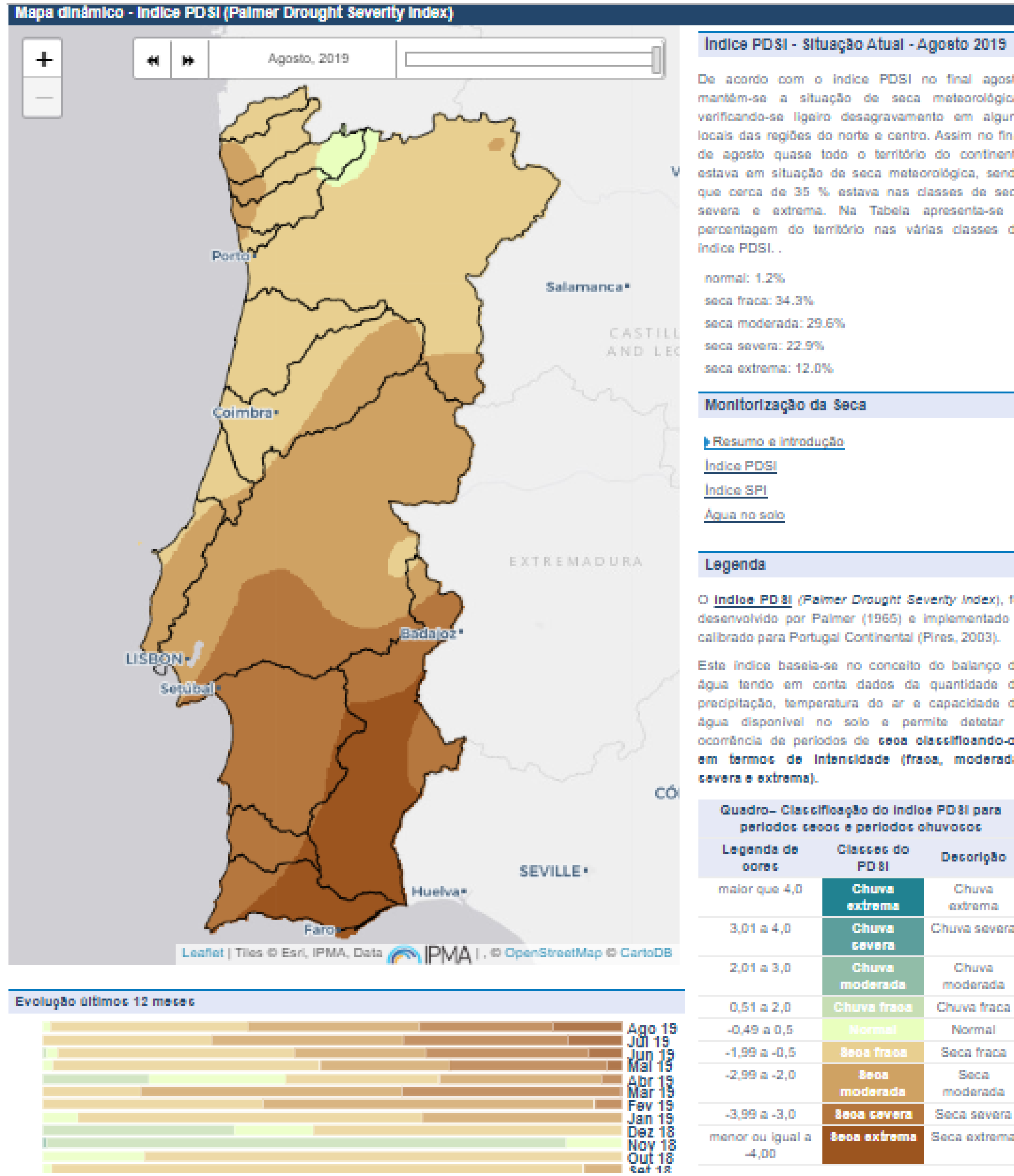


View by Variable interface. View Maximum Daily Temperature variable in Climate Explorer.

