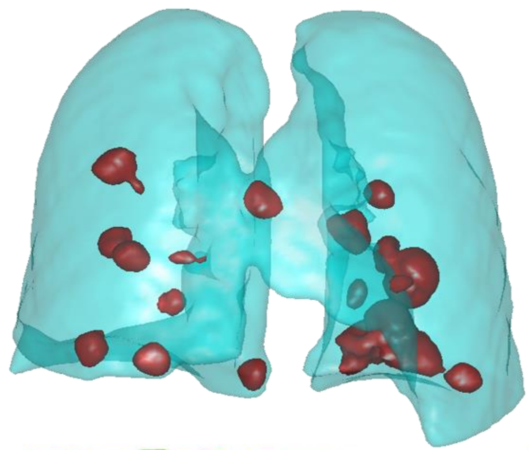
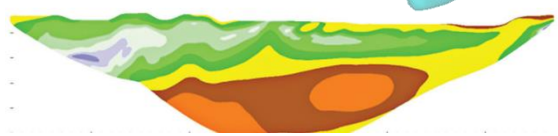
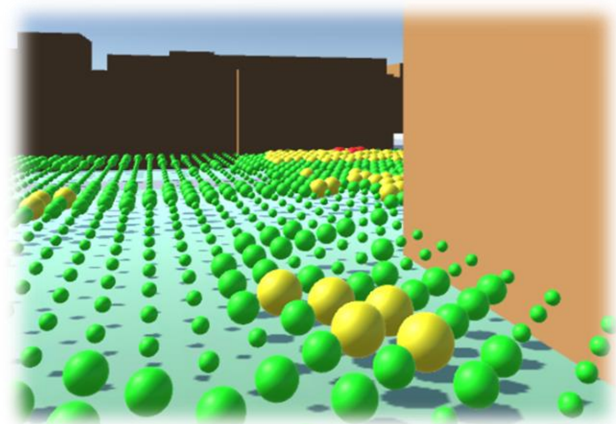
Universidade de Aveiro
Departamento de Electrónica,
Telecomunicações e Informática

An Introduction to Visualization







Beatriz Sousa Santos, University of Aveiro, 2025

Definition

Objectives

History

Applications

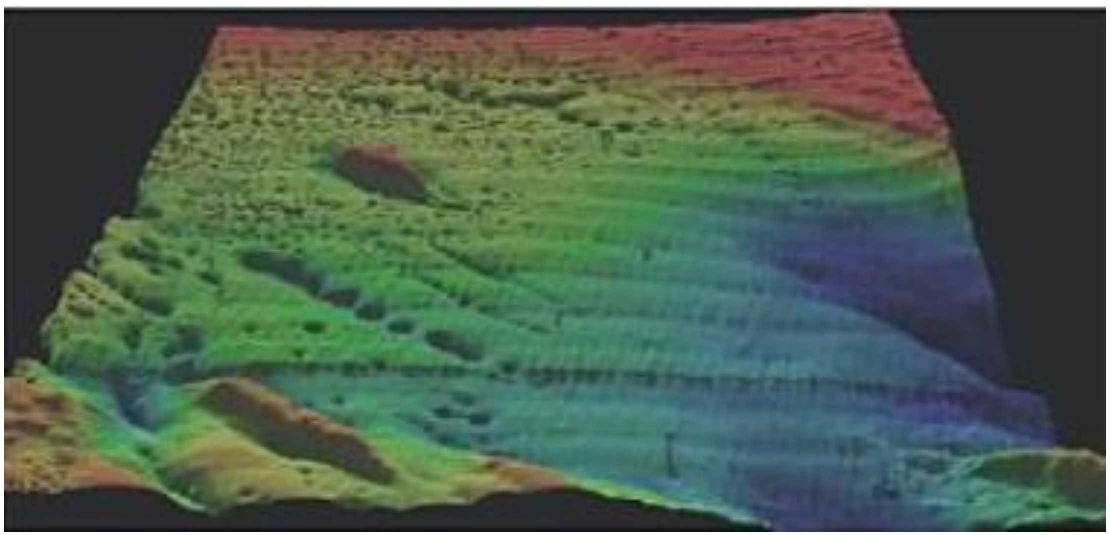
Model

How to create a Visualization?

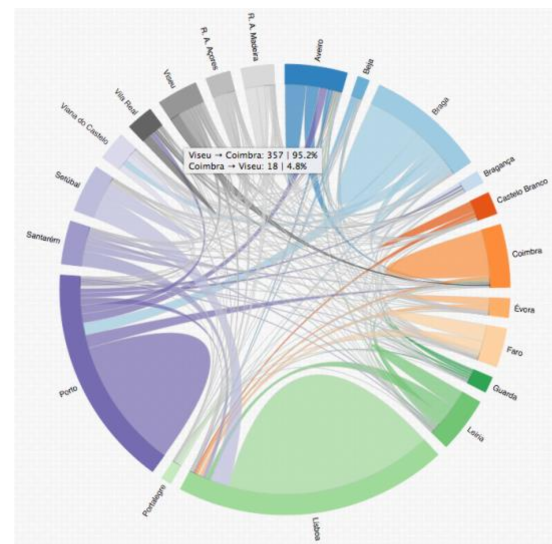
What is Visualization?

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

"augmenting human capabilities" (Munzner, 2014)



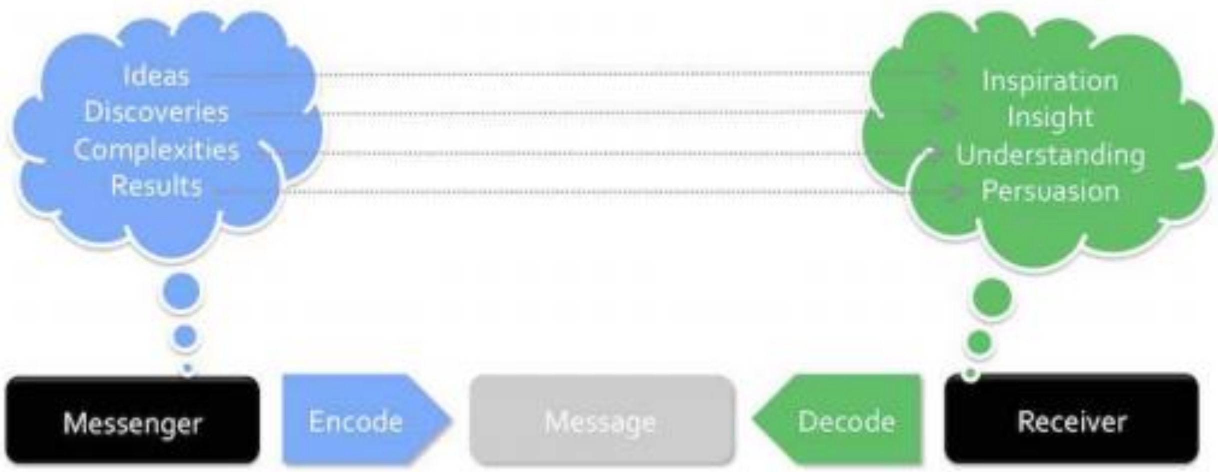
Passamoquoddy Bay
(10^6 measures)
(Ware, 2019)



Portuguese Higher Education
(data from 120 000 candidates)

Definition (yet another)

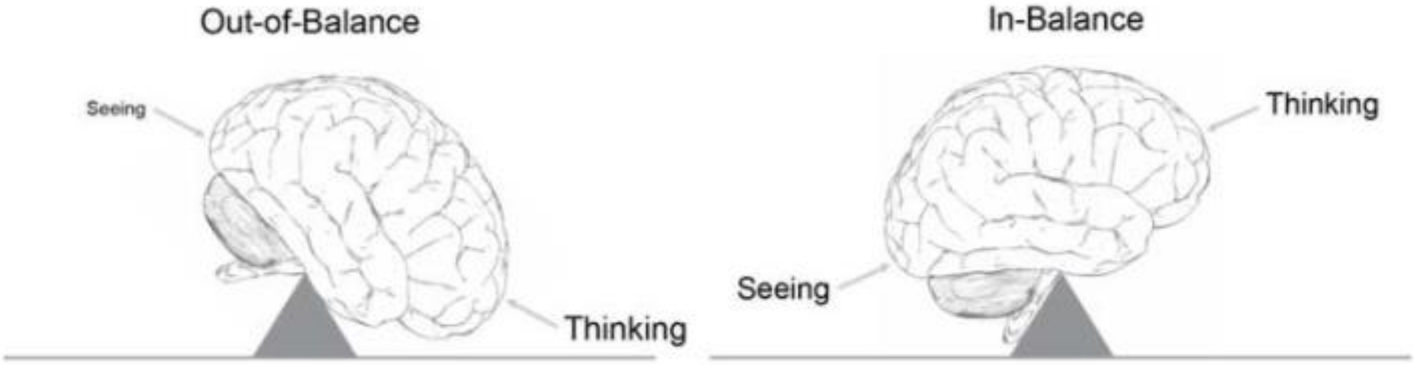
- “The representation and presentation of data that exploits our visual perception abilities in order to amplify cognition” *(Kirk, 2012)*



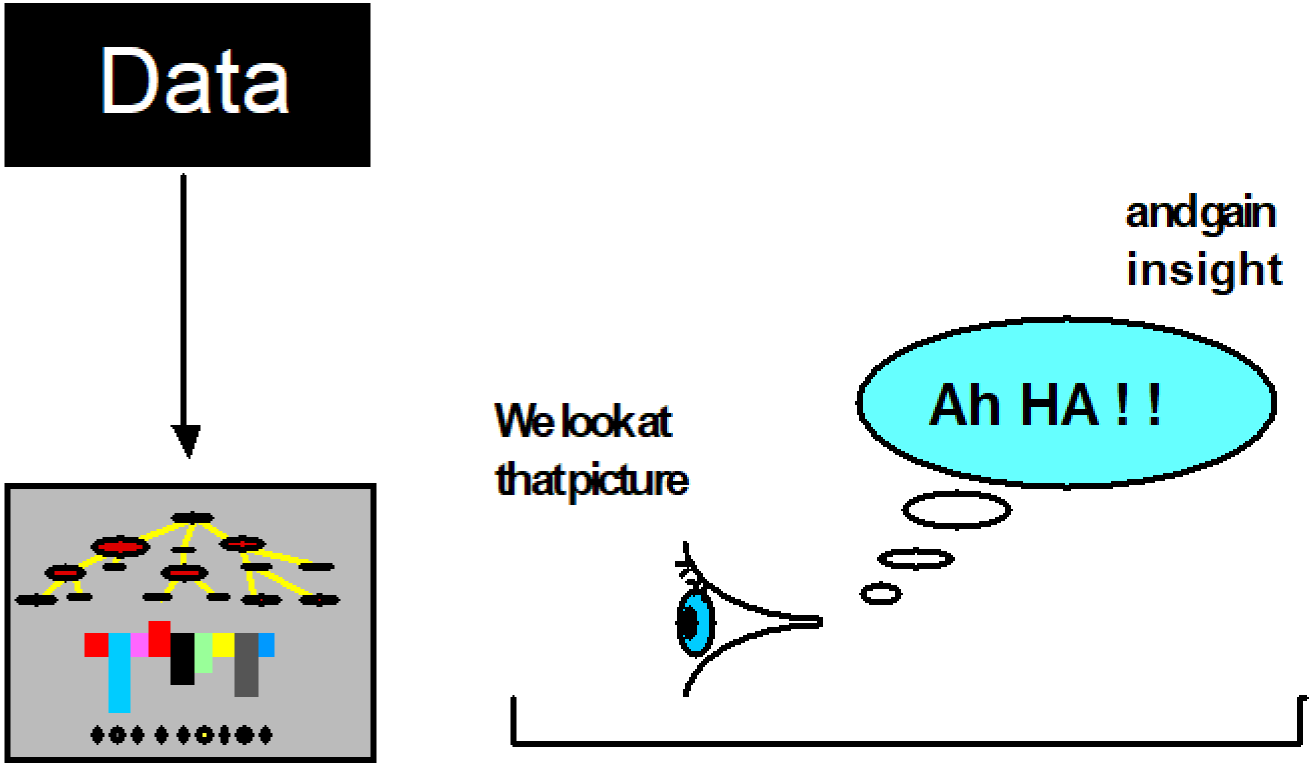
(Kirk, 2012)

Visualization benefits

- Helps us think
- Reduces load on working memory
- Offloads cognition
- Uses the power of human perception



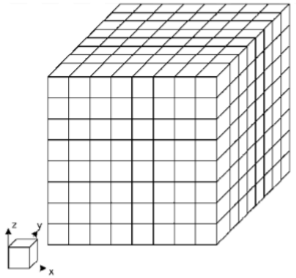
https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/data-visualization-for-human-perception



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:

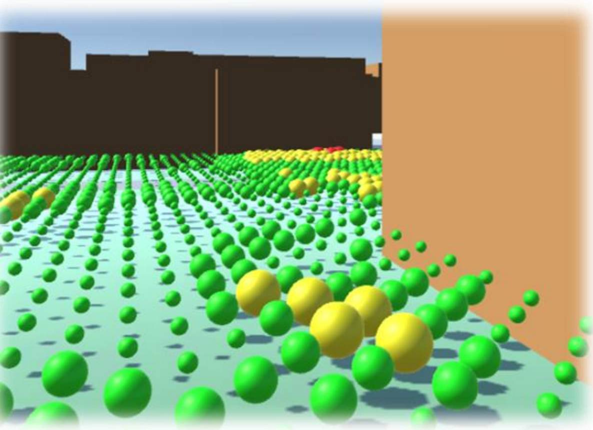
  Scientific Visualization (**SciVis**) - Data having an inherent spatial structure
  (e.g., CAT, MR, geophysical, meteorological, fluid dynamics data)

  Information Visualization (**InfoVis**) – “Abstract” tabular data not having an inherent spatial structure (tabular data)
  (e.g., stock exchange, census, S/W, social networks, text data)

