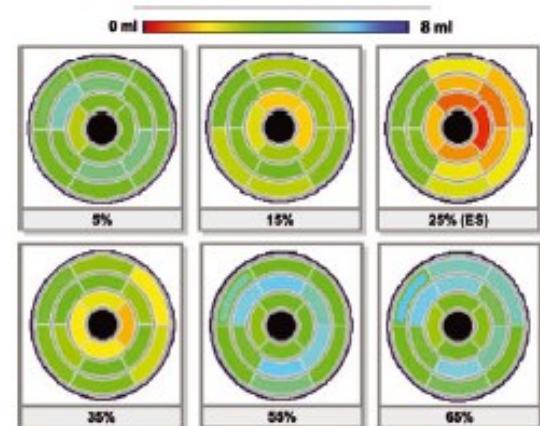
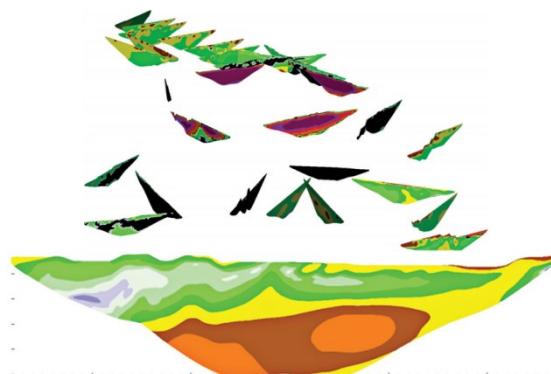
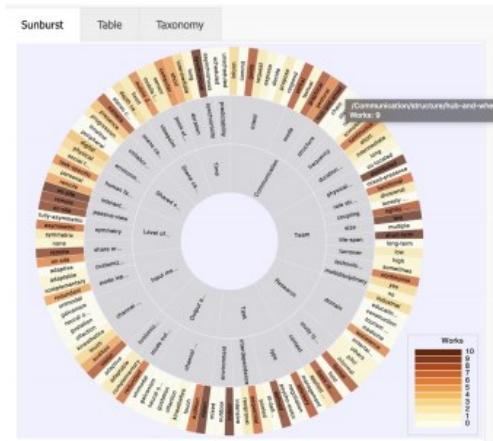




# An Introduction to Data Visualization



Definition

Objectives

History

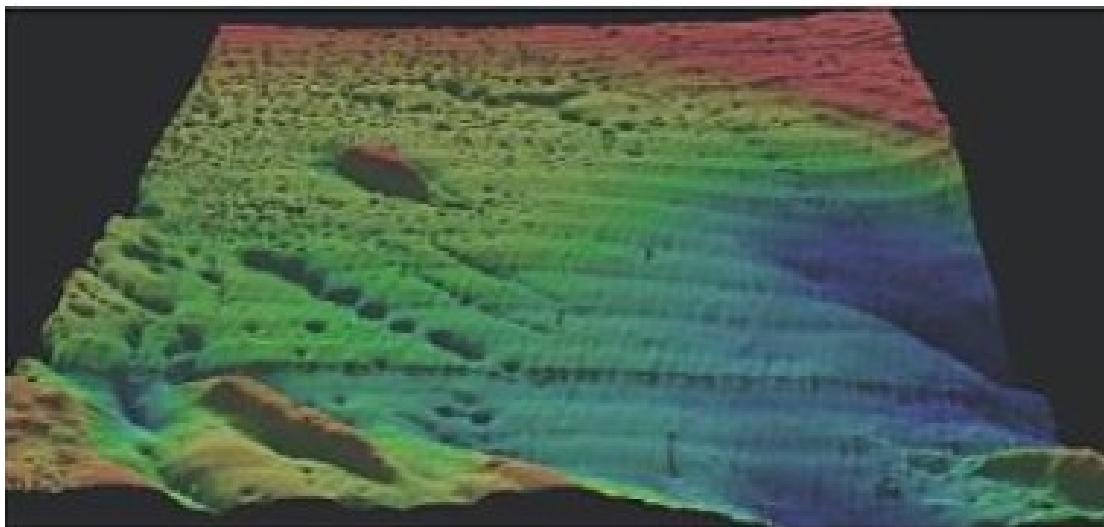
Applications

Model

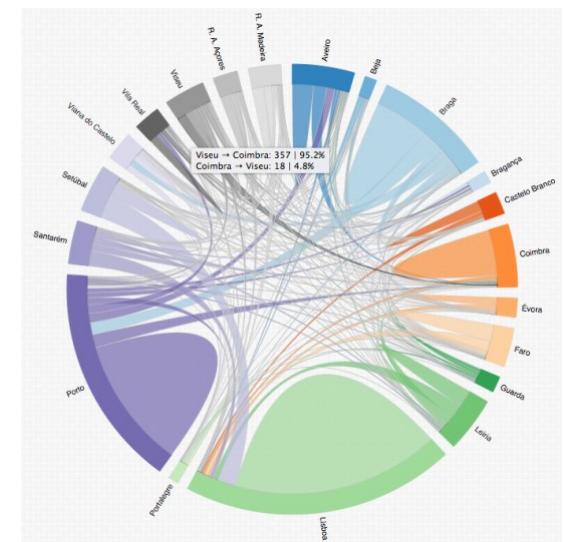
How to obtain and evaluate a Visualization?

# What is Visualization?

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



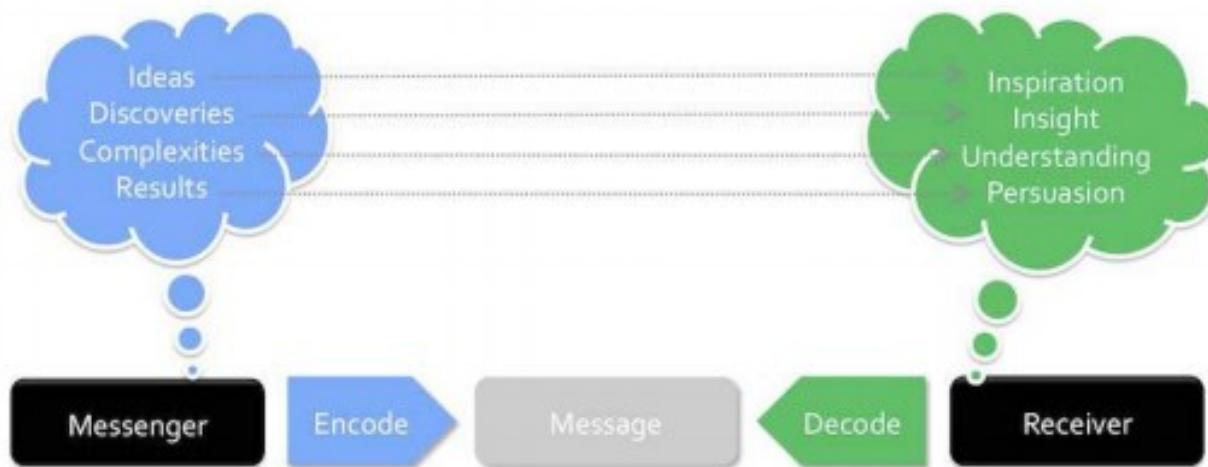
Passamaquoddy Bay  
( $10^6$  measures)  
(Ware 2019)



Portuguese Higher Education  
(data from 120 000 candidates)

## Definition (yet another)

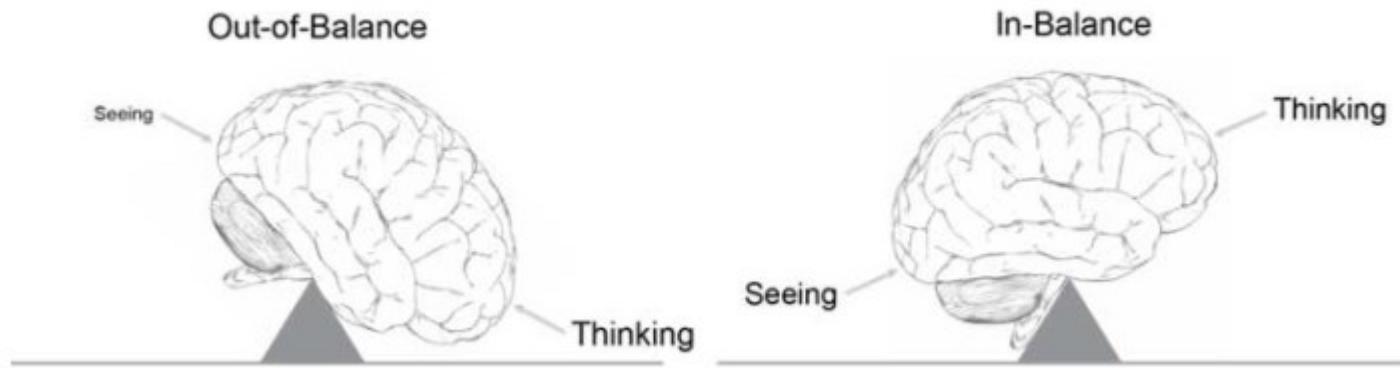
- “The representation and presentation of data that exploits our visual perception abilities in order to amplify cognition” (*Kirk, 2012*)