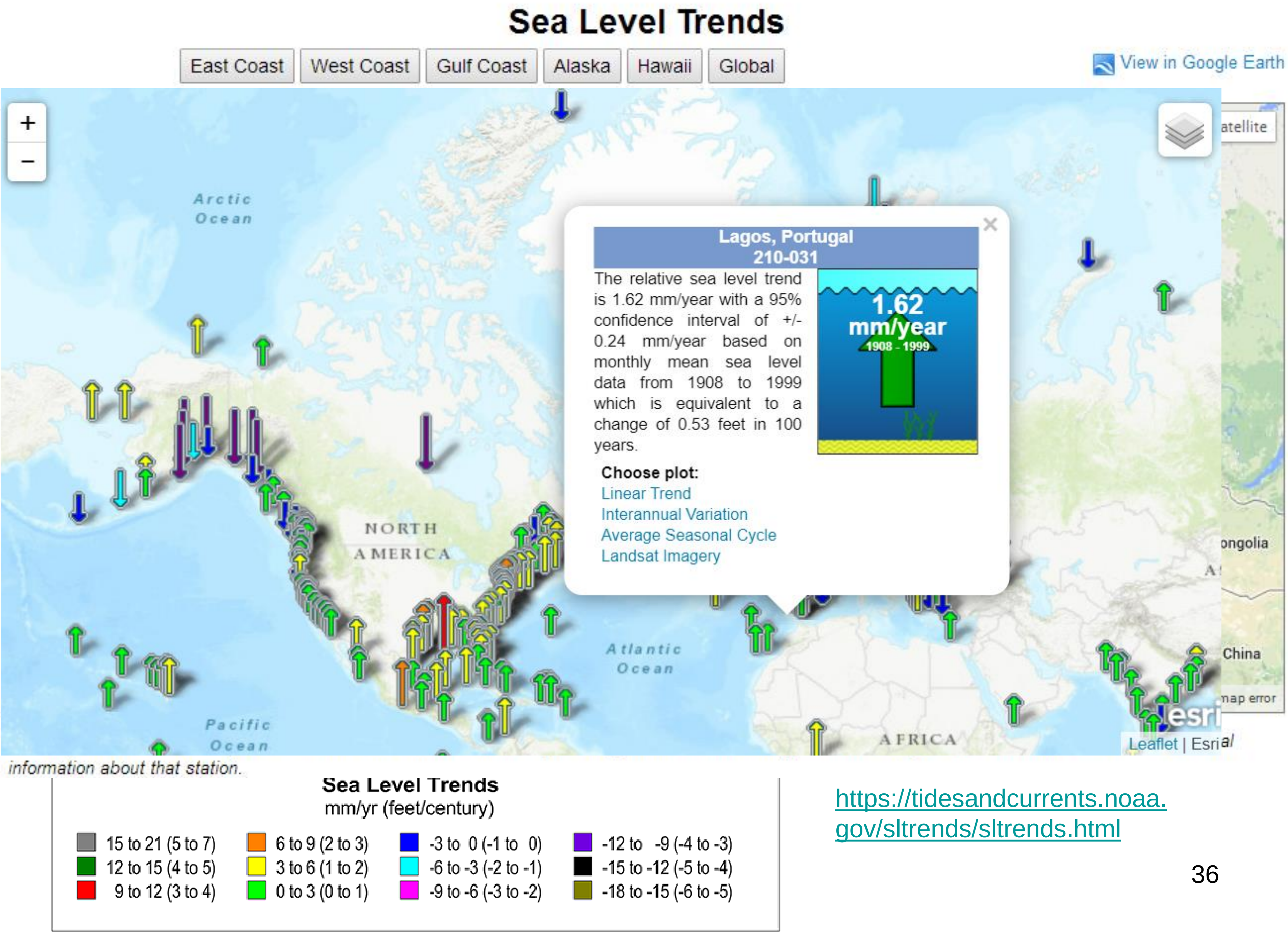
https://toolkit.climate.gov/tools/climate-explorer

Example in Climate monitoring:

Drought Severity Index (by IPMA)