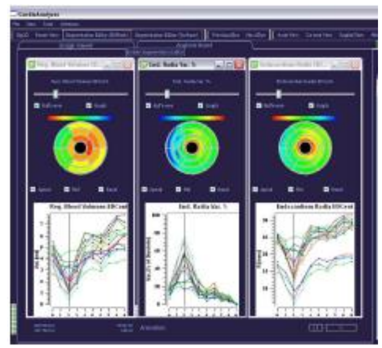
Census Year	Population by age group		
	Group 1: 0-14 years	**Groups 2: 15-64 years**	**Group 3: 65 + years**
1960	2591955	5588868	708569
1970	2451850	5326515	832760
1981	2508673	6198883	1125458
1991	1972403	6552000	1342744
2001	1656602	7006022	1693493
2011	1572329	6979785	2010064
2021	1331188	6588239	2423639

- Borders between these areas are not well defined …

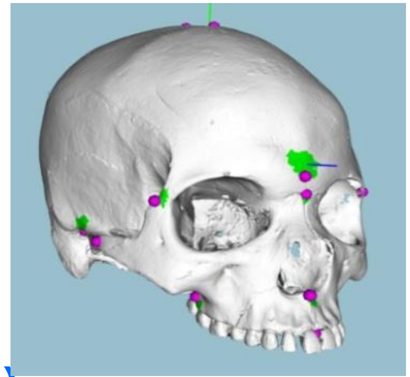
Scientific Visualization **(examples "made in UA")**



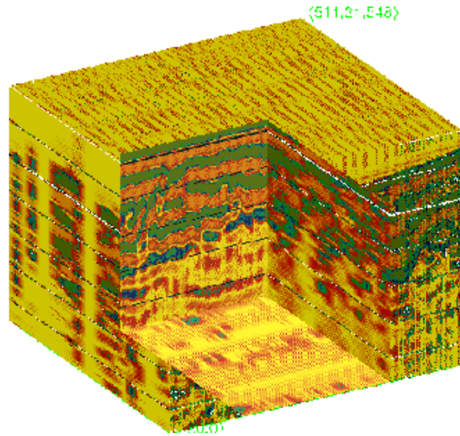
Air pollution (2022)



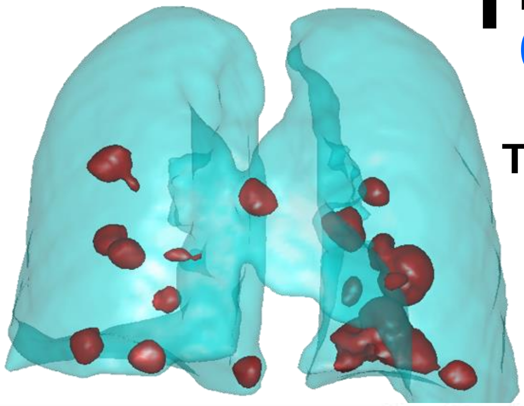
Tomography (2011)



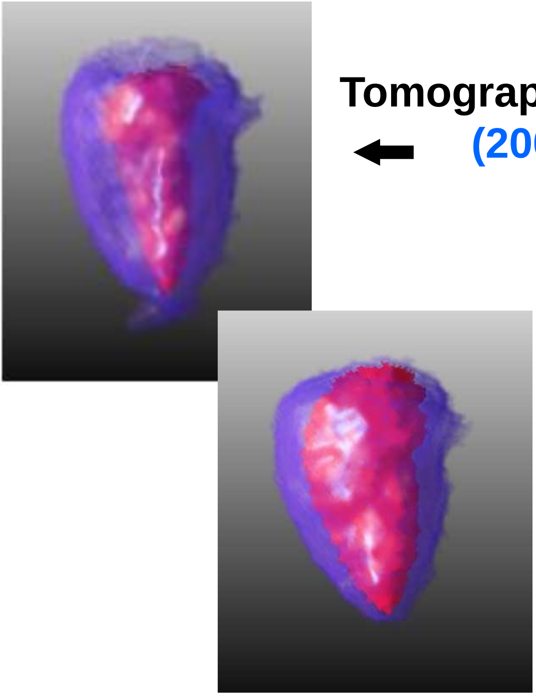
Laser scanner (2015)



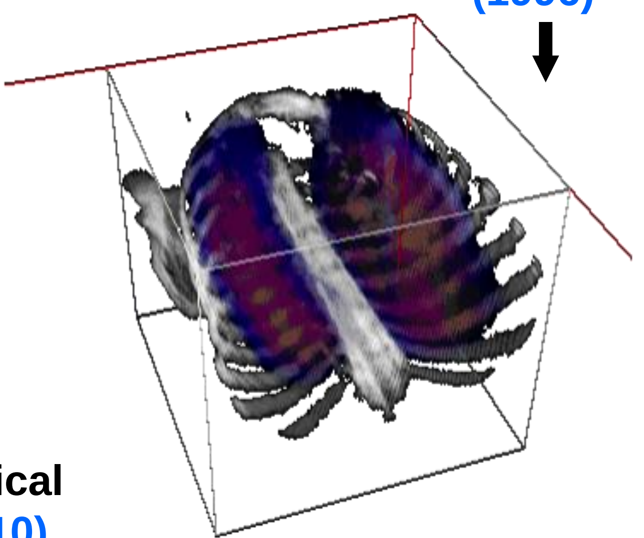
Ground Penetrating Radar (1999)



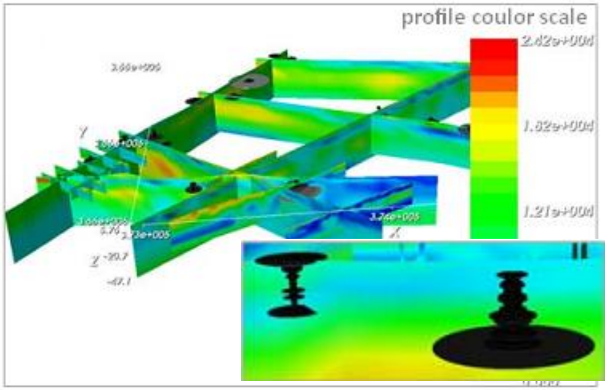
Tomography (2004)



Tomography (2008)



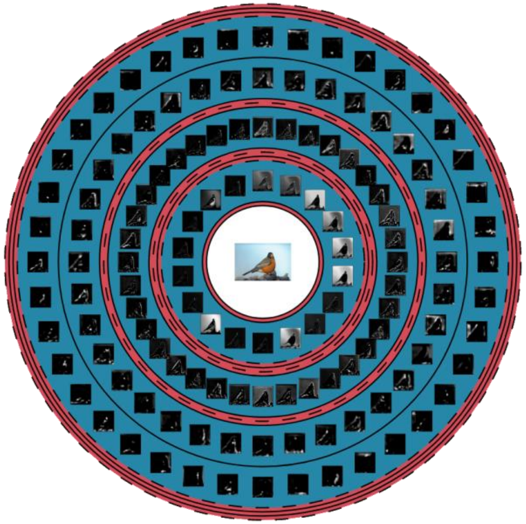
Tomography and SPECT (1996)



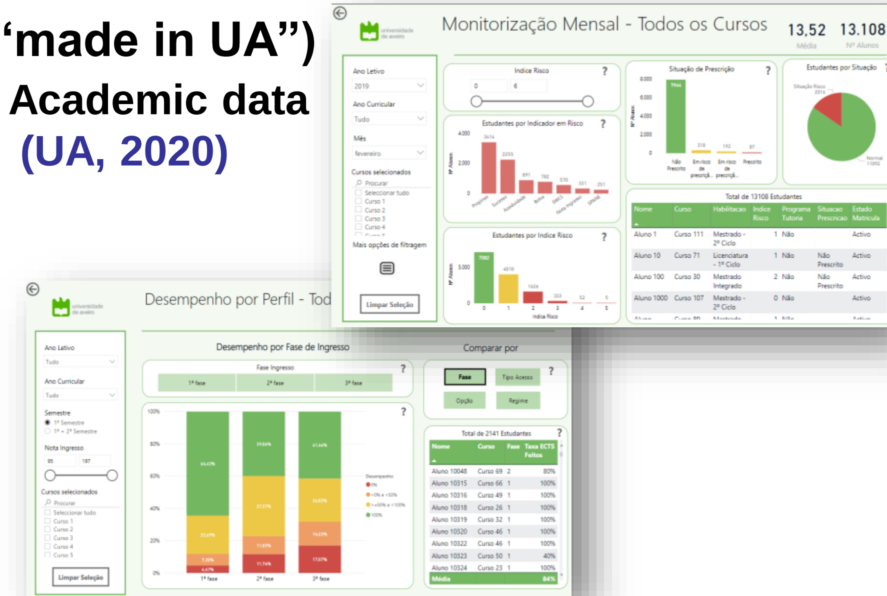
Electrical and mechanical ground resistivity (2010)

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

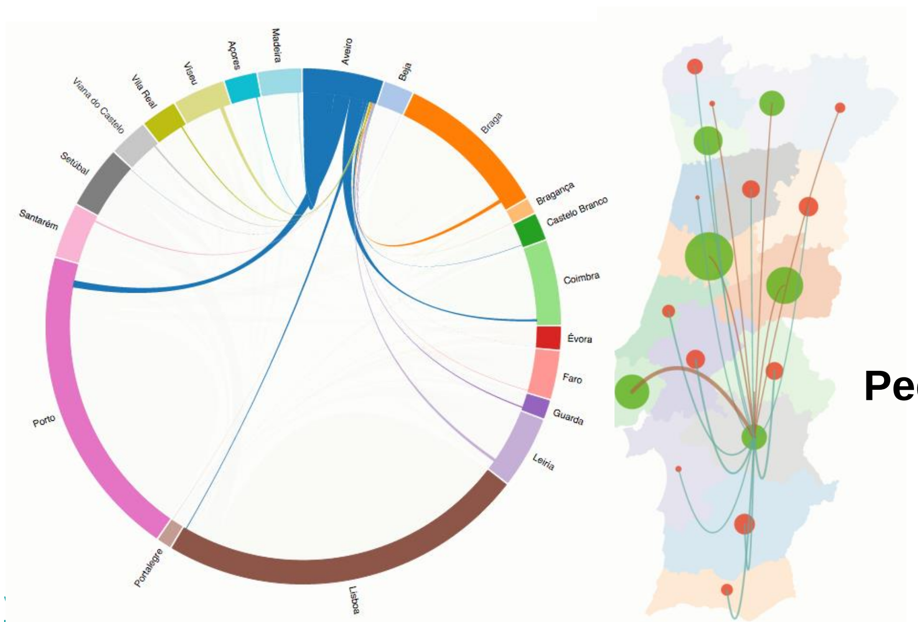
Machine Learning Visualization (XAI)
(UA, 2020)



Academic data
(UA, 2020)

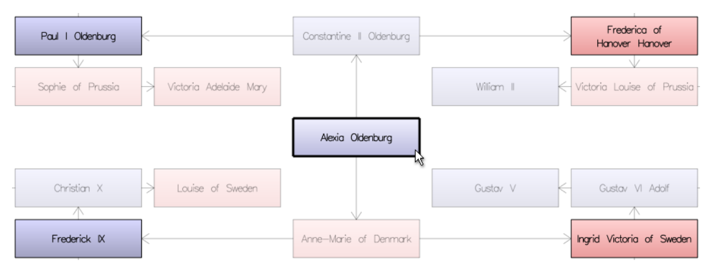


Student Migrations
(UA, 2015)

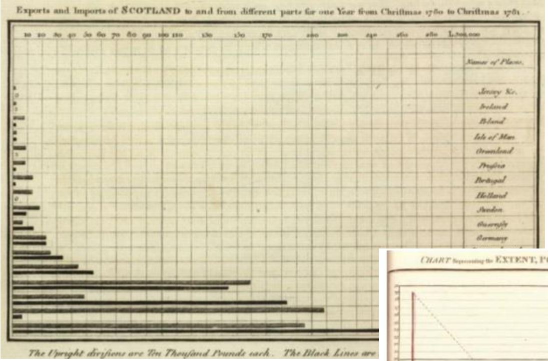


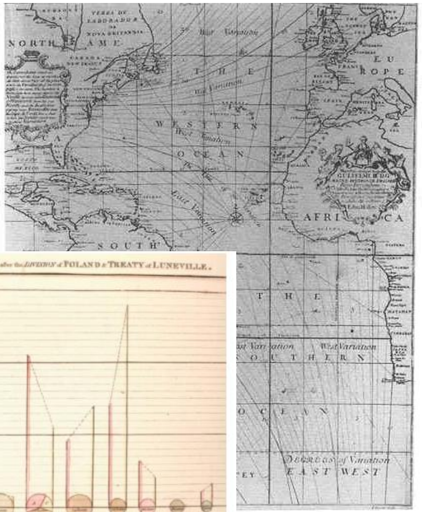
Taxonomy Visualization
(UA, 2021)

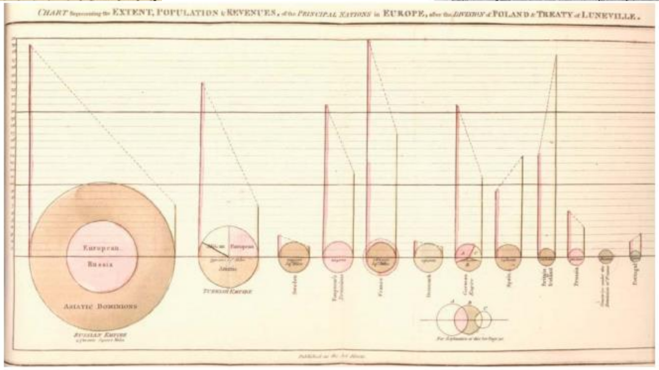
Pedigree trees
(UA, 2011)