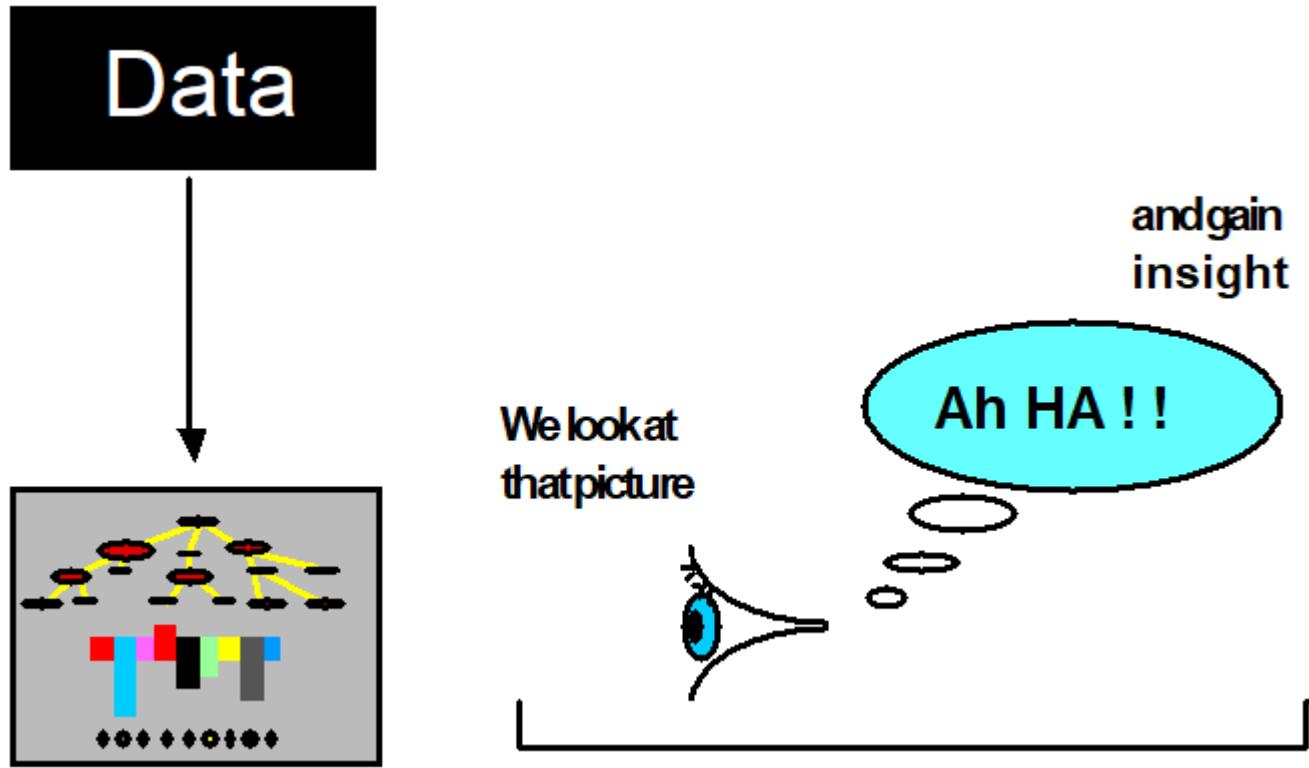
(*Kirk, 2012*)

# 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)

# Data and Information Visualization

- In general:

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

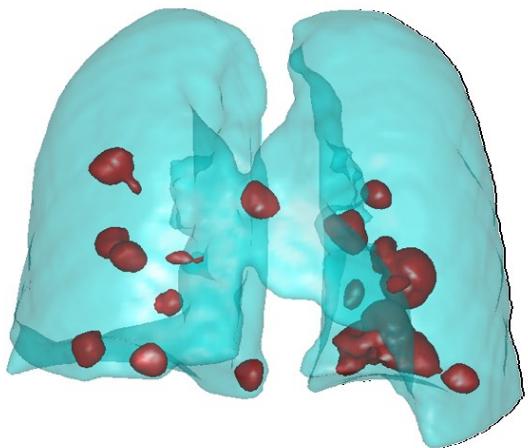
(e.g., CAT, MR, geophysical, meteorological, fluid dynamics data)

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

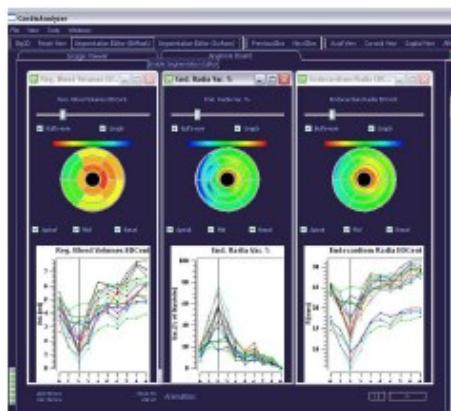
(e.g., stock exchange , S/W, Web usage patterns, text)

- 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 ...

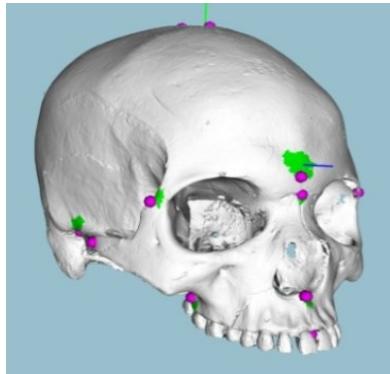
# Scientific Visualization (examples “made in UA”)



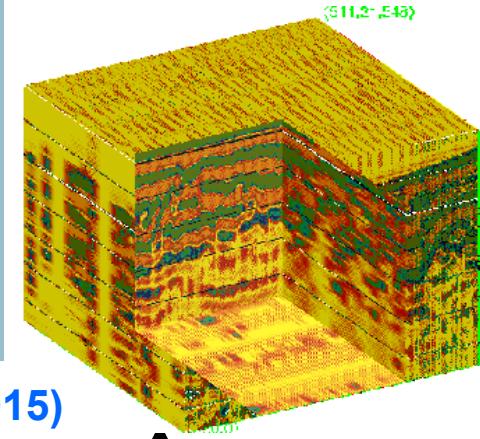
Tomography  
(2004)



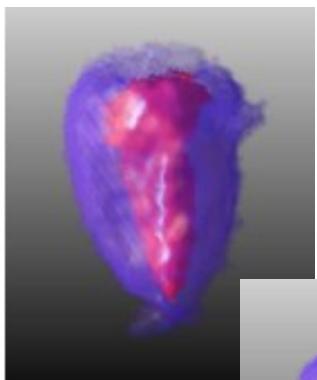
↑ Tomography (2011)



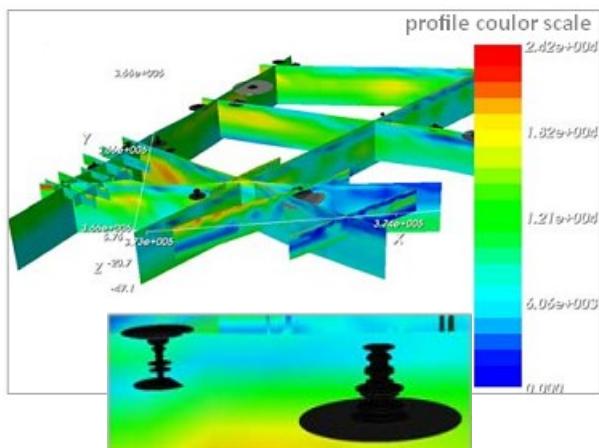
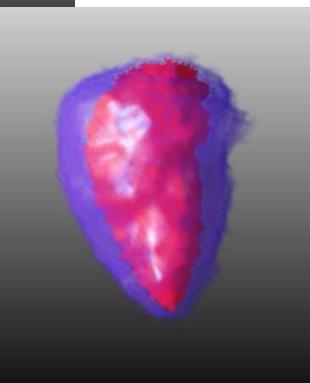
↑ Laser scanner (2015)



↑ Ground  
Penetrating Radar (1999)

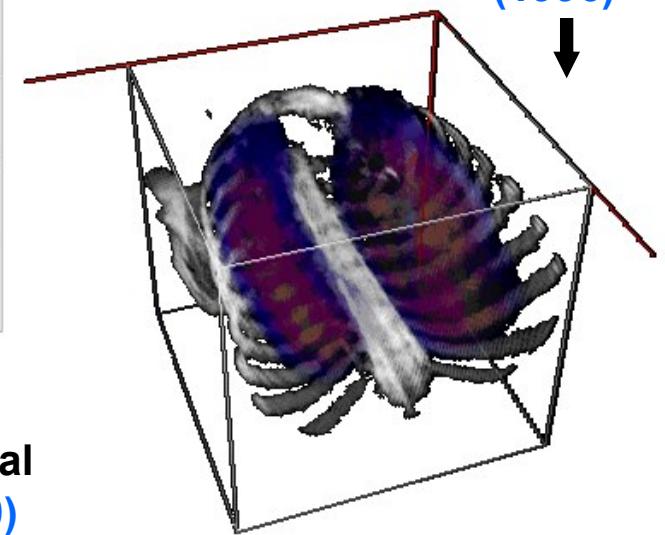


Tomography  
(2008)

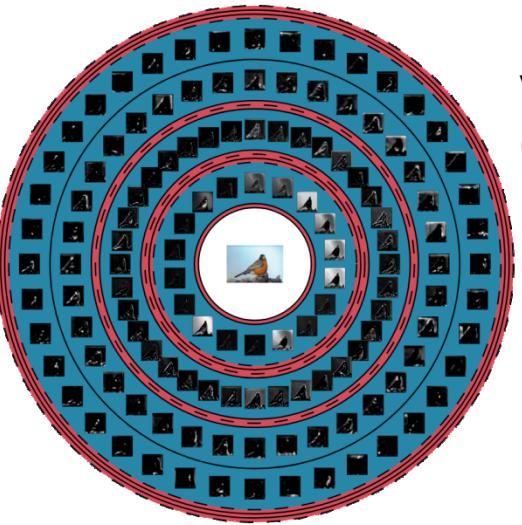


↑ Electrical and mechanical  
ground resistivity (2010)

Tomography and SPECT  
(1996)