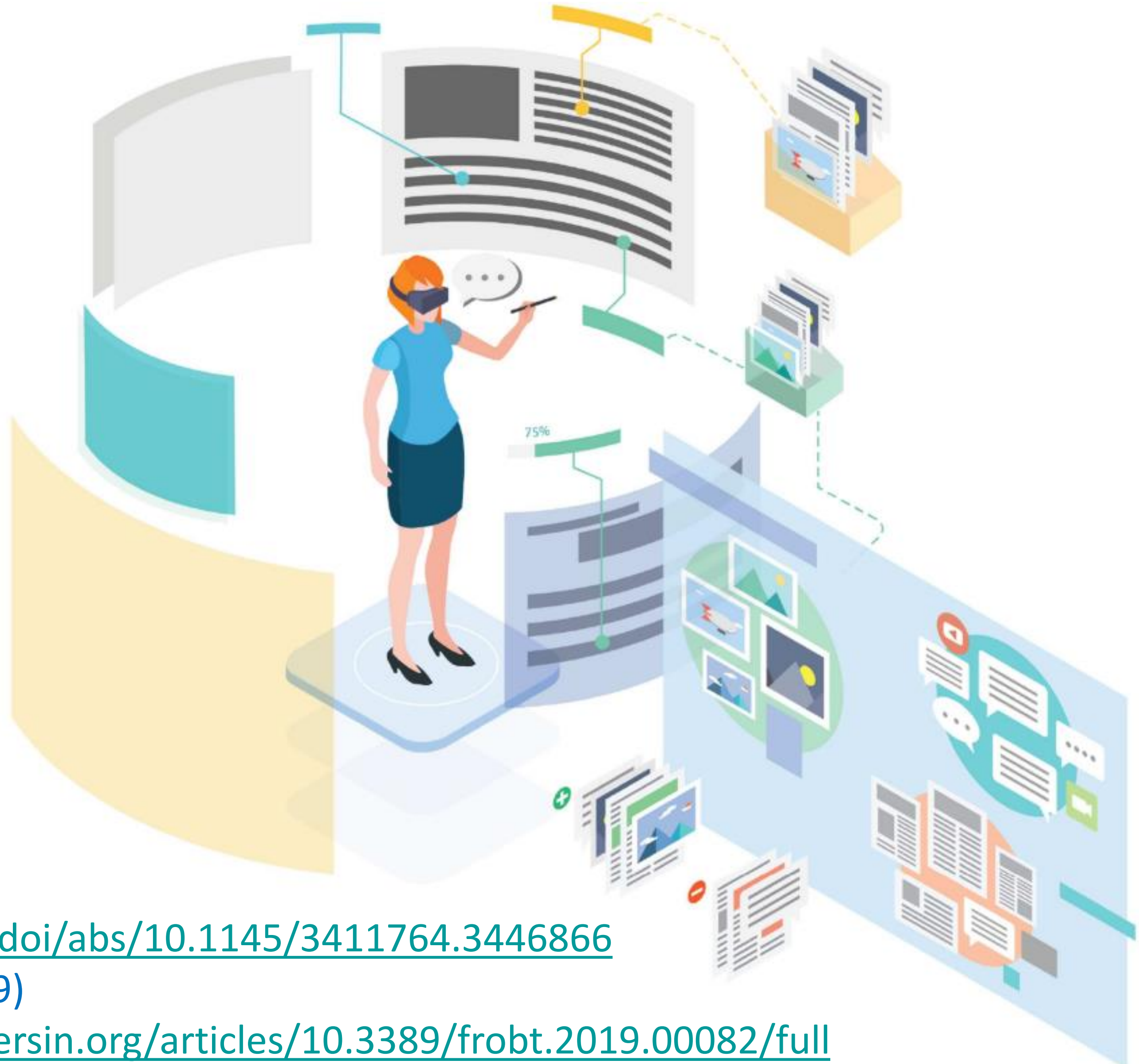


http://www.ipma.pt/pt/oclima/observatorio.secas/



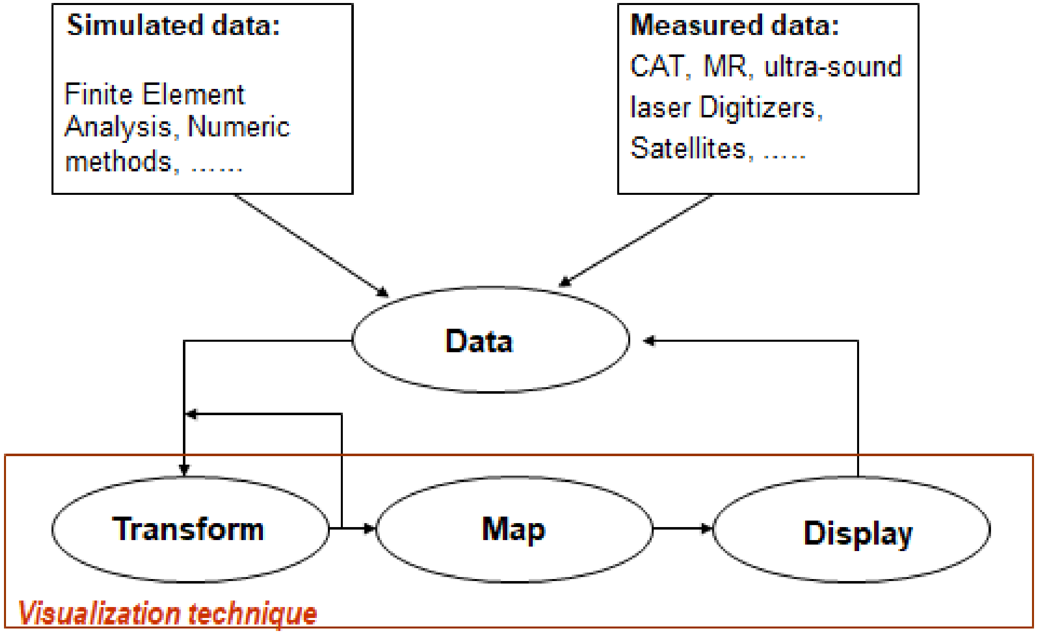
https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

What about the future of Visualization?



(Barret et al., 2021)
https://dl.acm.org/doi/abs/10.1145/3411764.3446866
(Skarbez et al., 2019)
https://www.frontiersin.org/articles/10.3389/frobt.2019.00082/full

Scientific Visualization reference model



(adapted from Schroeder et al., 2006)

The visualization creator is involved in all the phases after obtaining the data

The user should get insights from the visualization

- "***human-in-the-loop***" problems involve the user as a part of the system

- They are very complex due to the facts that:

  - humans are very complex systems

  - not well known

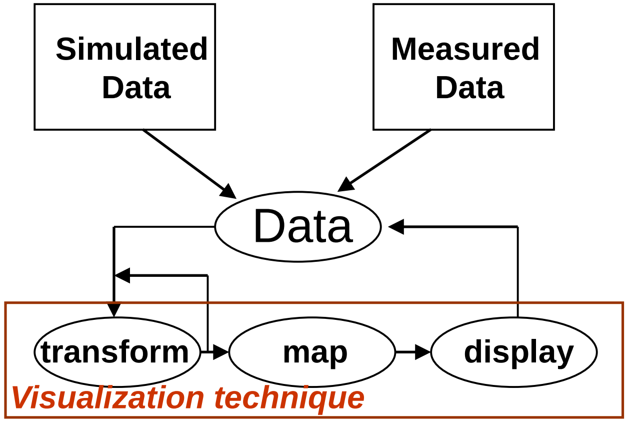
  - in general we cannot change them

- Target users profile, needs, and context of use must be carefully considered whenever designing a visualization

•:**Data can be**

- simulated
  (e.g. stress of a mechanical part, phantom of the human body, etc.)

- measured from real phenomena



- Then a **visualization technique** is applied, involving:

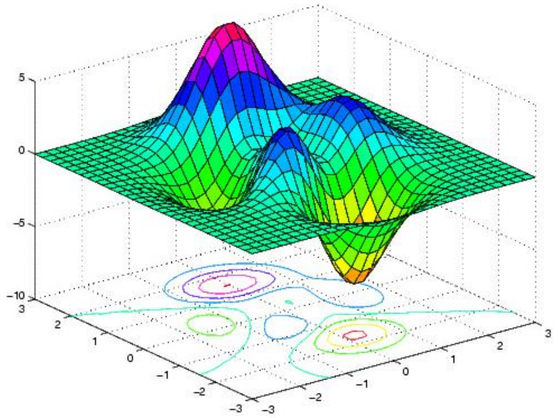
  - data **transformation** through several methods
    (e.g. scale transformation, noise filtering, outlier elimination, changing resolution, etc.)
  - **mapping** to an adequate form to represent data visually
    (e.g. lines, points, color)