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

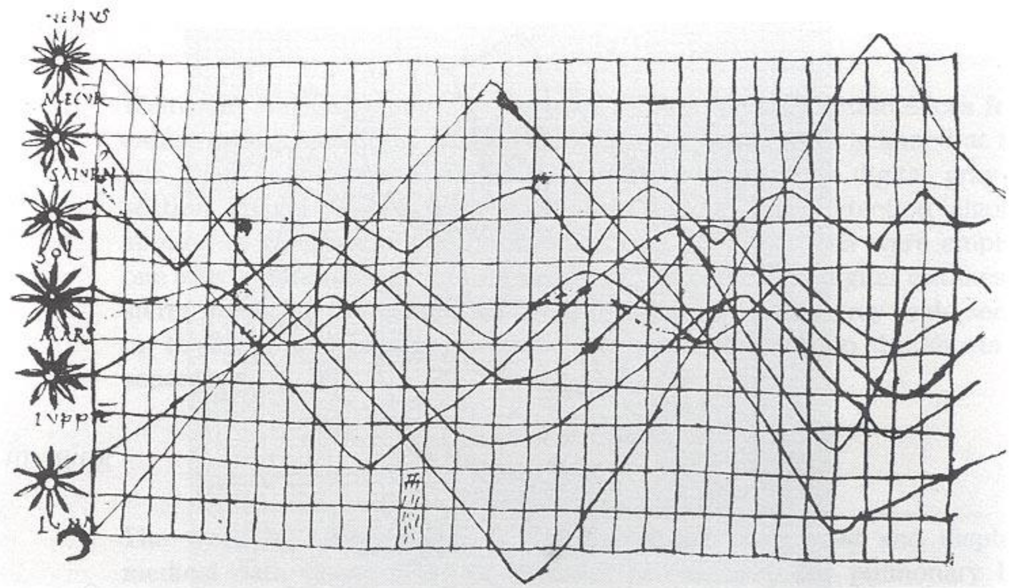
Visualization in Scientific Computing
(McCormick, de Fanti and Brown – 1987)

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

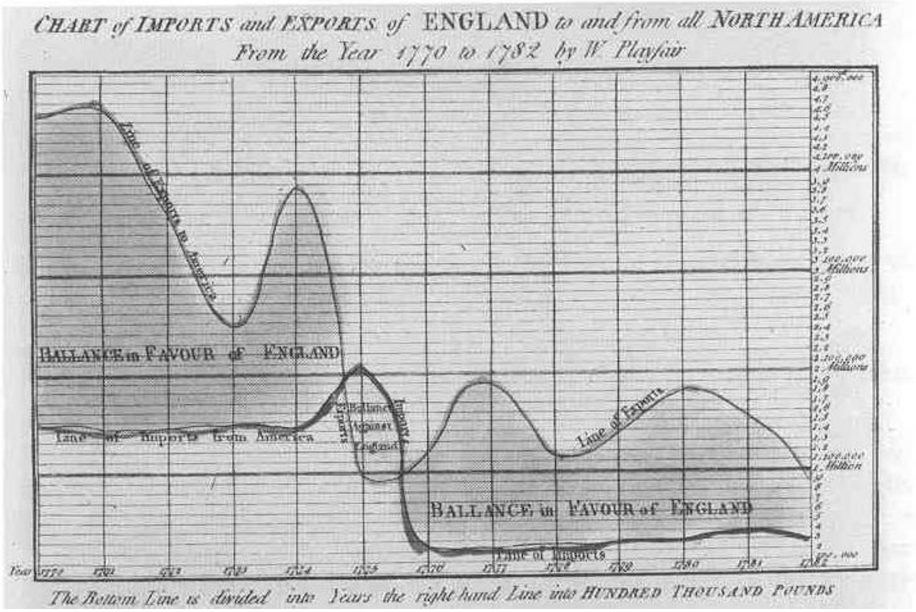
“Pre-computer” Visualization:

One of the oldest known Visualizations



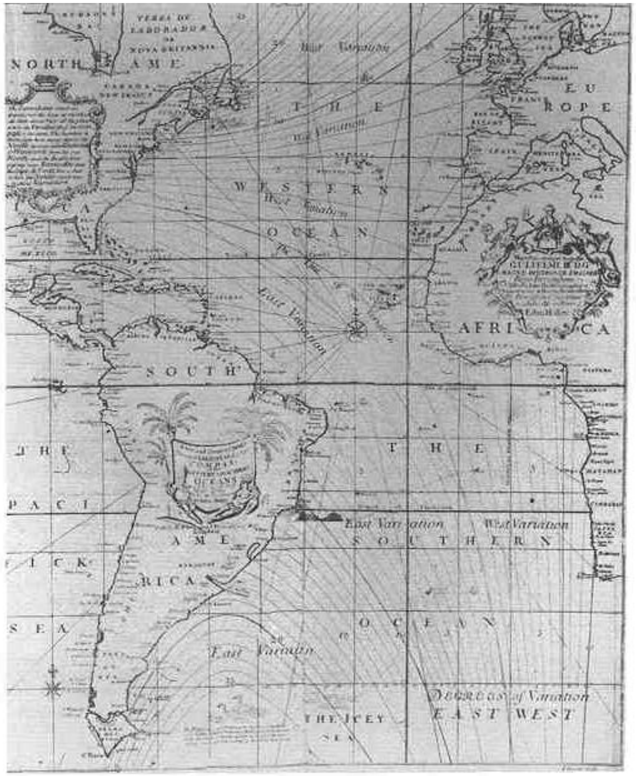
Inclination of orbits along the time - Xth century (Tufte,1983)

One of the first Visualizations used in “business”



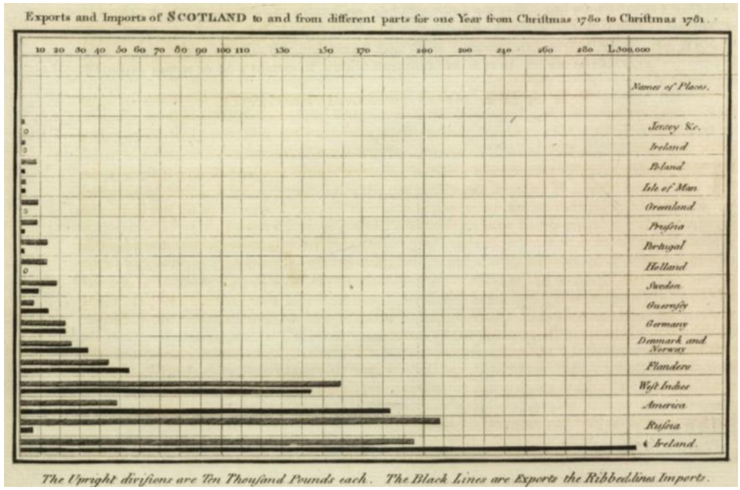
Import/export during the period from1770 to1782 by William Playfair (Tufte, 1983)

One of the first visualizations using contours (isolines)



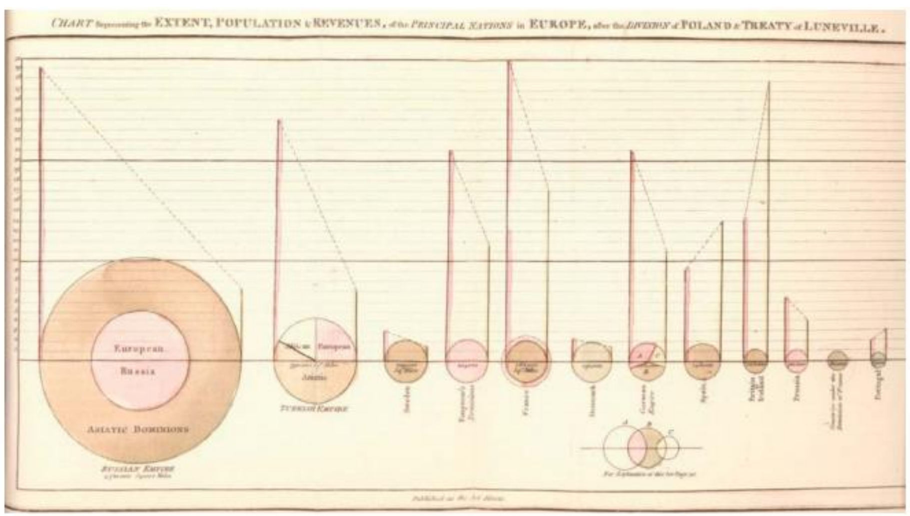
Magnetic declination 1701 Edmund Halley (Tufte,1983)

“Ancestors” of simple representations of univariate data

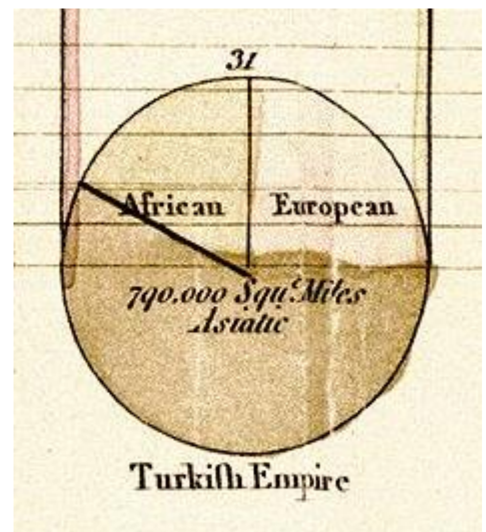


Exports and Imports of Scotland to and from different parts for one
W. Playfair’s *The Commercial and Political Atlas, 1871*

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

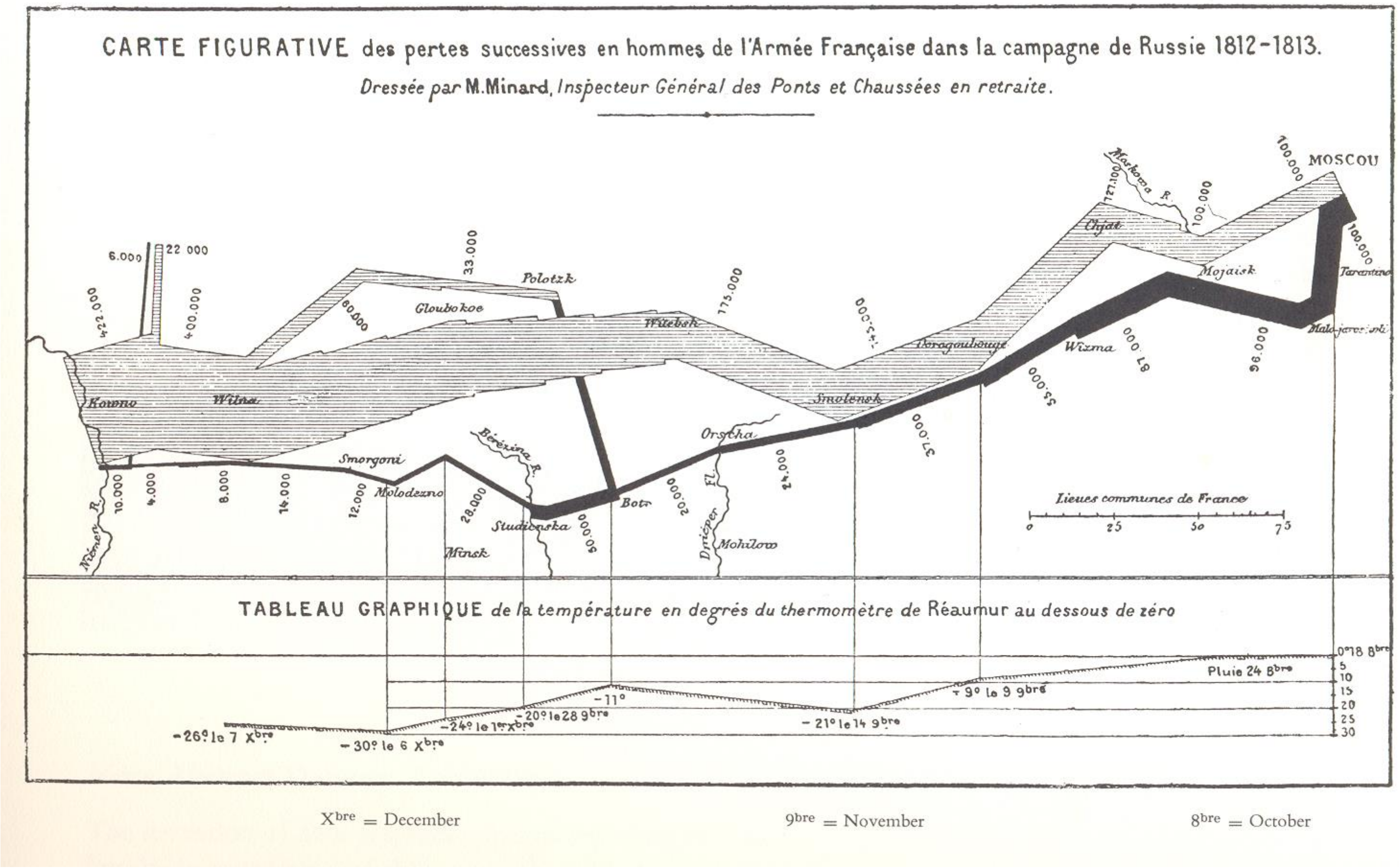


W. Playfair, *Statistical Breviary*, 1801



Multidimensional Visualization

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



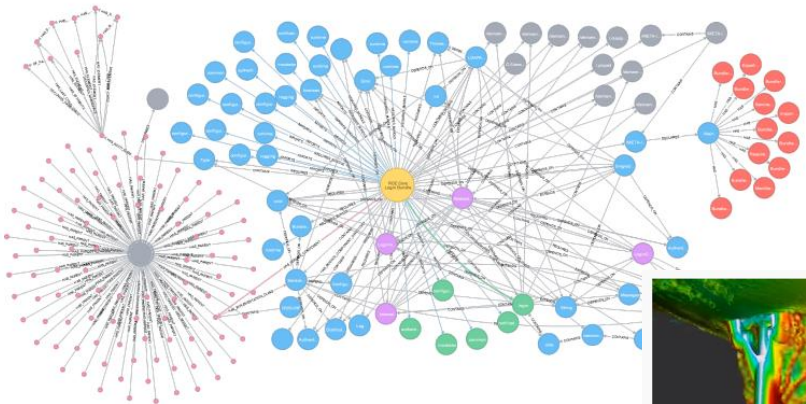
Russia campaign of Napoleon 1861 by Charles Minard (Tufte,1983)