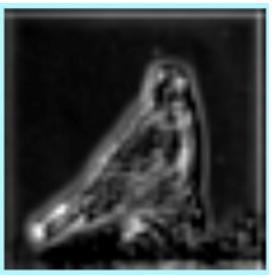


# Information Visualization (examples “made in UA”)

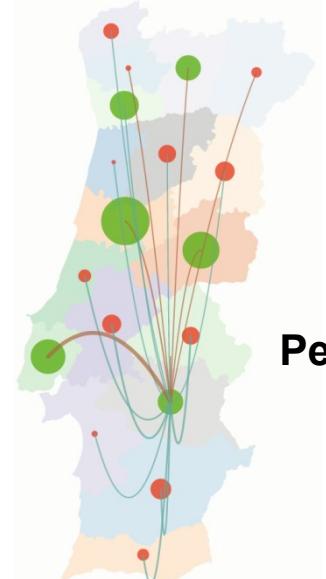


**Student Migrations**  
(UA, 2015)

**Machine Learning  
Visualization (XAI)  
(UA, 2020)**



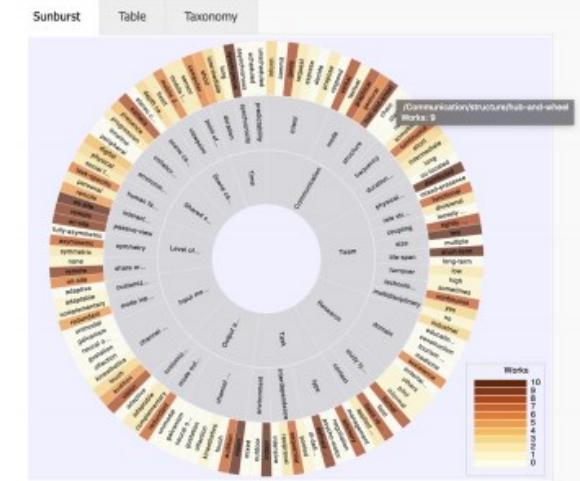
www.portugal-migration.info



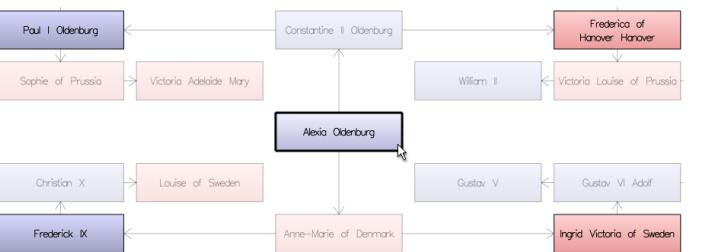
**Taxonomy Visualization**  
(UA, 2021)



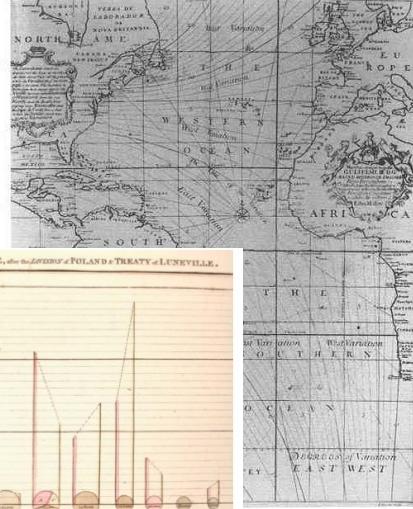
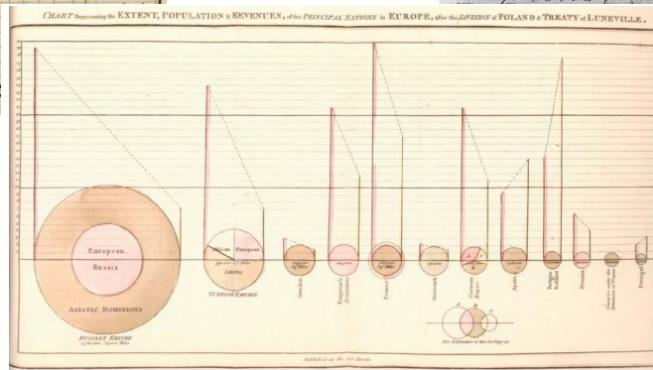
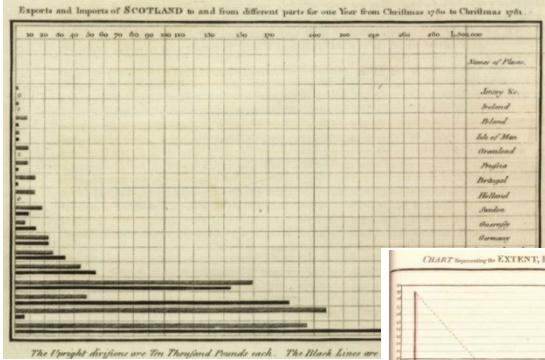
**Academic data  
(UA, 2020)**



**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

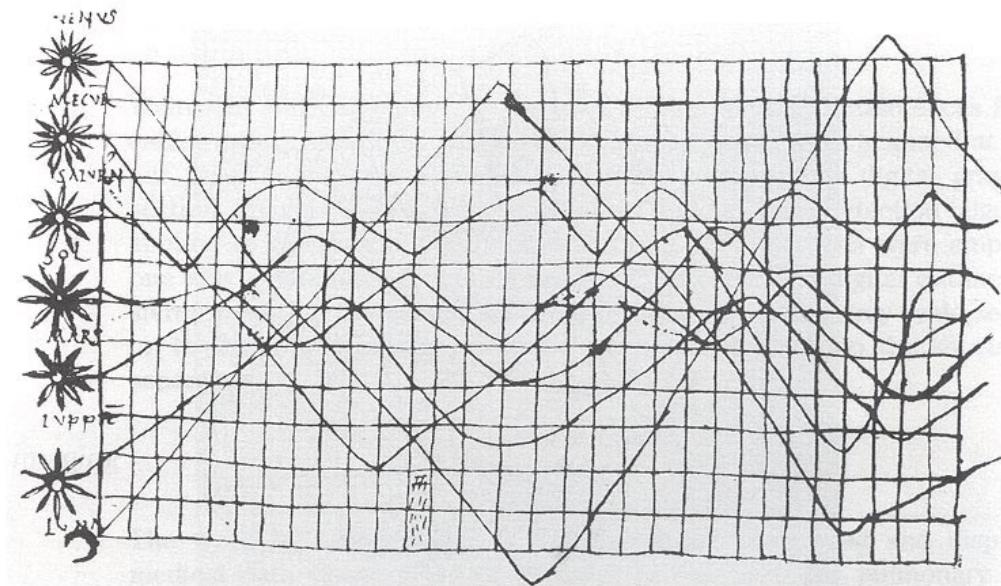
*Visualization in Scientific Computing*  
(McCormick, de Fanti and Brown – 1987)

# 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

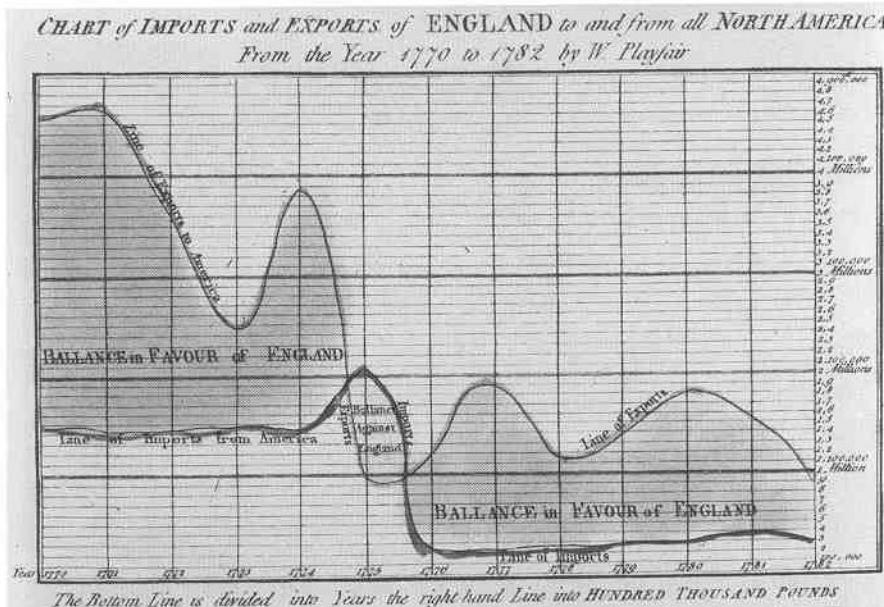
# “Pre-computer” Visualization:

One of the oldest known Visualizations



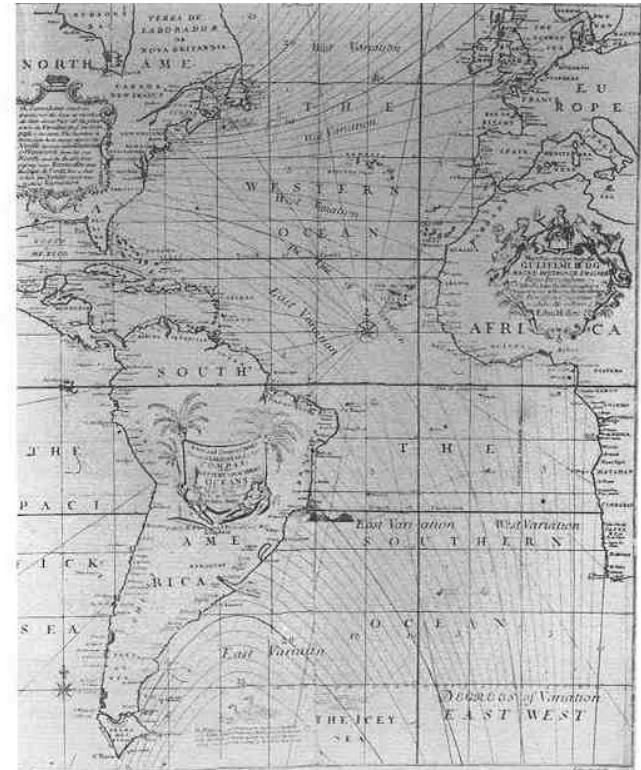
*Inclination of orbits along the time - Xth century (Tufte, 1983)*

# One of the first Visualizations used in “business”



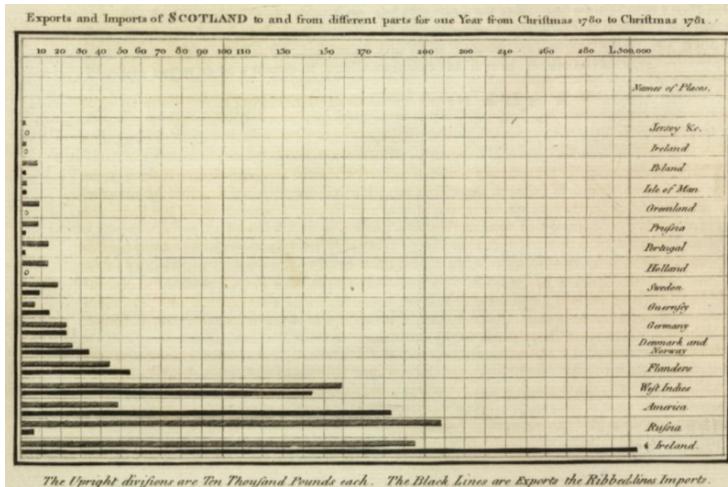
Import/export during the period from 1770 to 1782  
by William Playfair ([Tufte, 1983](#))