  - producing an image or sequence of images (rendering)

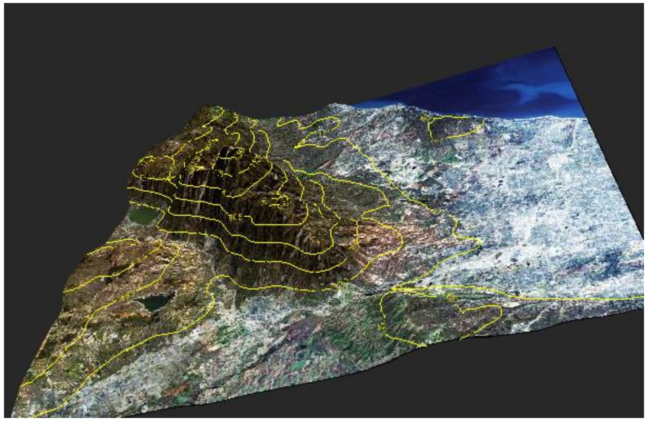
- **This process is repeated as needed to provide insight**

- The choice of the right mapping is fundamental

- Consider the values of a function or terrain altitude data, or sea depth:



- different mappings or visualization techniques can be used, e.g.
  - three-dimensional surface
  - pseudo-color
  - contours (isolines)



- Visualization may be used with different purposes:

  - personal exploration
  - discussion with colleagues
  - presentation to other people

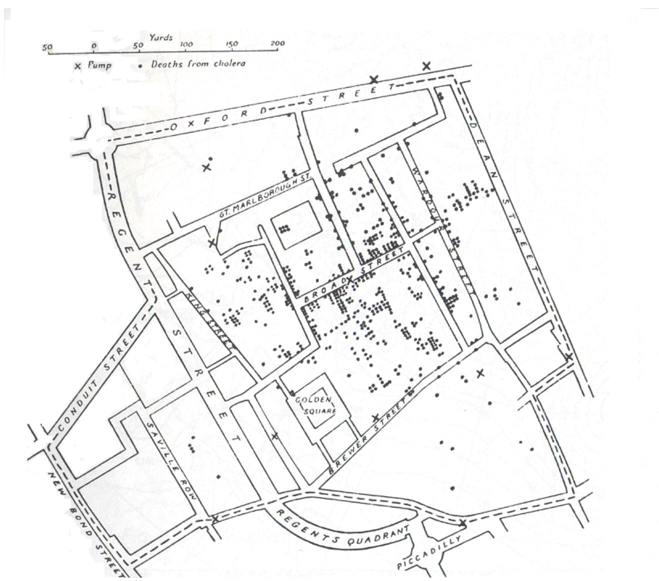
  for

  - explorative analysis
  - confirmative analysis

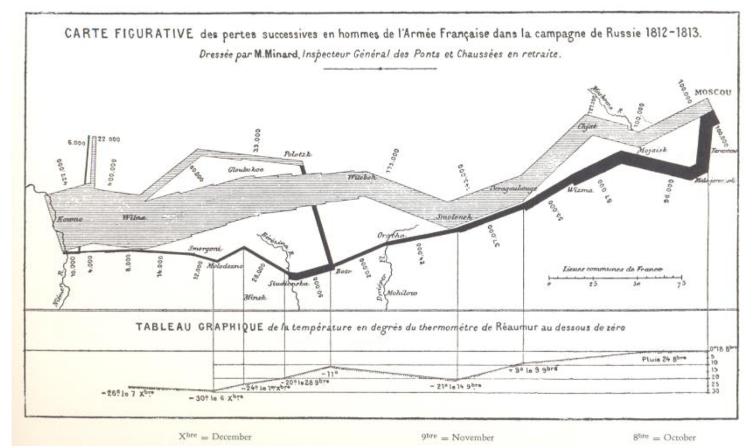
Classical examples for:

a) exploration
b) presentation

a)



b)



Whatever the purpose, a visualization:

- Should allow **offload internal cognition and memory** usage to the **perceptual system**, using **carefully designed images** as a form of external representations (external memory)

- To **support users' tasks**

To design simple or complex visualizations:

- Need to **find what are the questions** users will ask!