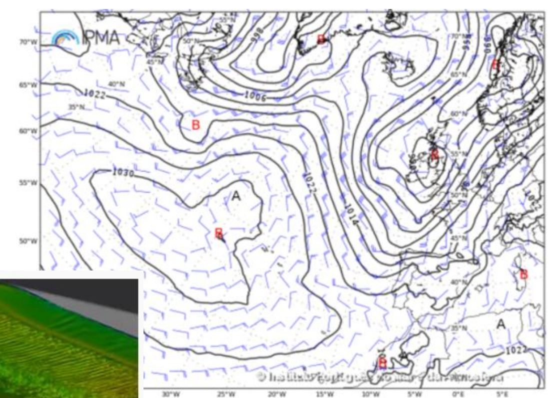
Visualization in scientific discovery

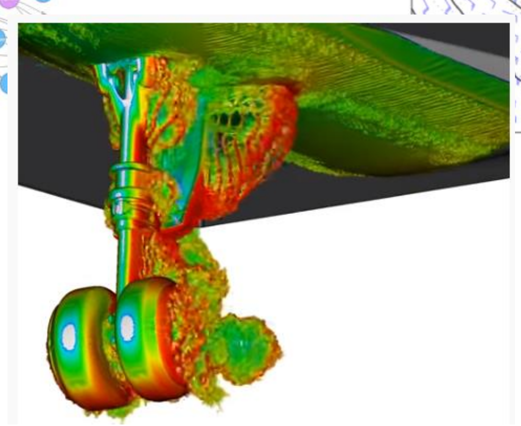
Discovering the cause of the London cholera out brake, 1853-54
(Wikipedia)

Dr. John Snow

Applications







Applications of Scientific Visualization

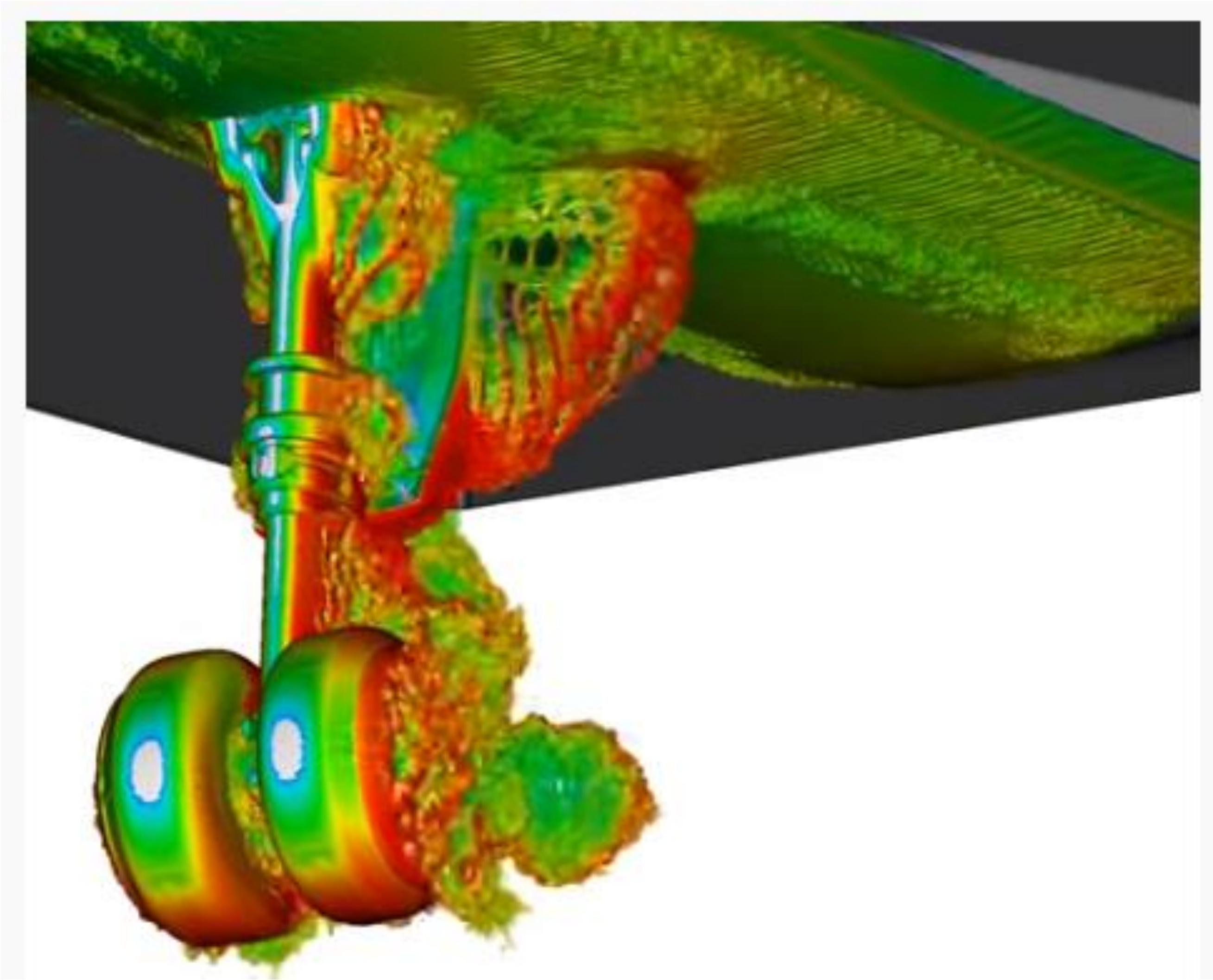
- **Scientific Visualization** is currently used in many scientific areas:
  - All engineering fields …
  - Medicine
  - Meteorology, climatology, oceanography
  - Fluid dynamics
  - Cosmology
  - etc., etc.

- 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

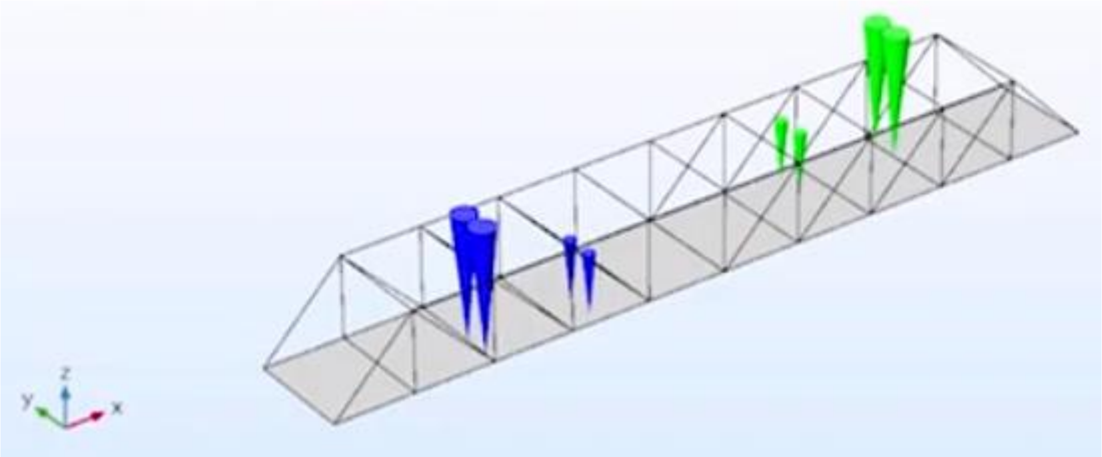
Visualization and Virtual Reality at the Automotive Industry

90% of the new Maserati M20 was digitally developed

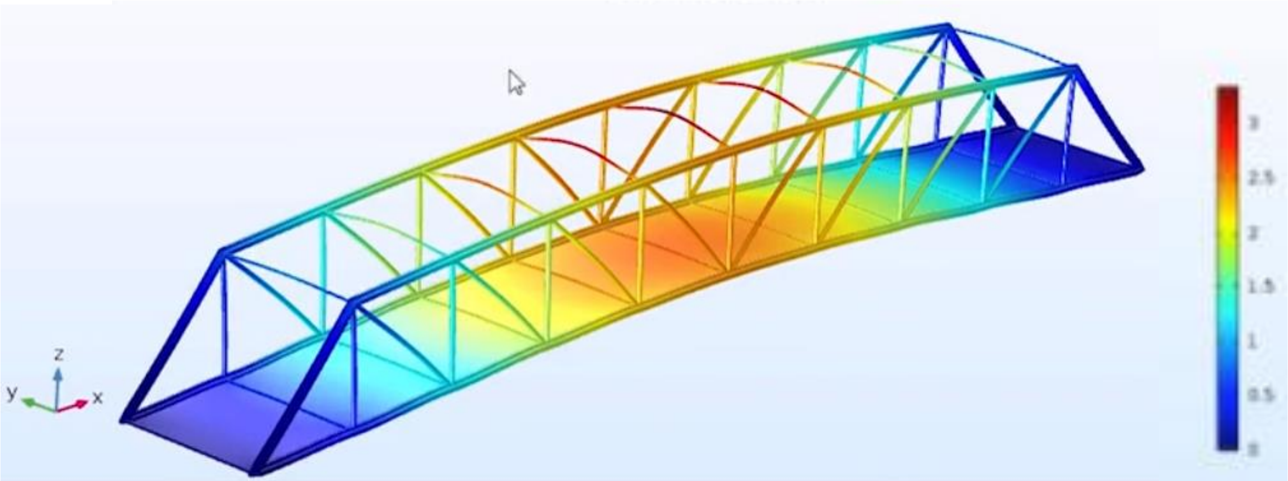
Tested in a VR simulator, improving results, reducing time and cost of development

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

Civil engineering visualization

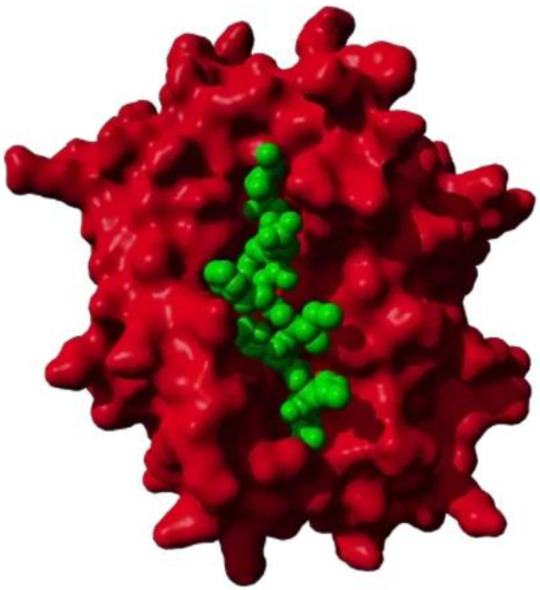


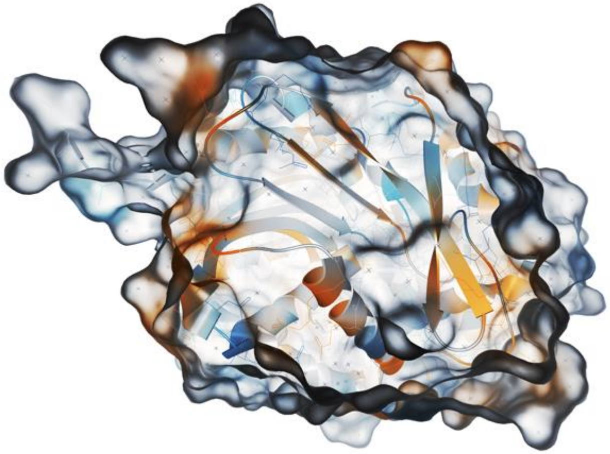
Bridge project:
Visualizing Displacement, Force and Moment in Beams, Stress in Beams, and Stress in Roadway

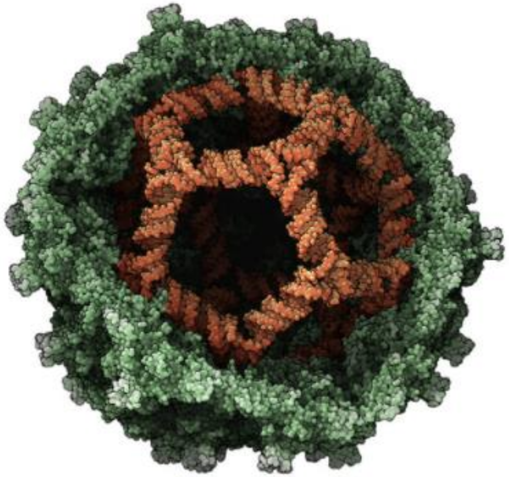


https://www.comsol.com/blogs/efficiently-analyze-civil-engineering-designs-using-an-app