One of the first visualizations  
using contours (isolines)



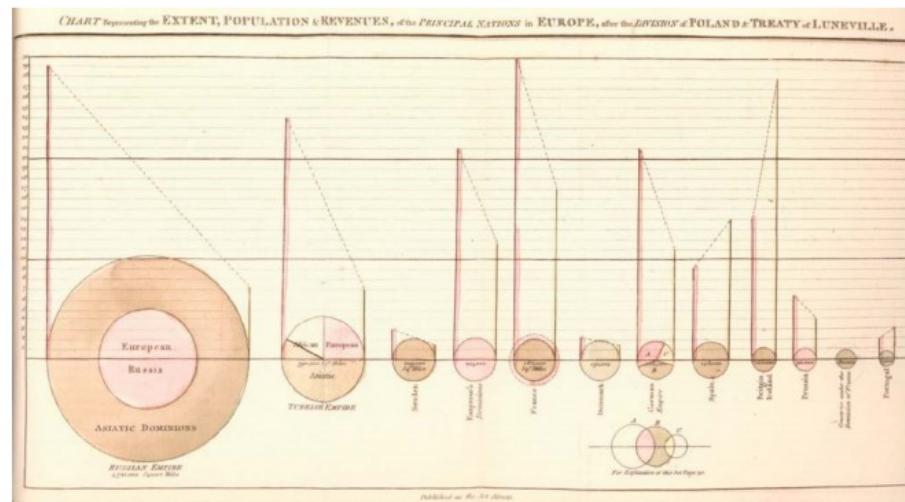
Magnetic declination 1701  
Edmund Halley ([Tufte, 1983](#))

# “Ancestors” of simple representations of univariate data

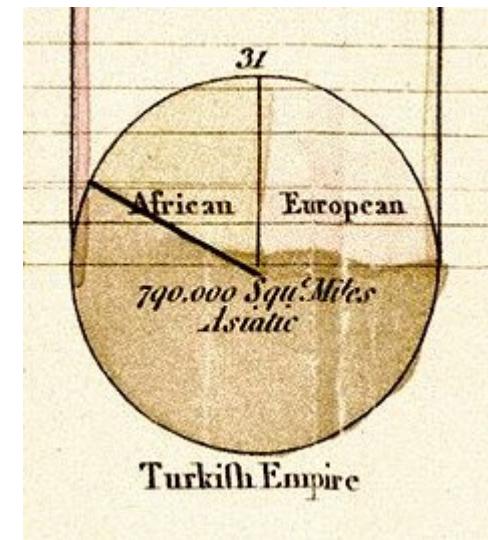


Exports and Imports of Scotland to and from different parts for one  
W. Playfair's *The Commercial and Political Atlas*, 1871

[https://en.wikipedia.org/wiki/William\\_Playfair](https://en.wikipedia.org/wiki/William_Playfair)

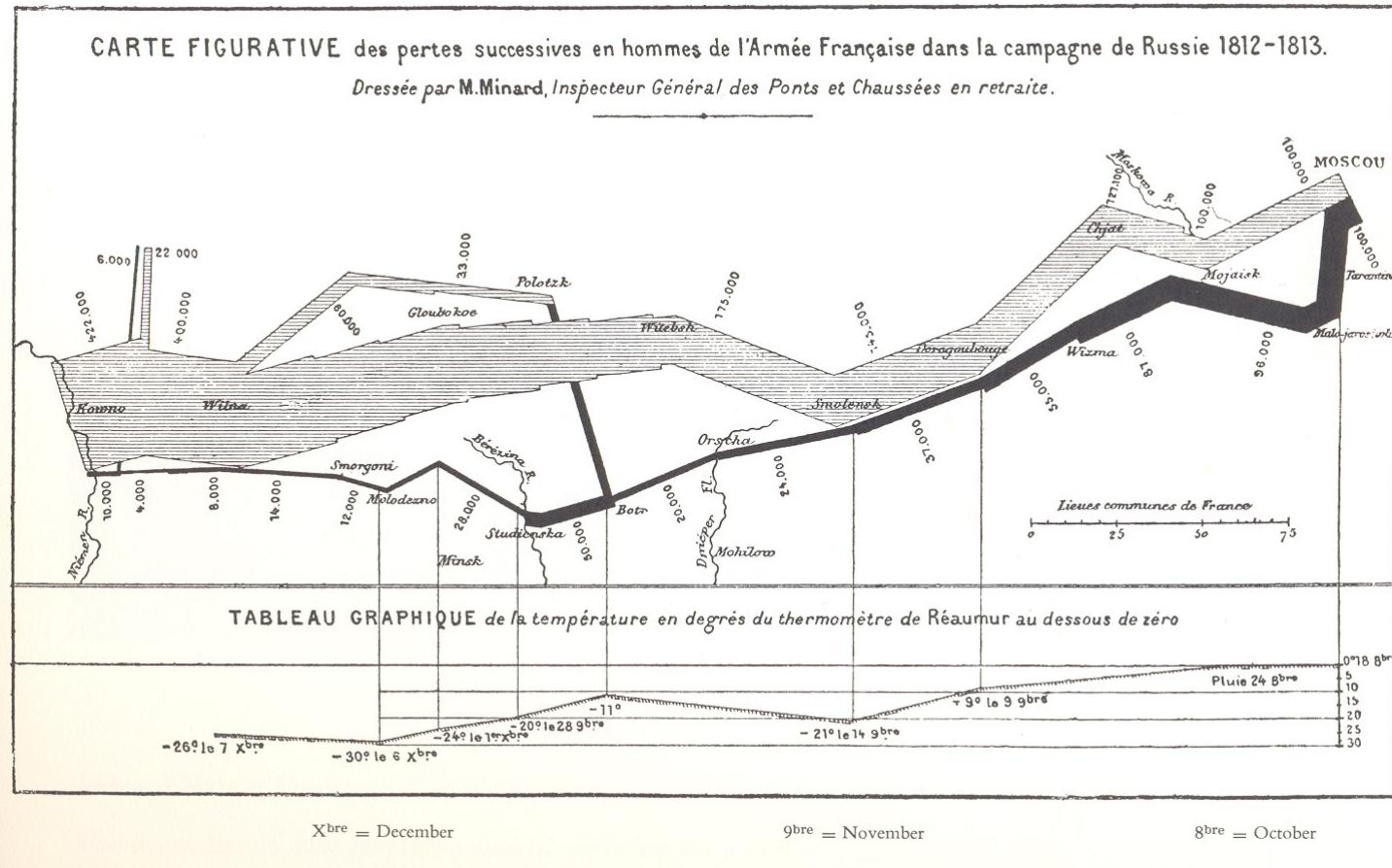


W. Playfair, *Statistical Breviary*, 1801



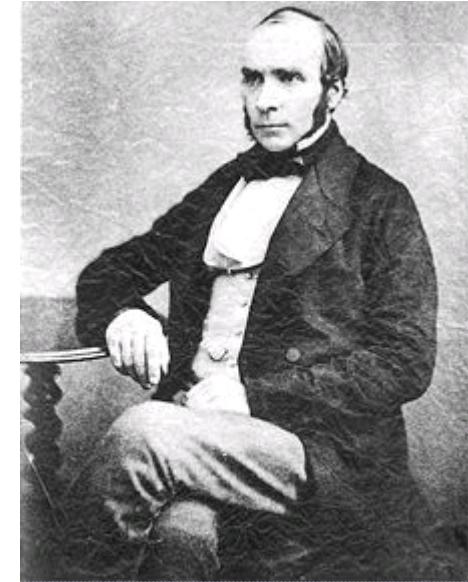
# Multidimensional Visualization

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



Russia campaign of Napoleon 1812 by Charles Minard (*Tufte, 1983*)