Example: how to select simple charts?

Max and Min temperatures along the month of February (in ºC):

day	Max T	Min. T
1	15	7
2	14	8
3	13	6
4	13	6
5	12	6
6	13	7
7	13	7
8	14	8
9	15	5
10	12	5
11	13	6
12	12	7
13	11	8
14	11	8
15	12	8
16	12	9
17	13	9
18	14	9
19	14	8
20	13	8
21	13	8
22	12	7
23	12	7
24	11	7
25	11	6
26	11	7
27	13	6
28	14	6

Q1- What were the maximum and minimum values of MaxT?

Q2- What was the most frequent MaxT?

Q3- In how many days was that MaxT value attained?

Q4- How were the daily temperature ranges?

Q5 – What was the maximum temperature range?

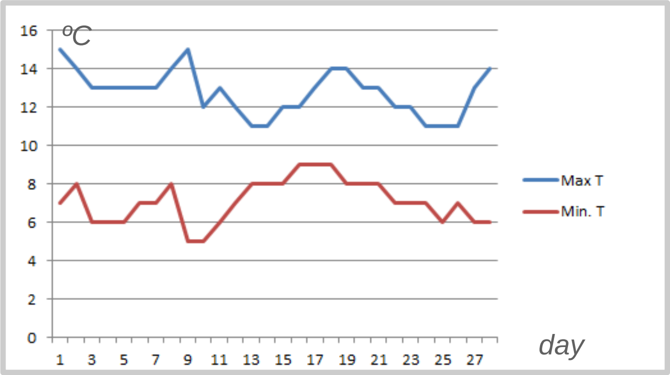
- What type of chart would you use to answer Q1?

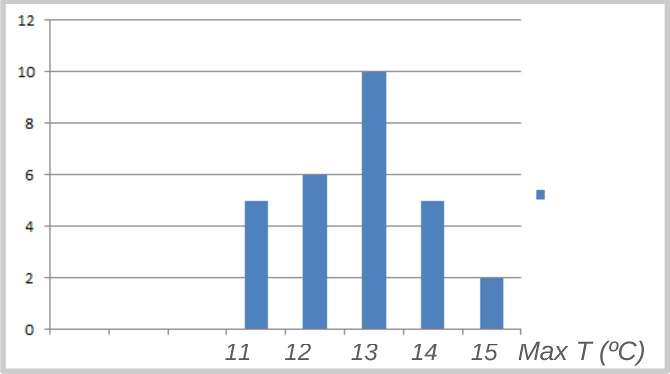
- And the other questions?

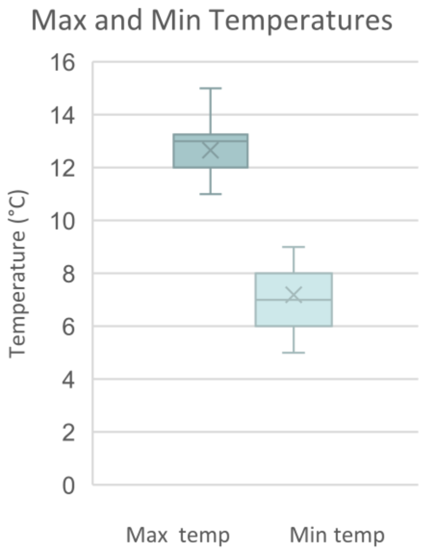
Example: how to select simple charts?

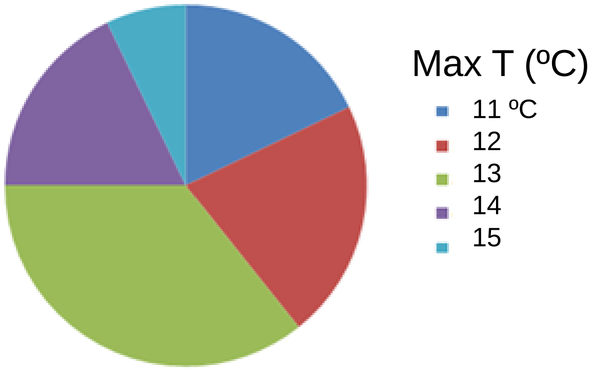
Temperatures along the month of February (in ºC): a few possible charts

day	Max T	Min. T
1	15	7
2	14	8
3	13	6
4	13	6
5	12	6
6	13	7
7	13	7
8	14	8
9	15	5
10	12	5
11	13	6
12	12	7
13	11	8
14	11	8
15	12	8
16	12	9
17	13	9
18	14	9
19	14	8
20	13	8
21	13	8
22	12	7
23	12	7
24	11	7
25	11	6
26	11	7
27	13	6
28	14	6