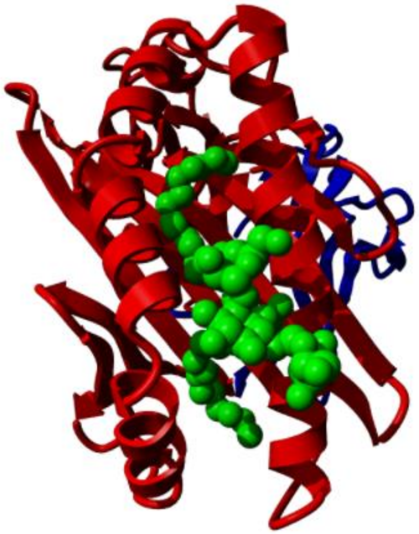
Molecule visualization





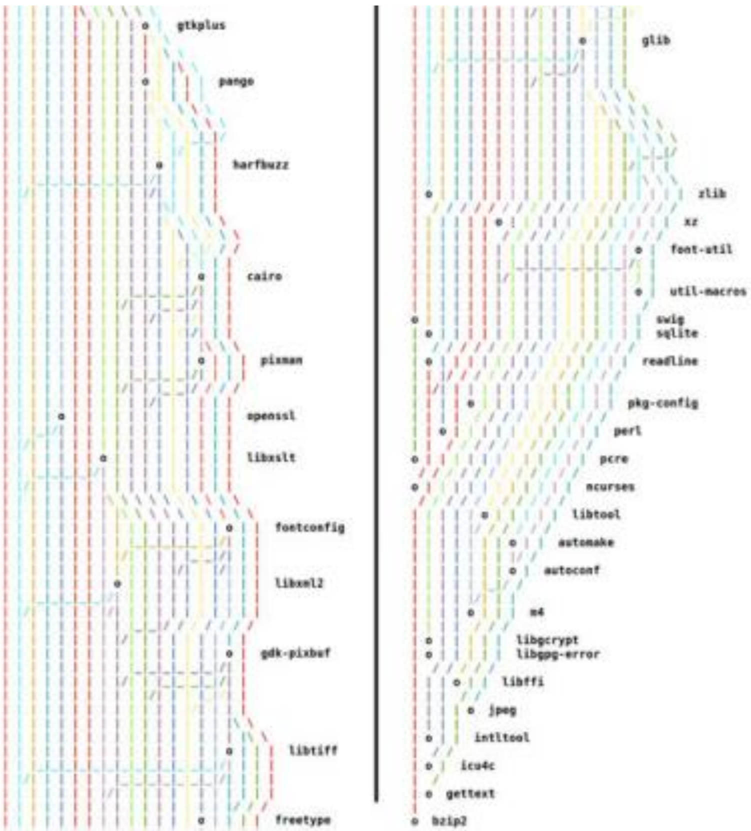


Design:
Drugs
Proteins
Materials
Nanosystems



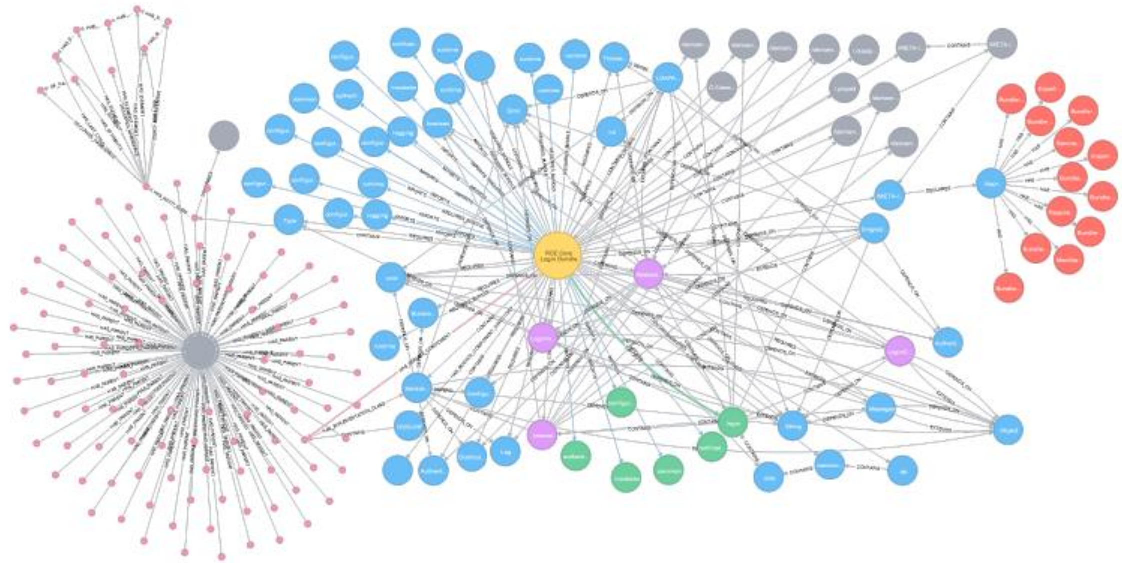
https://www.samson-connect.net/

Software visualization

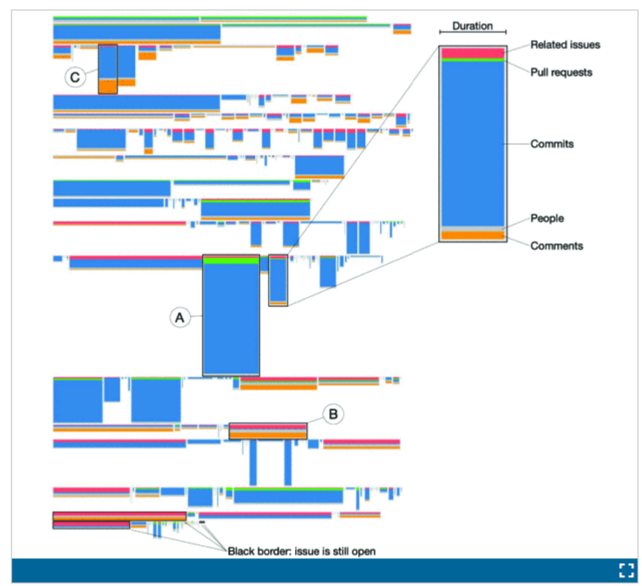


git-style package dependency graph of dia (also shown in Fig. 1). The freetype node has been duplicated to show alignment between the two halves.

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



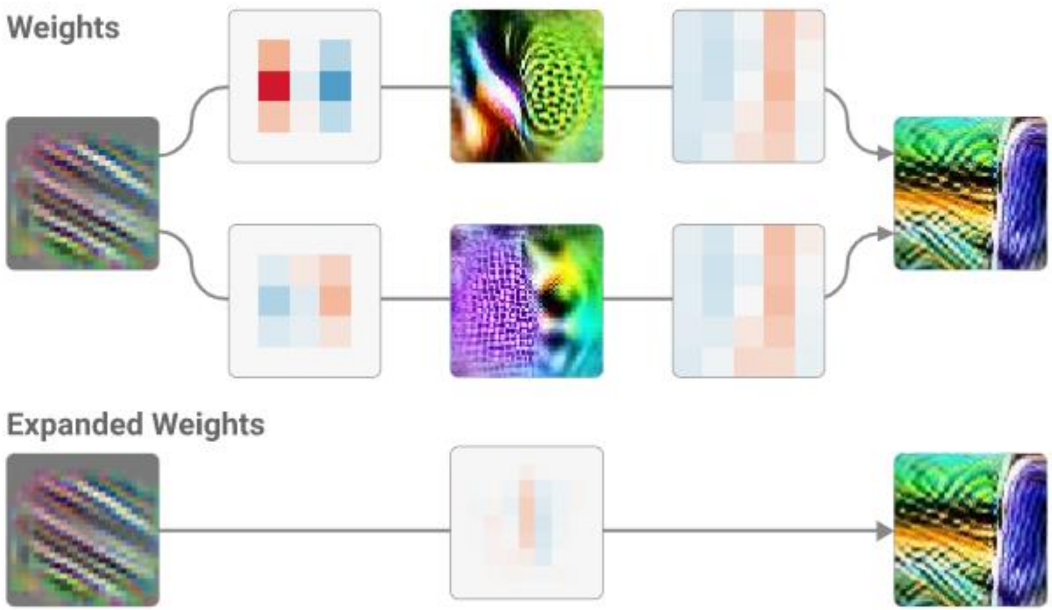
https://ieeexplore.ieee.org/document/8742198

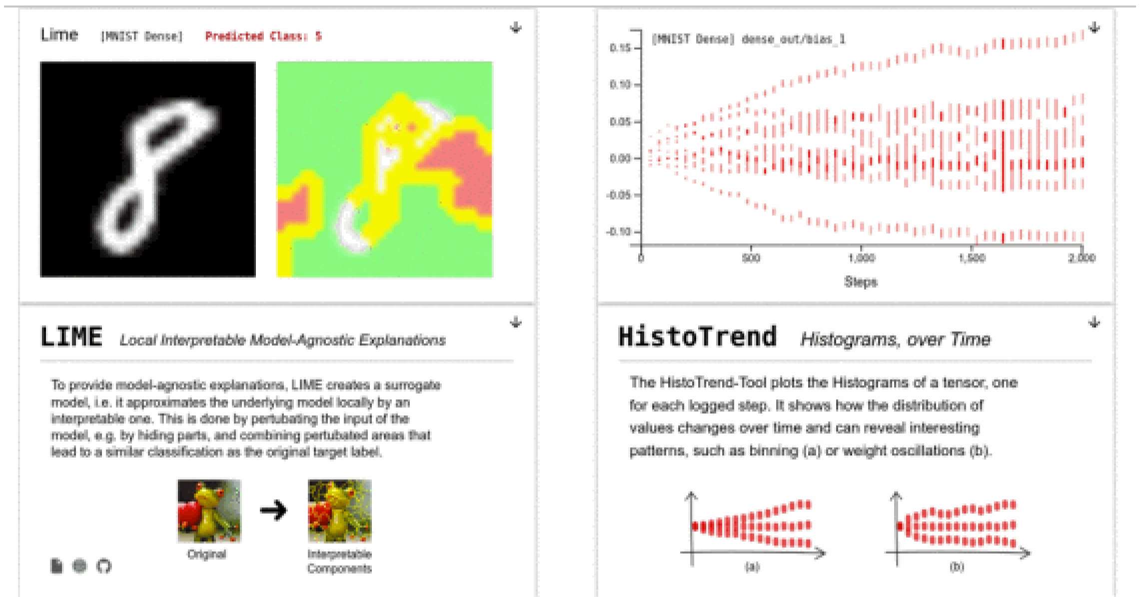


https://ieeexplore.ieee.org/document/9604892

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)

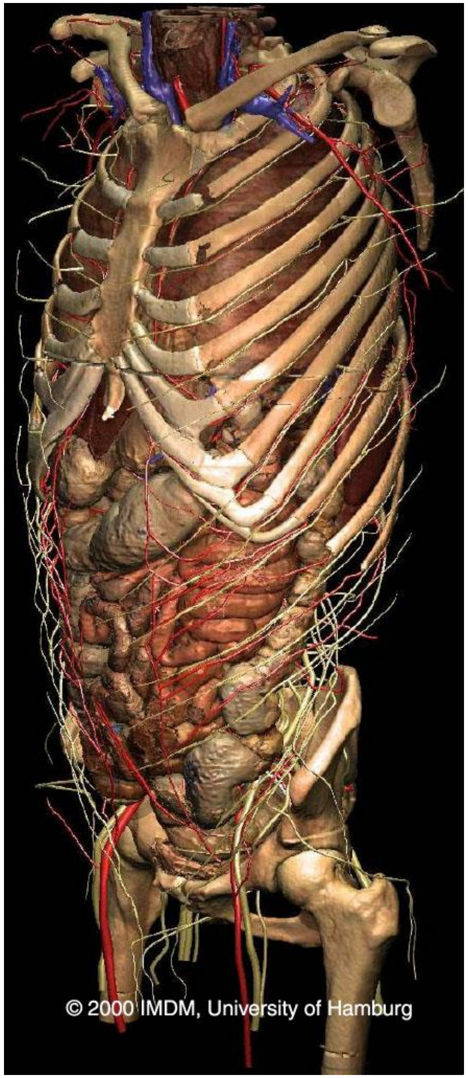
- Visible Human project
  (National Library of Medicine-USA)

https://www.visiblebody.com/

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

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

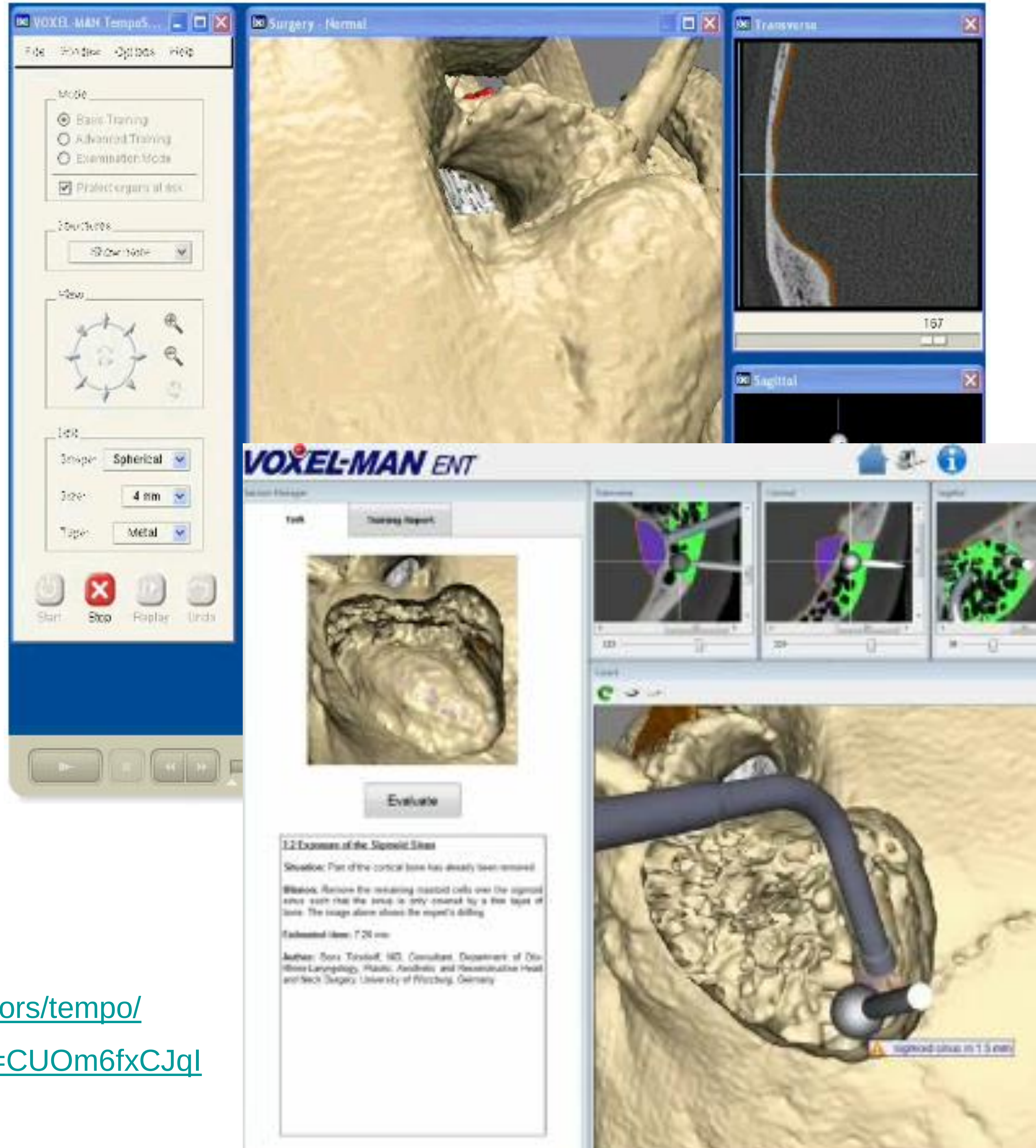
https://www.nlm.nih.gov/research/visible/applications.html



Medicine
(e.g. surgery training)