# Visualization in scientific discovery



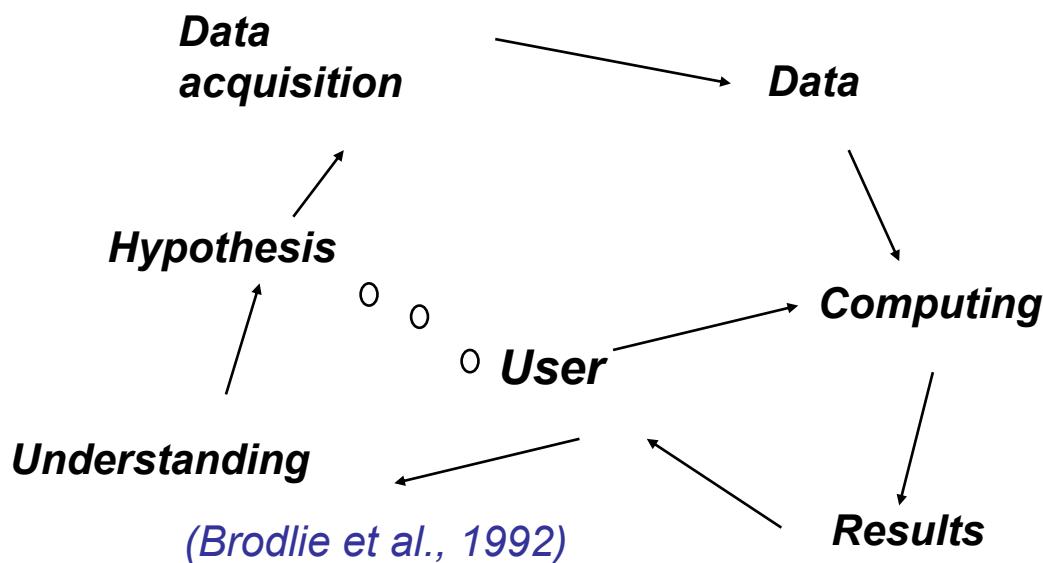
Dr. John Snow



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

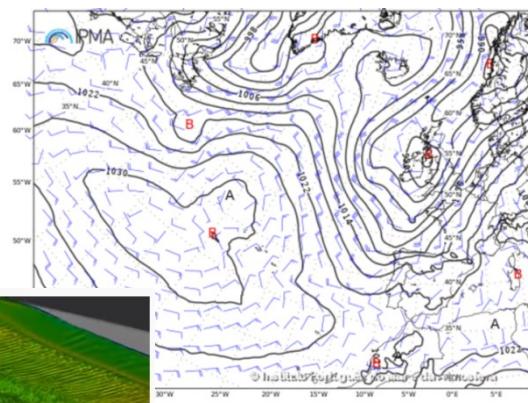
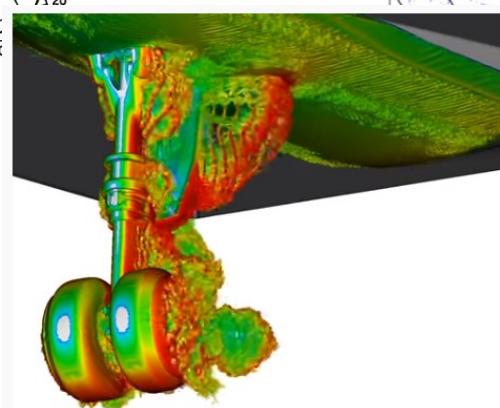
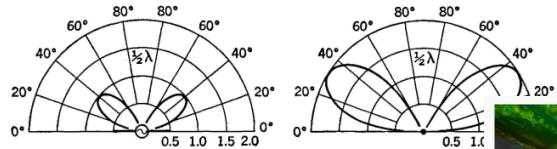
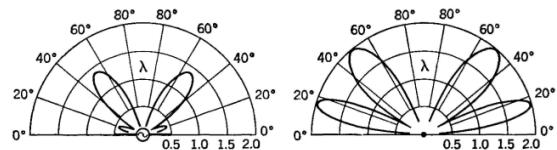
# Framework

- Visualization includes not only images/charts production from the data, but also their **transformation** and **manipulation** (if possible their acquisition)



- It is a “**human-in-the-loop**” problem

# Applications

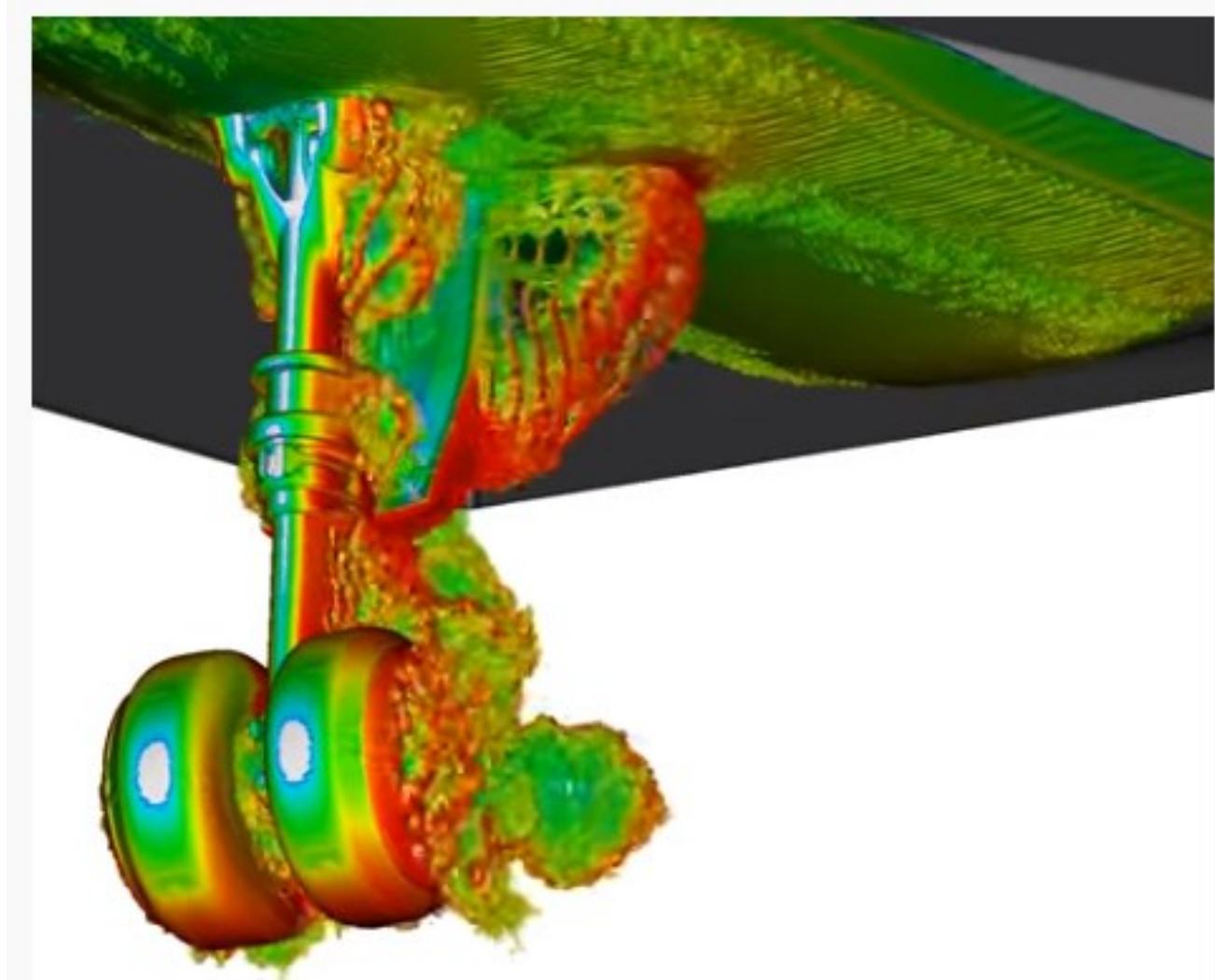


# Applications of Scientific Visualization

- **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?