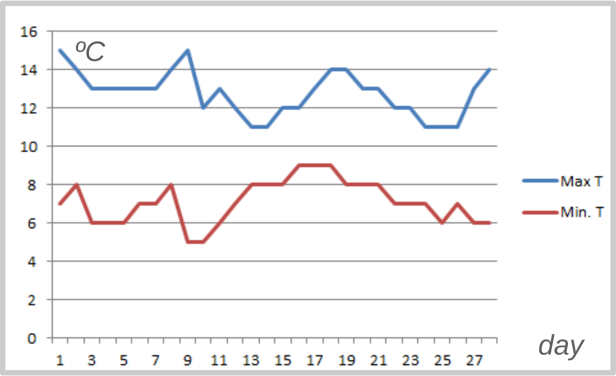




Simple example

Temperatures along the month of February (in ºC):

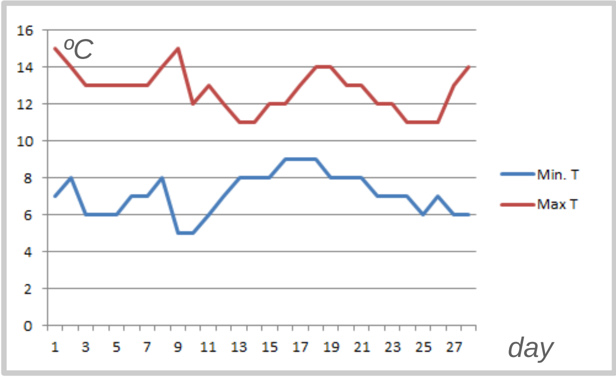
Anything "odd" about this chart?

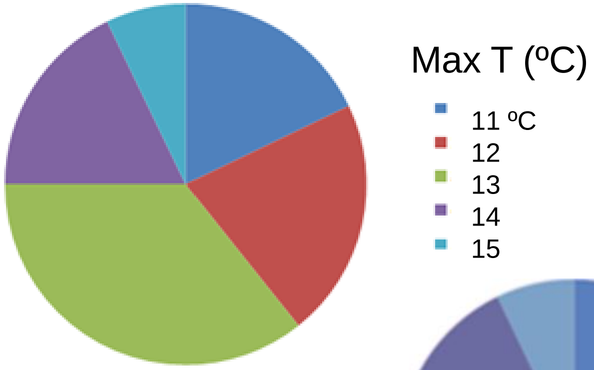


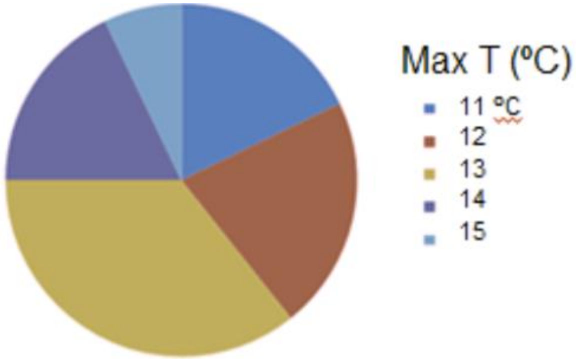
What if the user is color-blind?

Test it using https://www.color-blindness.com/coblis-color-blindness-simulator/

Would you prefer this one?







Do not forget "cultural" aspects, nor individual differences!

Next sessions:

- Data characteristics, the phenomena they represent and pre-processing
- Human characteristics fundamental for Visualization
- Creating a Visualization: visually representing
  - 1D, 2D, 3D and nD quantitative data
  - Other types of data (maps, networks, hierarchical data, text…)
- Effective Visualization