VOXELman,
University of Hamburg

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



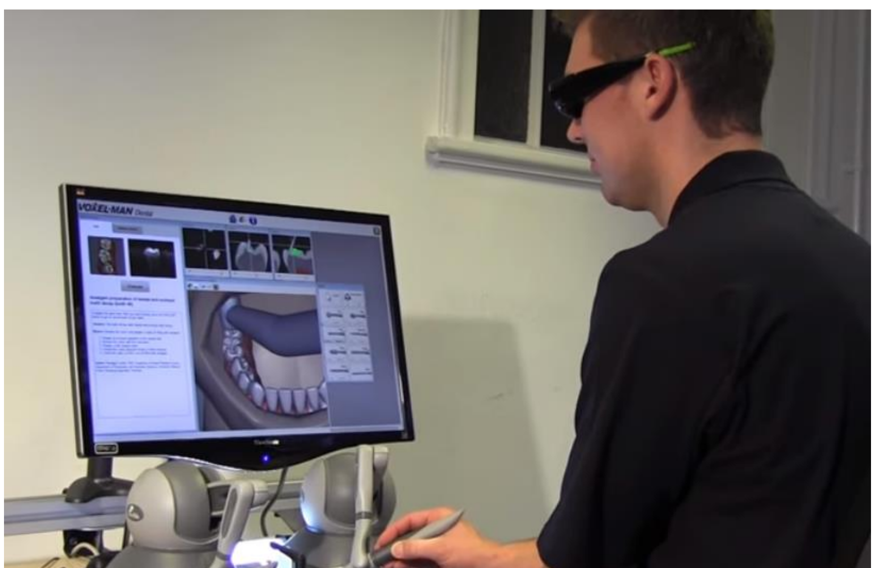
https://www.voxel-man.com/simulators/tempo/

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

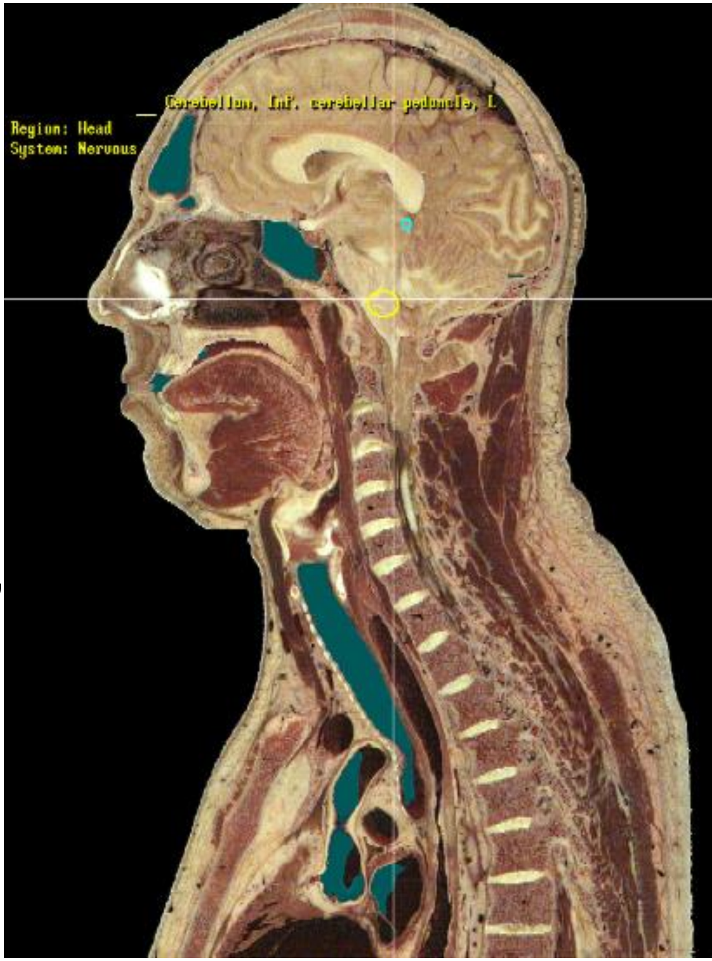
https://www.voxel-man.com/simulators/dental/

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.



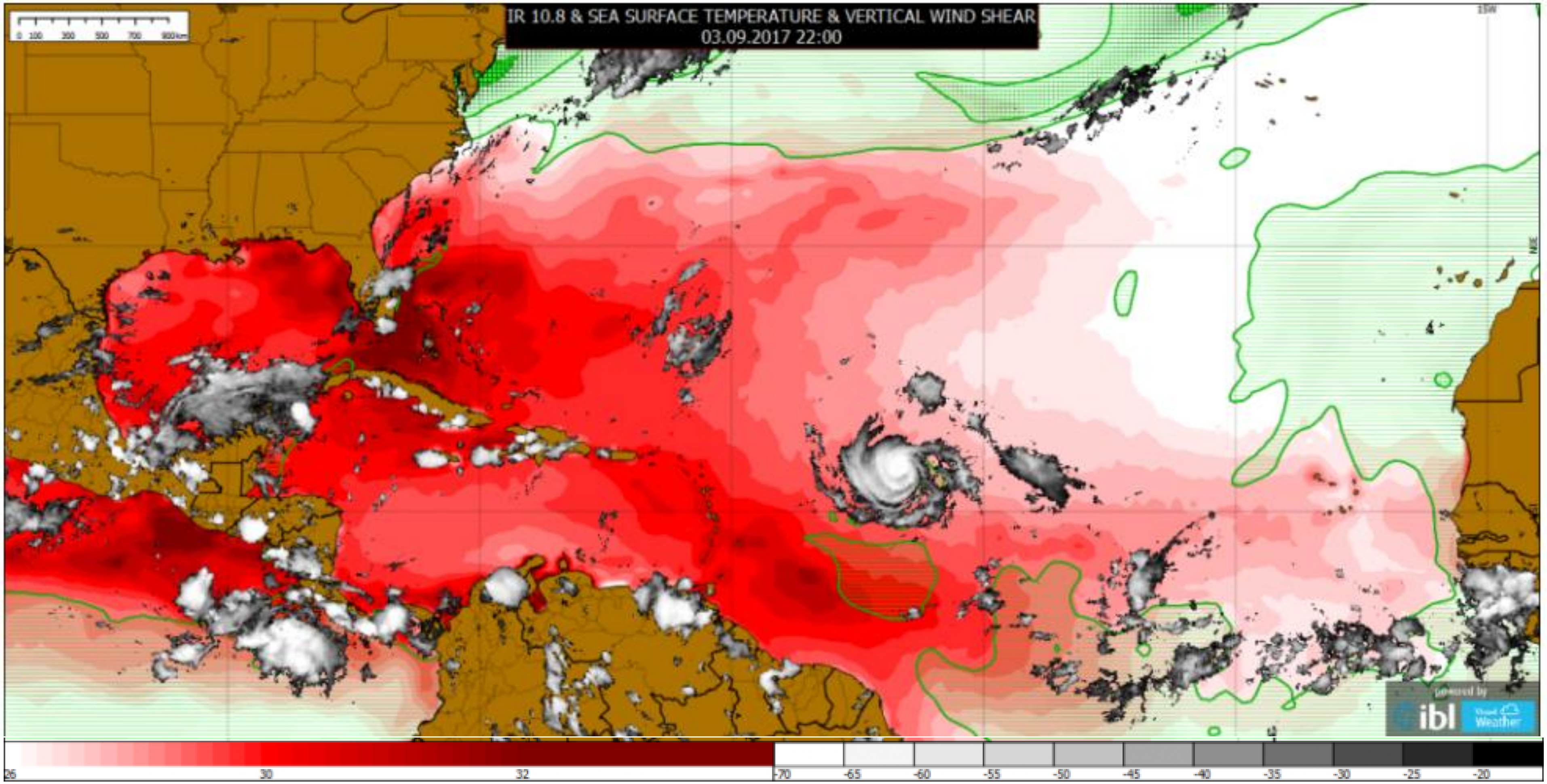
Have been applied to a wide range of educational, diagnostic, treatment planning, virtual reality, artistic, mathematical, and industrial uses.

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



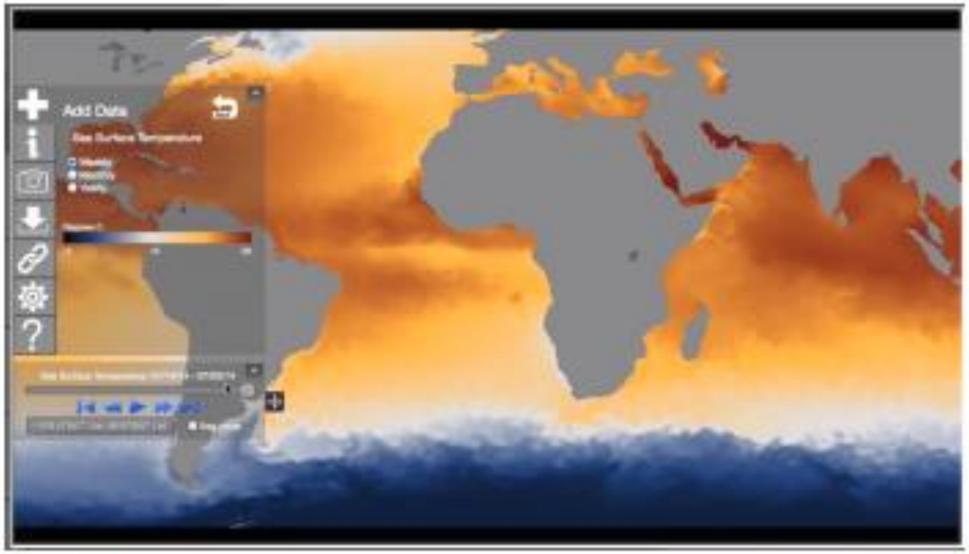
https://www.iblsoft.com/products/visualweather/

Climate research
(by NOAA)

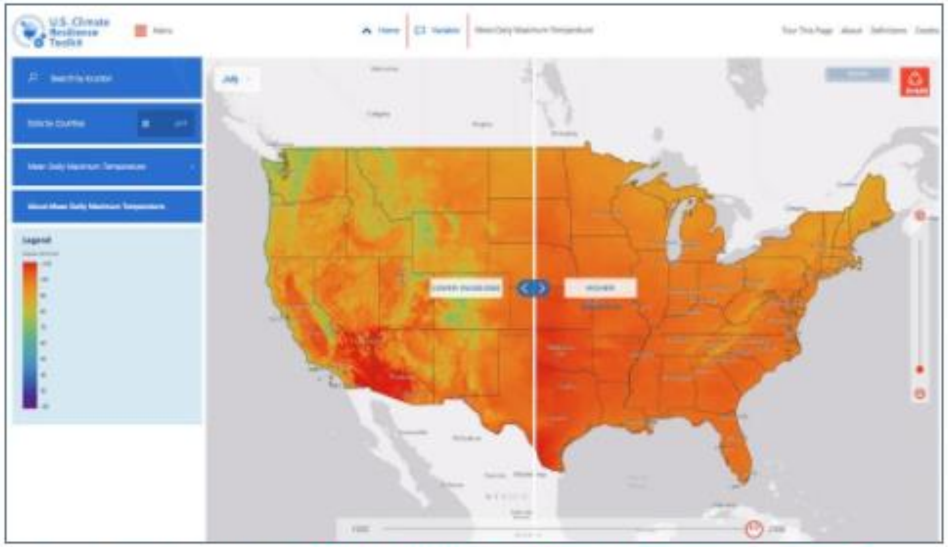
•The Climate Explorer offers graphs, maps, and data of observed and projected temperature, precipitation, and related climate variables for every county in the contiguous US

• 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

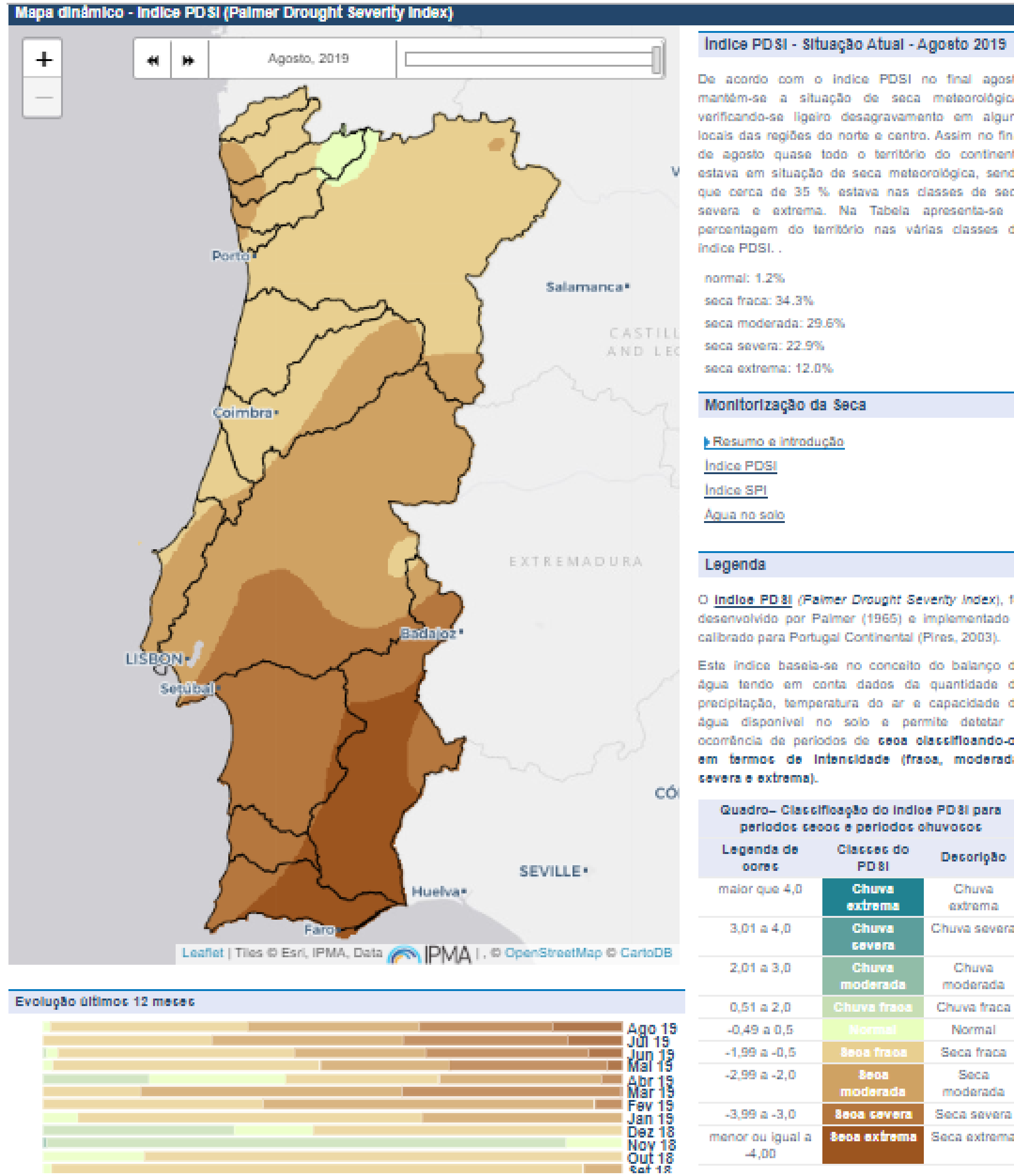


View by Variable interface. View Maximum Daily Temperature variable in Climate Explorer.