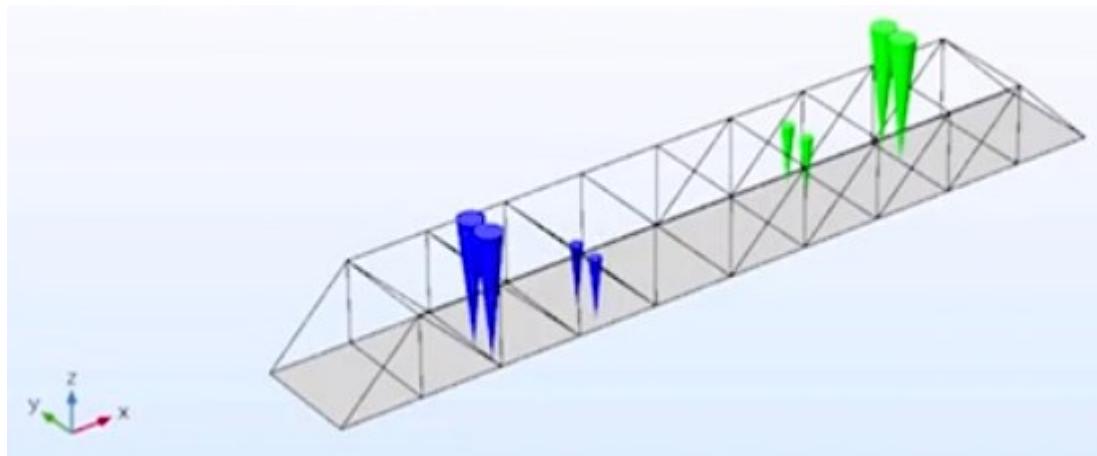
# Fluid mechanics visualization

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

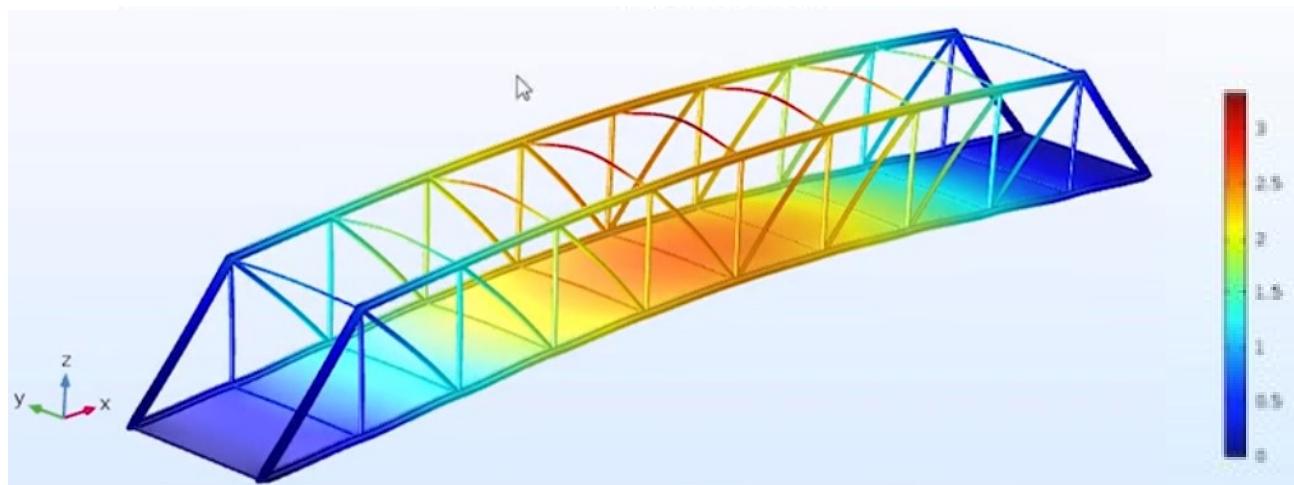


<https://www.youtube.com/watch?v=F9EFx7aQuhw>

# Civil engineering visualization

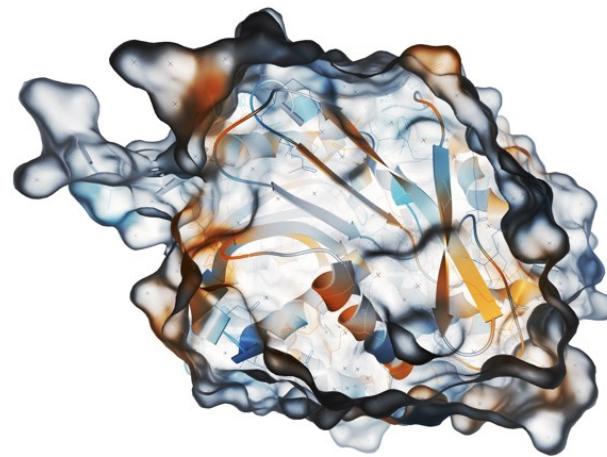
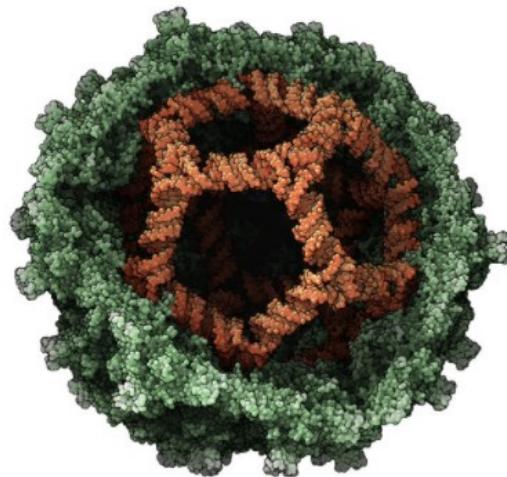
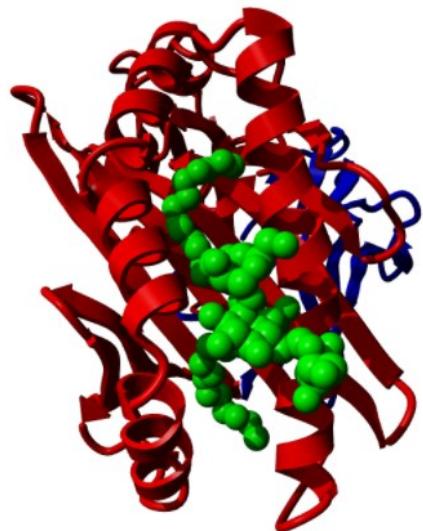
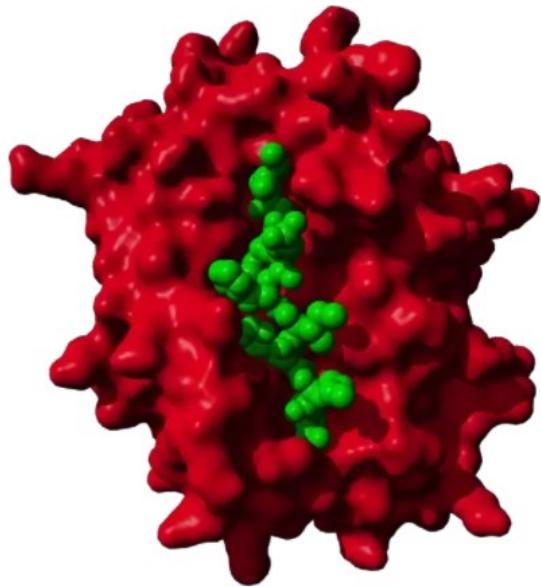


Bridge project:  
Visualizing Displacement, Force  
and Moment in Beams, Stress in  
Beams, and Stress in Roadway



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

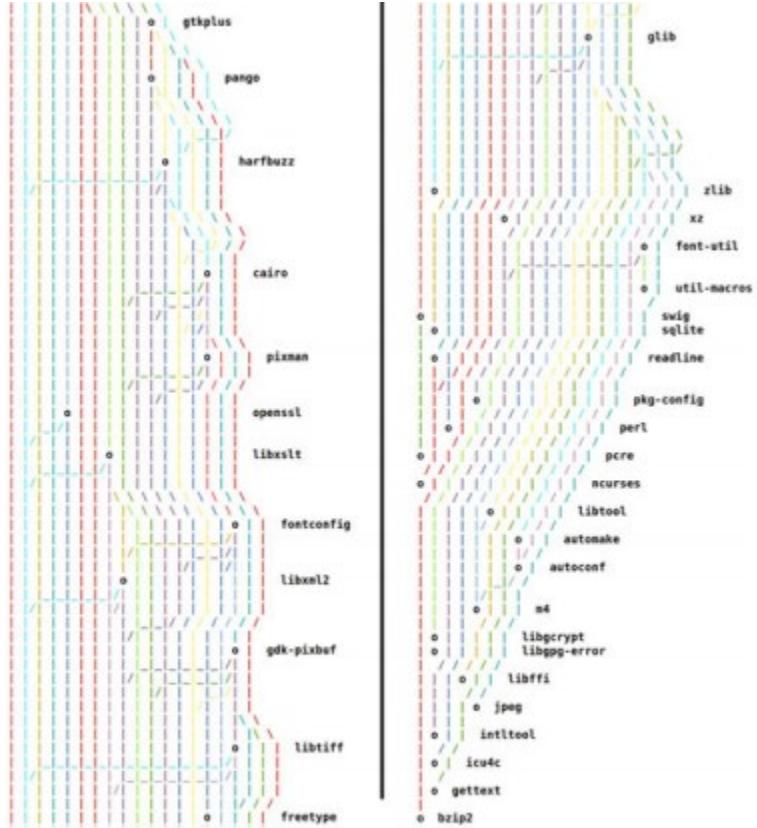
# Molecule visualization



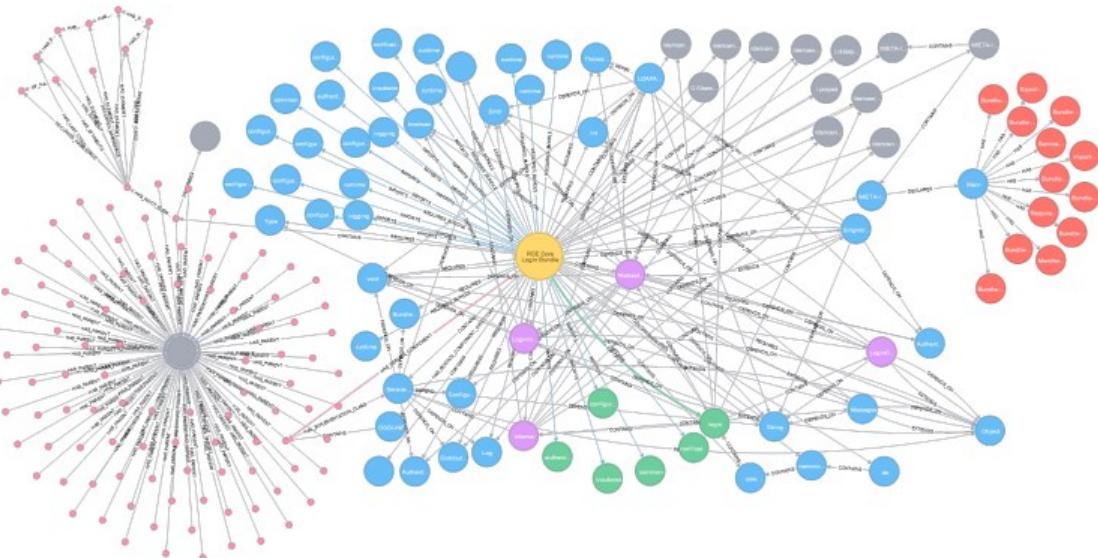
Design:  
Drugs  
Proteins  
Materials  
Nanosystems

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

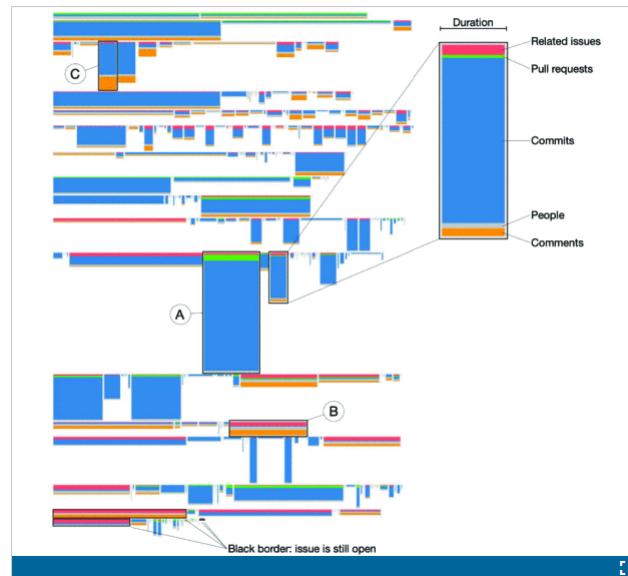
# Software visualization



<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>

Sorting

Training

array algorithm bubble select

Bitmask

Training

bit manipulation set cs3233 array

Hash Table

Training

open addressing linear quadratic

Binary Search Tree

Training

adelson velskii landis set table avl

Markdown

## Algorithm Visualizer

Algorithm Visualizer is an interactive online platform that visualizes algorithms from code.

contributors 23 license MIT

Learning an algorithm gets much easier with visualizing it. Don't get what we mean? Check it out:

[algorithm-visualizer.org](https://algorithm-visualizer.org/)

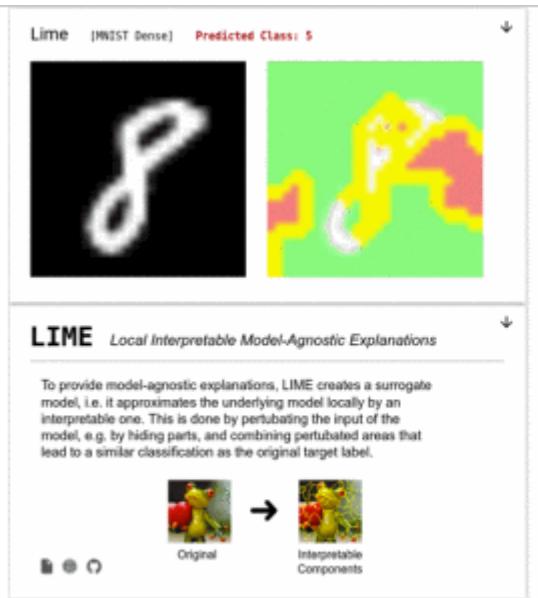
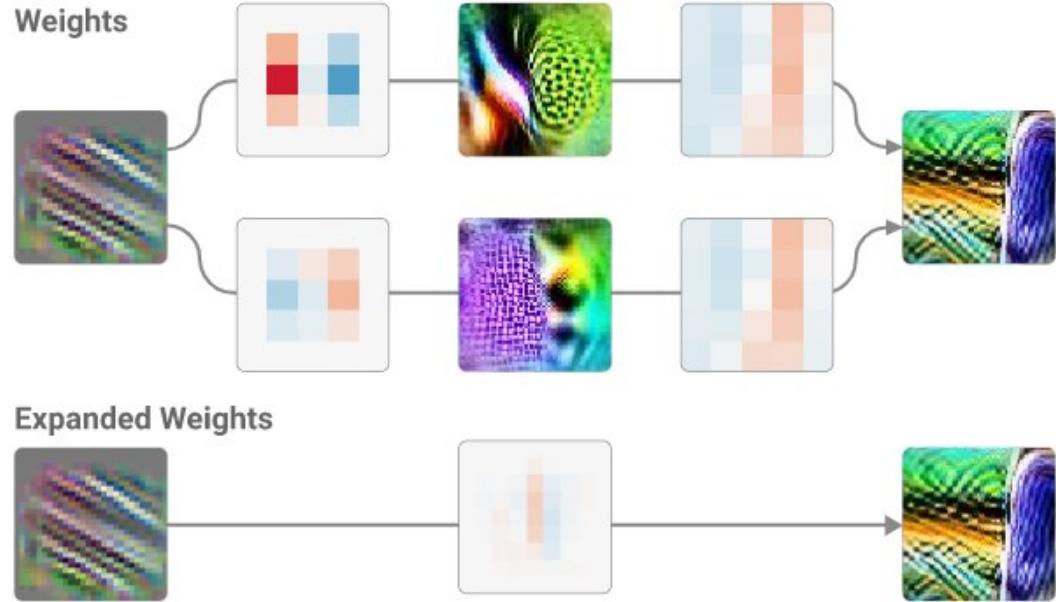
The screenshot shows the Algorithm Visualizer interface. At the top, there's a navigation bar with tabs for Home, Code, Results, Help, and Settings. Below the navigation is a search bar and a file menu. The main area has tabs for Sorting, Quicksort, and Insertion Sort. On the left, there's a sidebar with categories like Backtracking, Dynamic Programming, Depth First Search, Breadth First Search, Minimum Spanning Tree, Number Theory, Search, and various Sorts. In the center, there are three visualizers: a histogram titled 'ArrayTracer' showing data distribution, a truth table for 'AND' titled 'BitmaskTracer', and a tree diagram titled 'LegTracer'. To the right, there's a code editor with syntax highlighting for Python, showing code for quicksort and insertion sort. The bottom right corner includes links for GitHub, LinkedIn, and YouTube.

```
1 import java.util.TreeSet; import java.util.List; import java.util.ArrayList; import java.util.*; 2 3 class charTree { 4     char[] chars; 5     charTree[] children; 6     int count; 7     public charTree(char c) { 8         chars = new char[1]; 9         children = new charTree[1];10         chars[0] = c;11         count = 1;12     }13     public void insert(char c) {14         if (c == chars[0]) {15             count++;16         }17         else {18             if (children[0] == null) {19                 children[0] = new charTree(c);20             }21             else {22                 children[0].insert(c);23             }24         }25     }26     public void print() {27         System.out.print(chars[0]);28         for (charTree child : children) {29             child.print();30         }31     }32     public void printCount() {33         System.out.print(chars[0]);34         for (charTree child : children) {35             child.printCount();36         }37     }38     public void printCount2() {39         System.out.print(chars[0]);40         for (charTree child : children) {41             child.printCount2();42         }43     }44     public void printCount3() {45         System.out.print(chars[0]);46         for (charTree child : children) {47             child.printCount3();48         }49     }50     public void printCount4() {51         System.out.print(chars[0]);52         for (charTree child : children) {53             child.printCount4();54         }55     }56     public void printCount5() {57         System.out.print(chars[0]);58         for (charTree child : children) {59             child.printCount5();60         }61     }62     public void printCount6() {63         System.out.print(chars[0]);64         for (charTree child : children) {65             child.printCount6();66         }67     }68     public void printCount7() {69         System.out.print(chars[0]);70         for (charTree child : children) {71             child.printCount7();72         }73     }74     public void printCount8() {75         System.out.print(chars[0]);76         for (charTree child : children) {77             child.printCount8();78         }79     }80     public void printCount9() {81         System.out.print(chars[0]);82         for (charTree child : children) {83             child.printCount9();84         }85     }86     public void printCount10() {87         System.out.print(chars[0]);88         for (charTree child : children) {89             child.printCount10();90         }91     }92     public void printCount11() {93         System.out.print(chars[0]);94         for (charTree child : children) {95             child.printCount11();96         }97     }98     public void printCount12() {99         System.out.print(chars[0]);100        for (charTree child : children) {101            child.printCount12();102        }103    }104    public void printCount13() {105        System.out.print(chars[0]);106        for (charTree child : children) {107            child.printCount13();108        }109    }110    public void printCount14() {111        System.out.print(chars[0]);112        for (charTree child : children) {113            child.printCount14();114        }115    }116    public void printCount15() {117        System.out.print(chars[0]);118        for (charTree child : children) {119            child.printCount15();120        }121    }122    public void printCount16() {123        System.out.print(chars[0]);124        for (charTree child : children) {125            child.printCount16();126        }127    }128    public void printCount17() {129        System.out.print(chars[0]);130        for (charTree child : children) {131            child.printCount17();132        }133    }134    public void printCount18() {135        System.out.print(chars[0]);136        for (charTree child : children) {137            child.printCount18();138        }139    }140    public void printCount19() {141        System.out.print(chars[0]);142        for (charTree child : children) {143            child.printCount19();144        }145    }146    public void printCount20() {147        System.out.print(chars[0]);148        for (charTree child : children) {149            child.printCount20();150        }151    }152    public void printCount21() {153        System.out.print(chars[0]);154        for (charTree child : children) {155            child.printCount21();156        }157    }158    public void printCount22() {159        System.out.print(chars[0]);160        for (charTree child : children) {161            child.printCount22();162        }163    }164    public void printCount23() {165        System.out.print(chars[0]);166        for (charTree child : children) {167            child.printCount23();168        }169    }170    public void printCount24() {171        System.out.print(chars[0]);172        for (charTree child : children) {173            child.printCount24();174        }175    }176    public void printCount25() {177        System.out.print(chars[0]);178        for (charTree child : children) {179            child.printCount25();180        }181    }182    public void printCount26() {183        System.out.print(chars[0]);184        for (charTree child : children) {185            child.printCount26();186        }187    }188    public void printCount27() {189        System.out.print(chars[0]);190        for (charTree child : children) {191            child.printCount27();192        }193    }194    public void printCount28() {195        System.out.print(chars[0]);196        for (charTree child : children) {197            child.printCount28();198        }199    }199 }
```

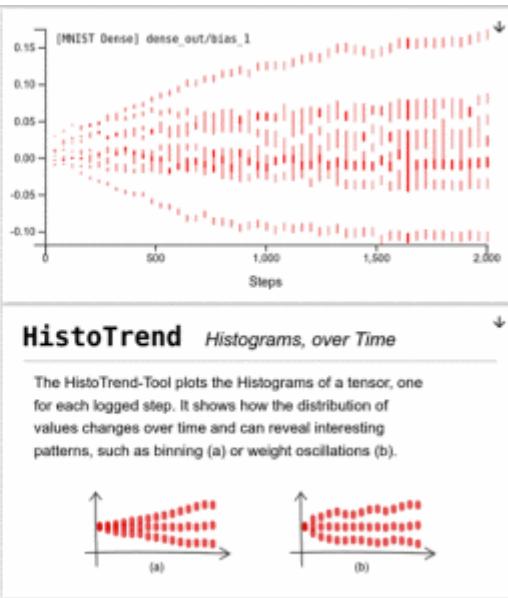
<https://algorithm-visualizer.org/>

# 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)

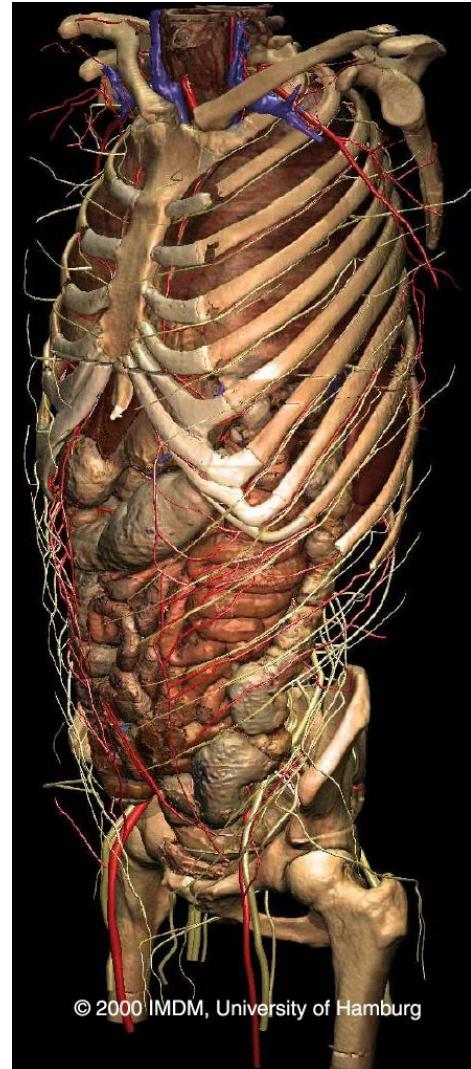
- Human anatomy
- using volume rendering
- VOXELman (University of Hamburg)
- Visible Human project  
(National Library of Medicine-USA)