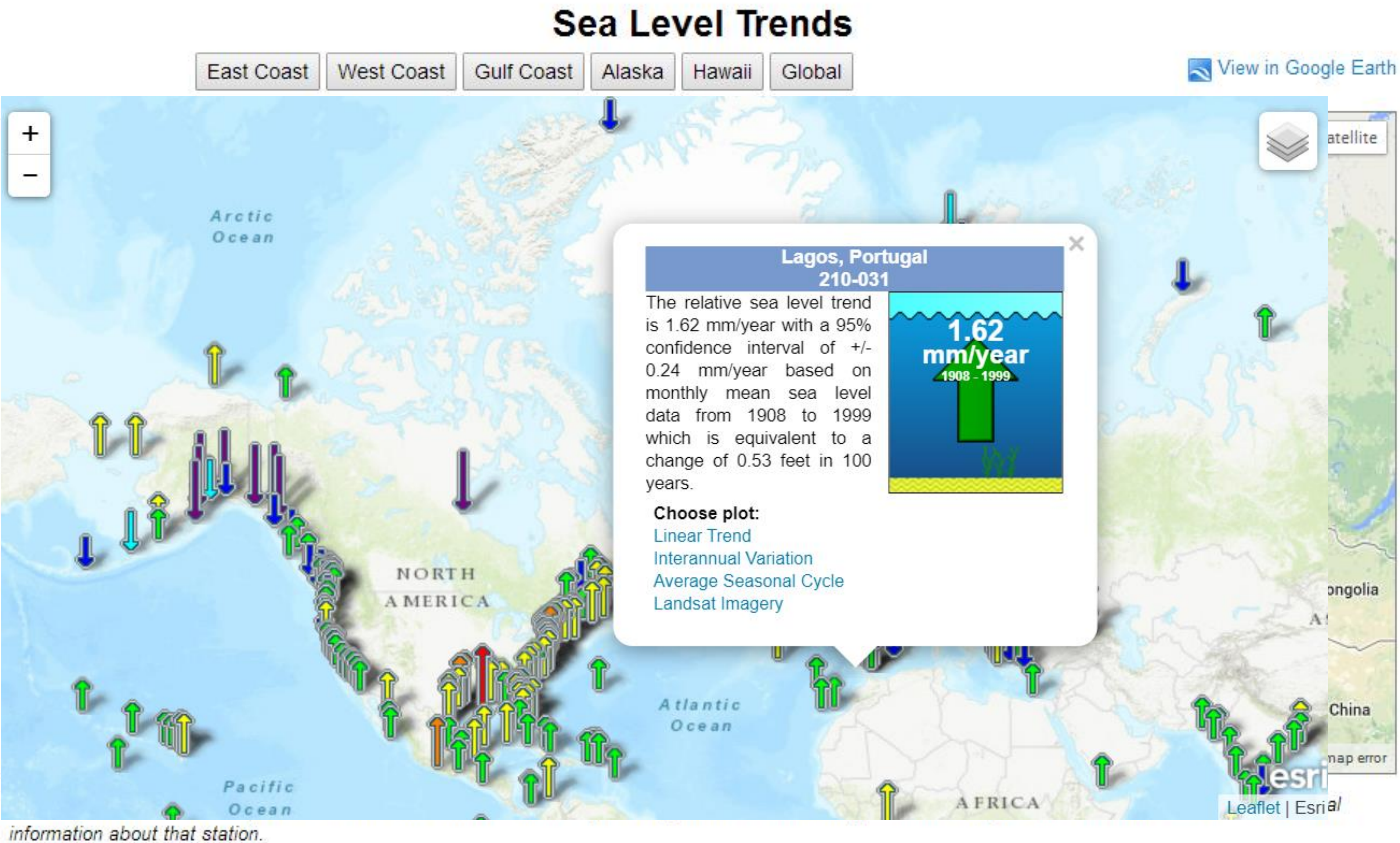
https://toolkit.climate.gov/tools/climate-explorer

Example in Climate monitoring:

Drought Severity Index (by IPMA)



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

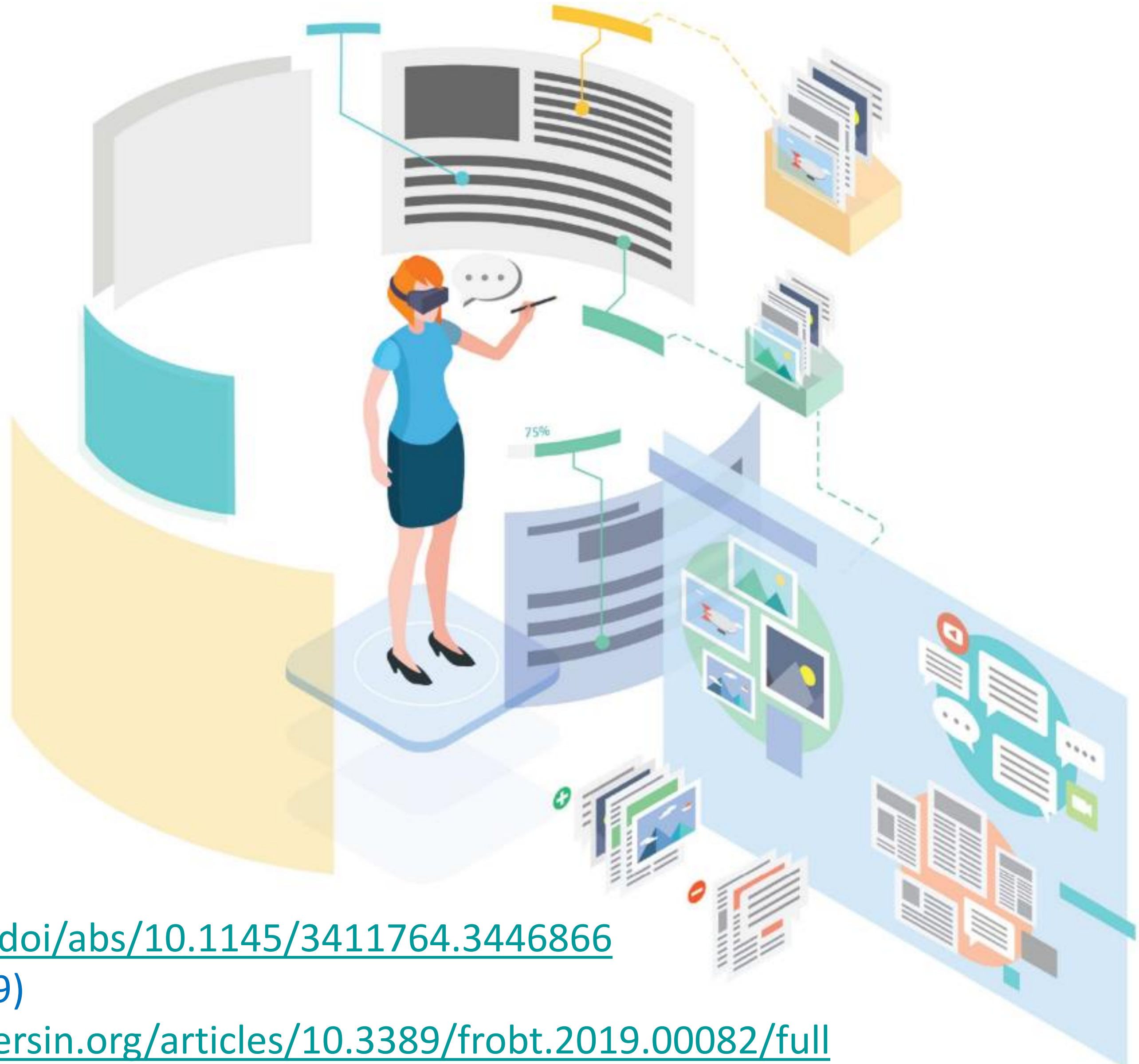


Sea Level Trends
mm/yr (feet/century)

15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)

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

What about the future of Visualization?

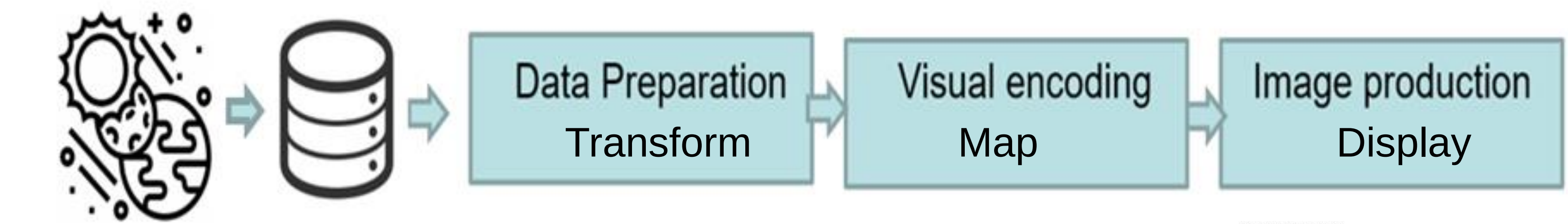


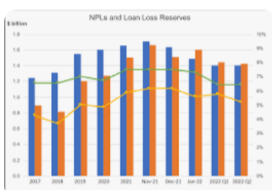
(Barret et al., 2021)
https://dl.acm.org/doi/abs/10.1145/3411764.3446866
(Skarbez et al., 2019)
https://www.frontiersin.org/articles/10.3389/frobt.2019.00082/full

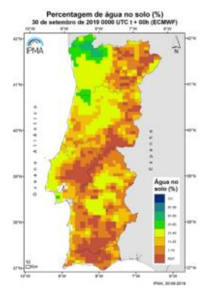
The process of creating a (simple) Visualization

The data may be **acquired from the world** (e.g. sensors, questionnaires)

or **simulated** (e.g. Finite Element Analysis, weather models)







The users should get **insights** from analyzing the visualization and be supported in their tasks (answer their questions)

It is a **human-in-the-loop process**

- “***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

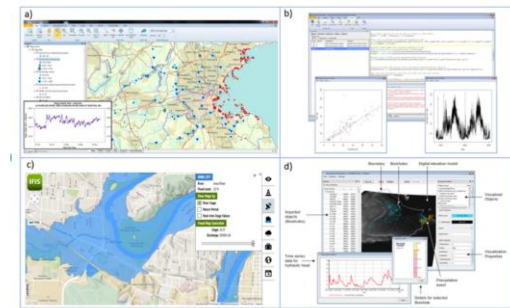
  - in general we cannot change them

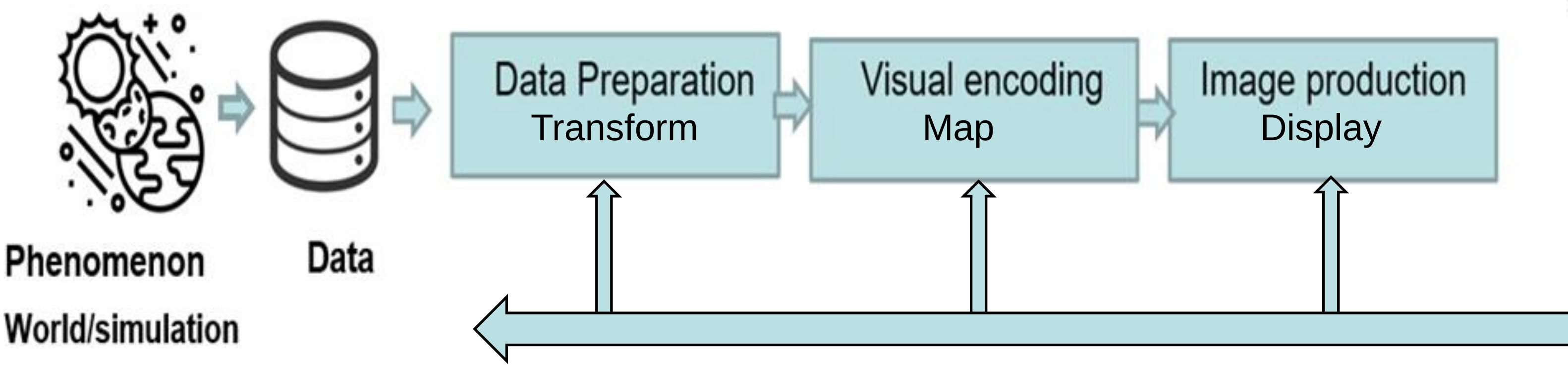
- Target users’ profile, needs, and context of use must be carefully considered whenever designing a visualization

Visual Data Exploration applications

To let the users visually and interactively explore data it is necessary to provide ways to interact along the process

https://doi.org/10.1016/j.envsoft.2022.105396





(adapted from Card et al., 1999)

Developing this type of application implies a specific approach:
Human-centred design

- :**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 t**ransformation** 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)

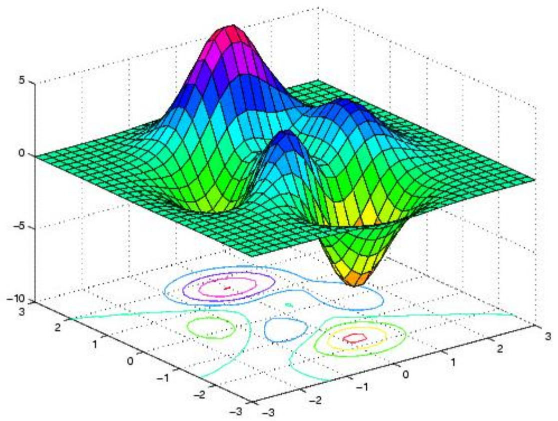
  - producing an image or sequence of images (**display**)

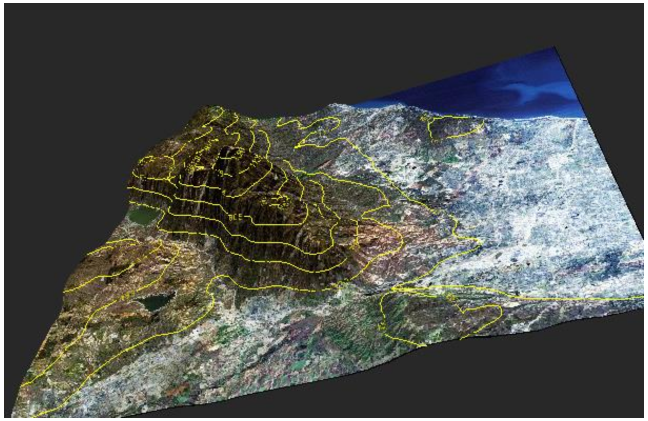
- **This process is repeated as needed to provide insight**

- 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:

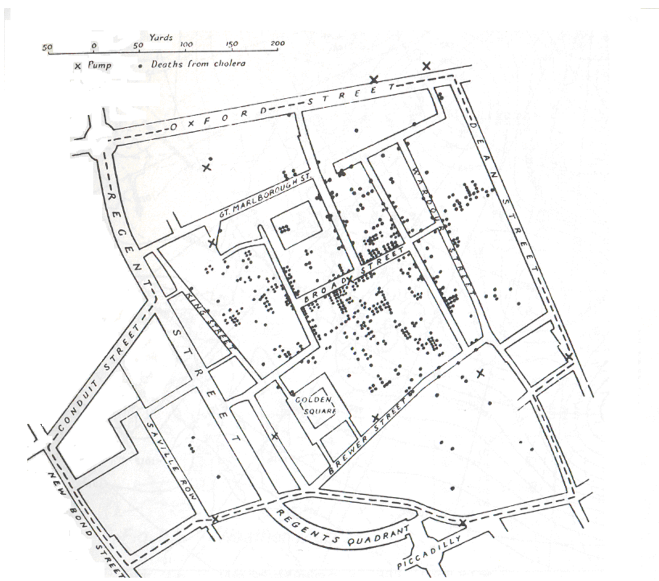
  - personal exploration
  - discussion with colleagues
  - presentation to other people

  for

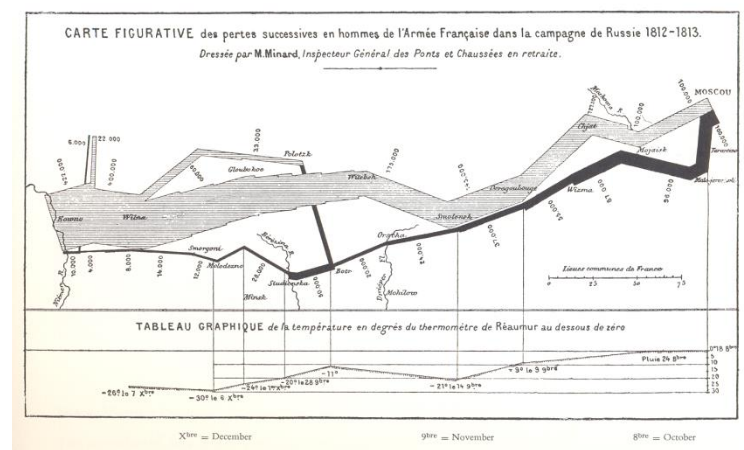
  - explorative analysis
  - confirmative analysis

Classical examples for:
a) exploration
b) presentation

a)



b)



Example of Presentation to other people: World health by Hans Rosling: 200 years of health/income – **120 000 values in 4 min**

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

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?

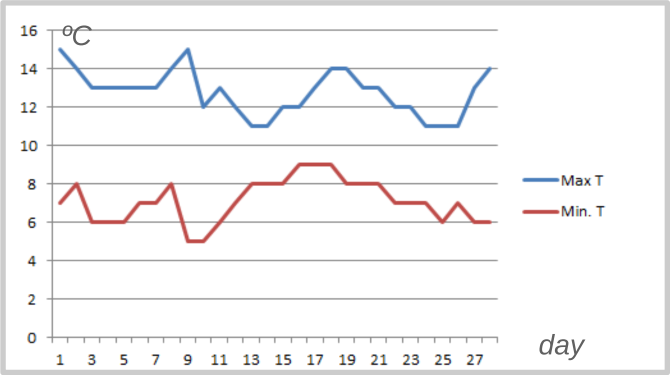
- What type of chart would you use to answer Q1?

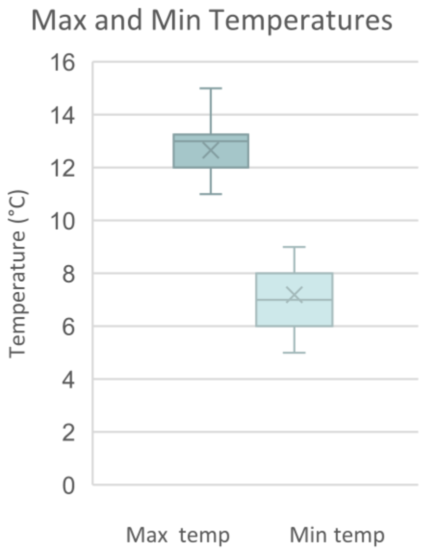
- And the other questions?

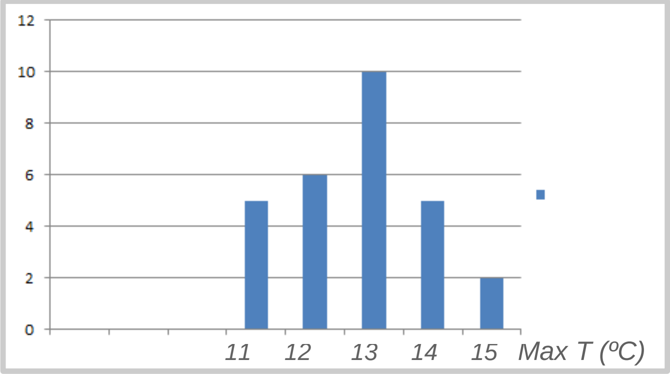
Example: how to select simple charts?

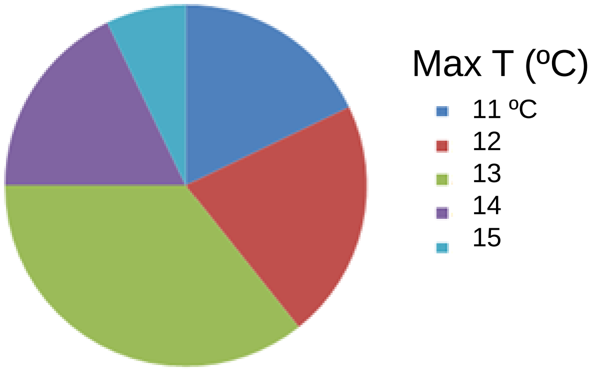
Temperatures along the month of February (in ºC): a few possible charts

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



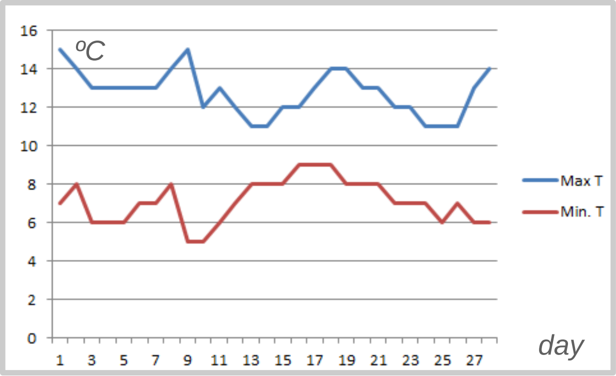






Simple example

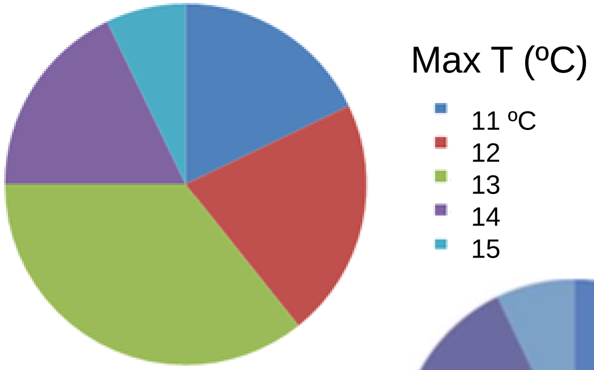
Temperatures along the month of February (in ºC):

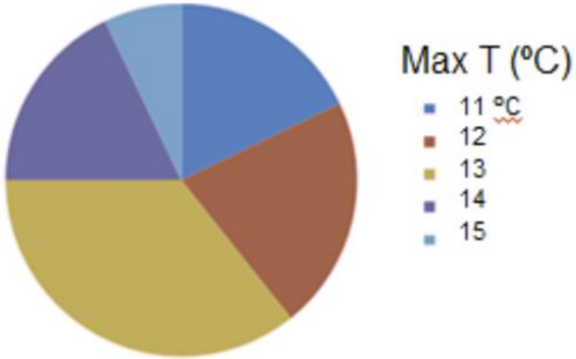


Anything “odd” about this chart?

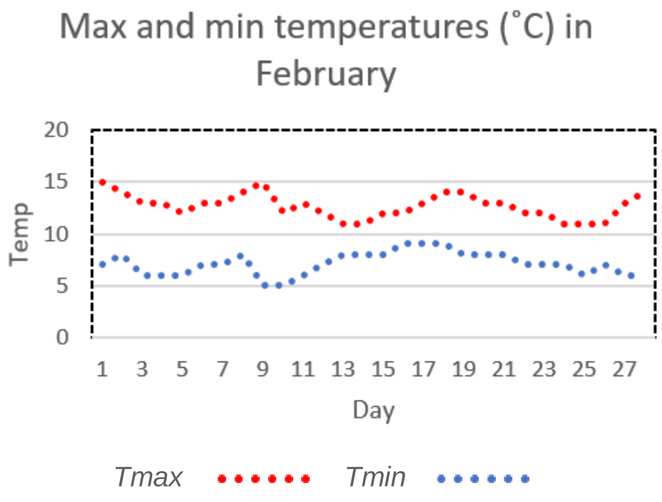
What if the user is color-blind?

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





Would you prefer this one?

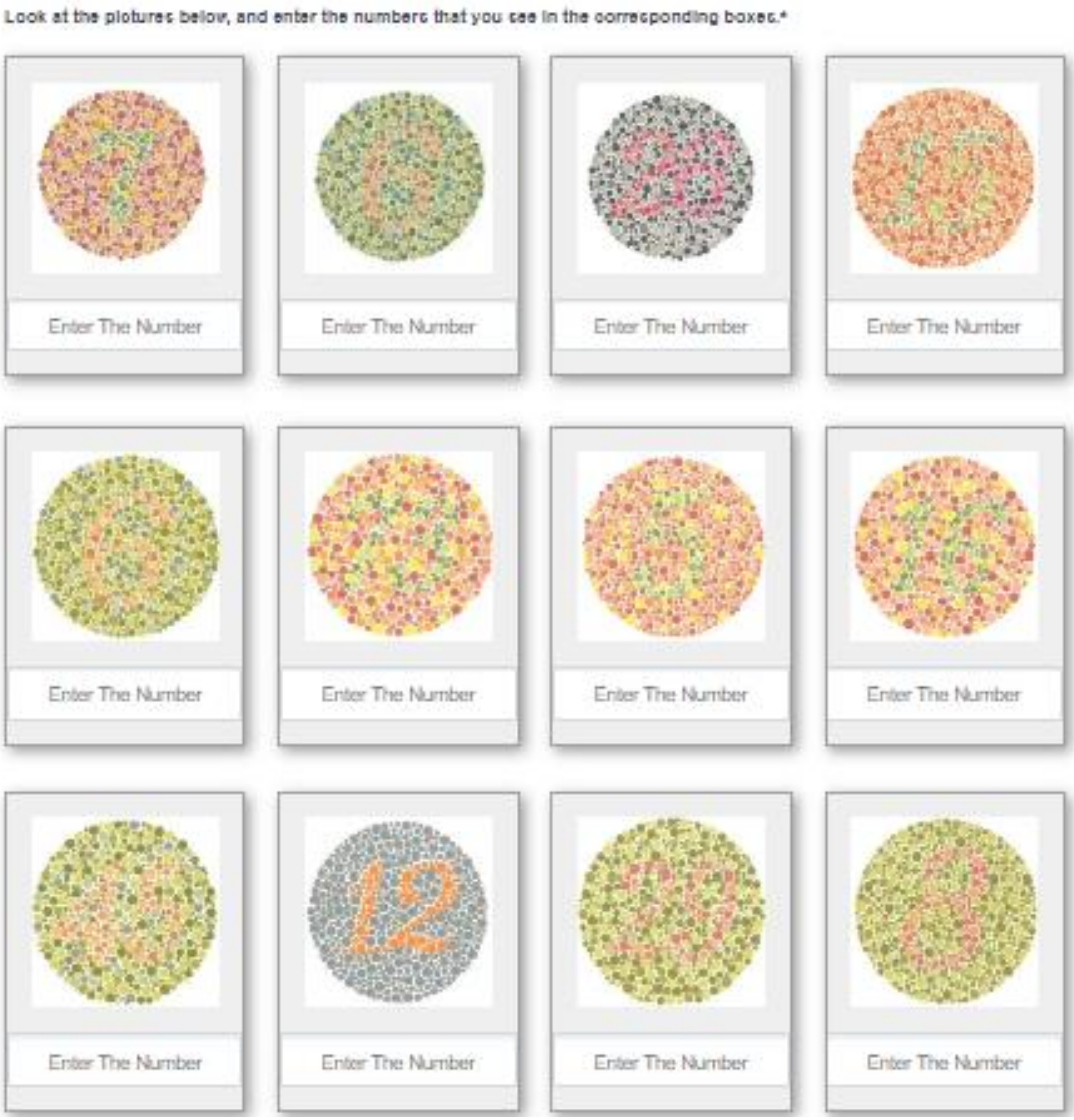


Do not forget “cultural” aspects, nor individual differences!

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

Ishiara test: color blindness test



https://colormax.org/color-blind-test/