<https://www.visiblebody.com/>

[http://www.voxel-man.de/3d-navigator/inner\\_organs/](http://www.voxel-man.de/3d-navigator/inner_organs/)

[http://www.nlm.nih.gov/research/visible/visible\\_human.html](http://www.nlm.nih.gov/research/visible/visible_human.html)

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

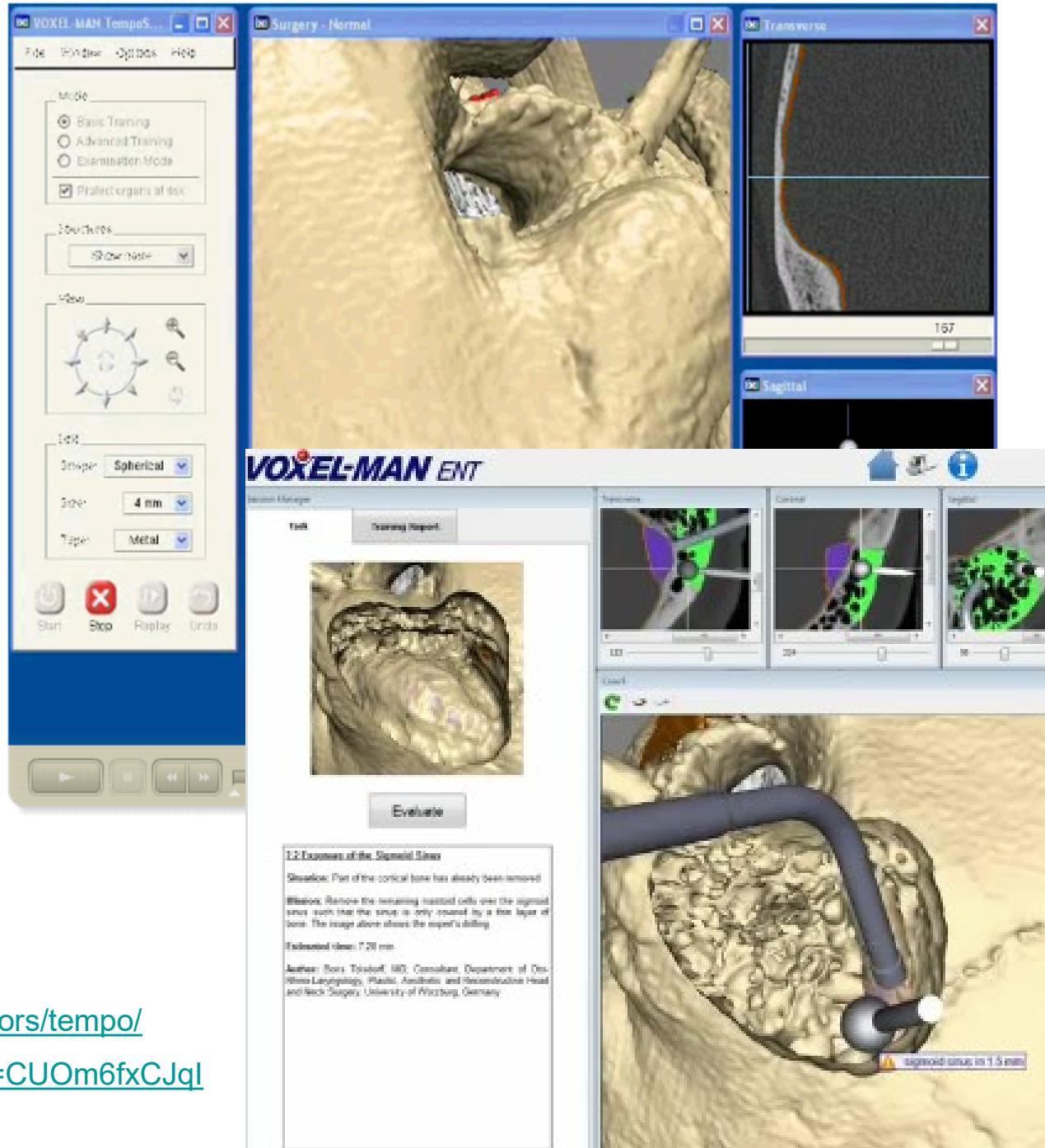


© 2000 IMDM, University of Hamburg

# 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>

# Dentistry (e.g. training)

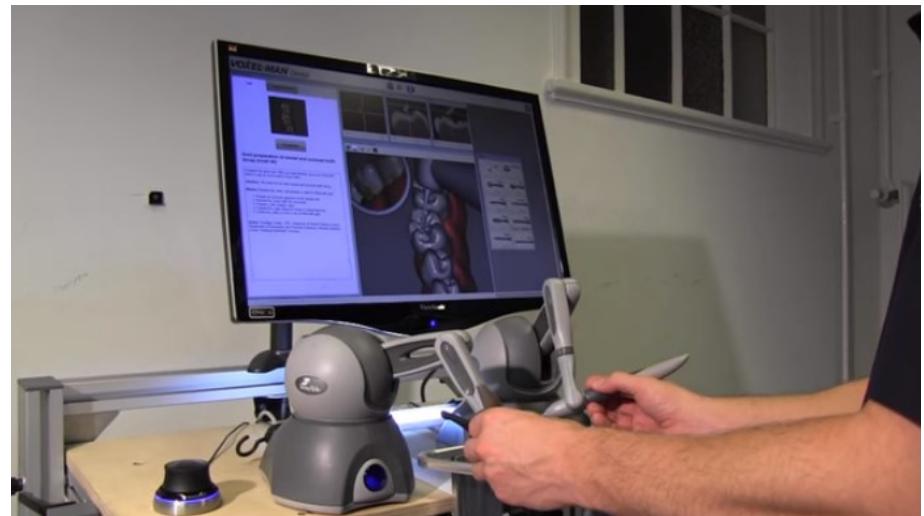


Stereoscopic display + glasses

Interaction devices:

- two force feedback devices
- foot pedal

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



[https://www.youtube.com/watch?v=CB\\_vdW6K42o](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.

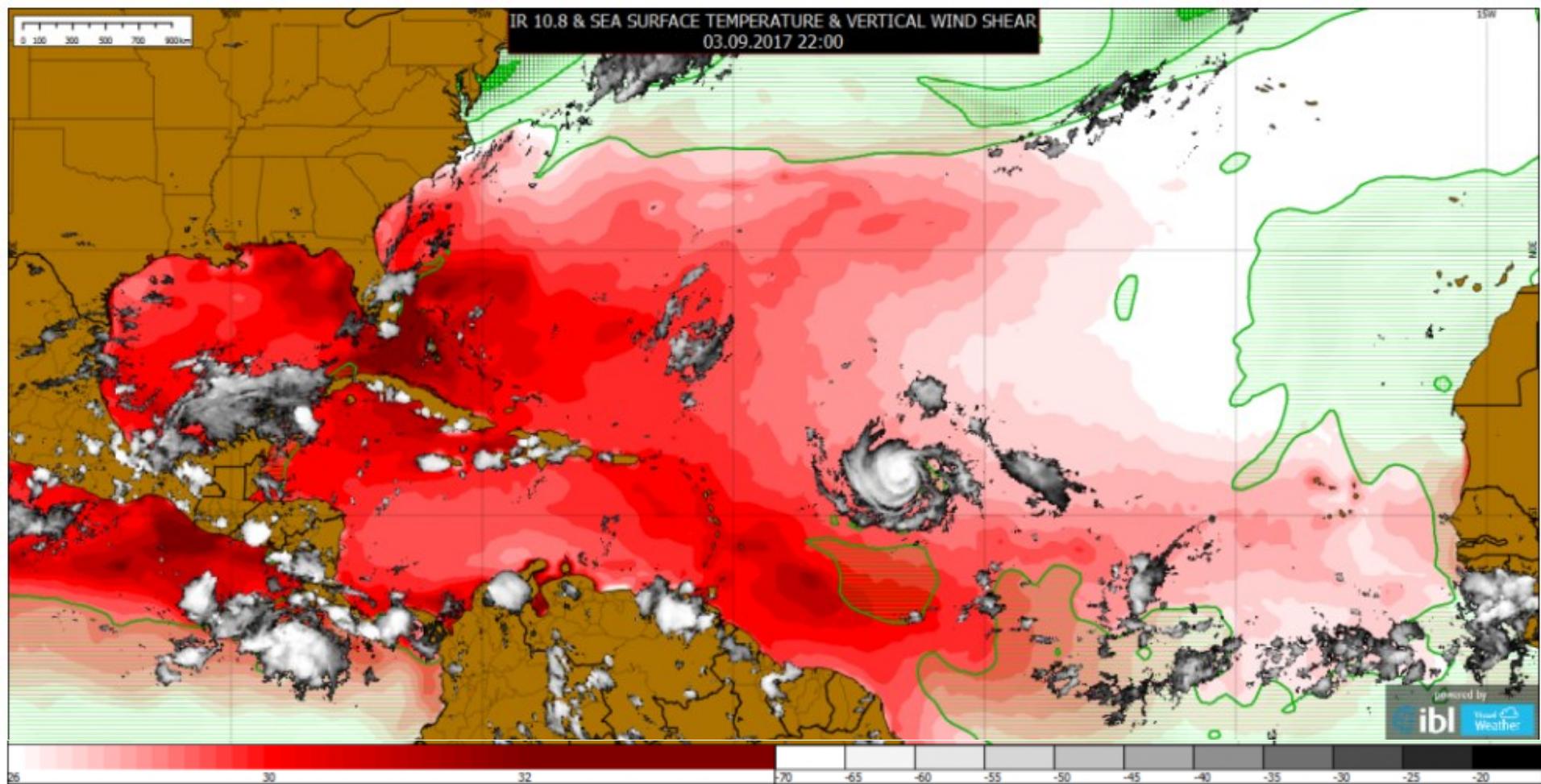
Have been applied to a wide range of educational, diagnostic, treatment planning, virtual reality, artistic, mathematical, and industrial uses.

About 4,000 licensees from 66 countries

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



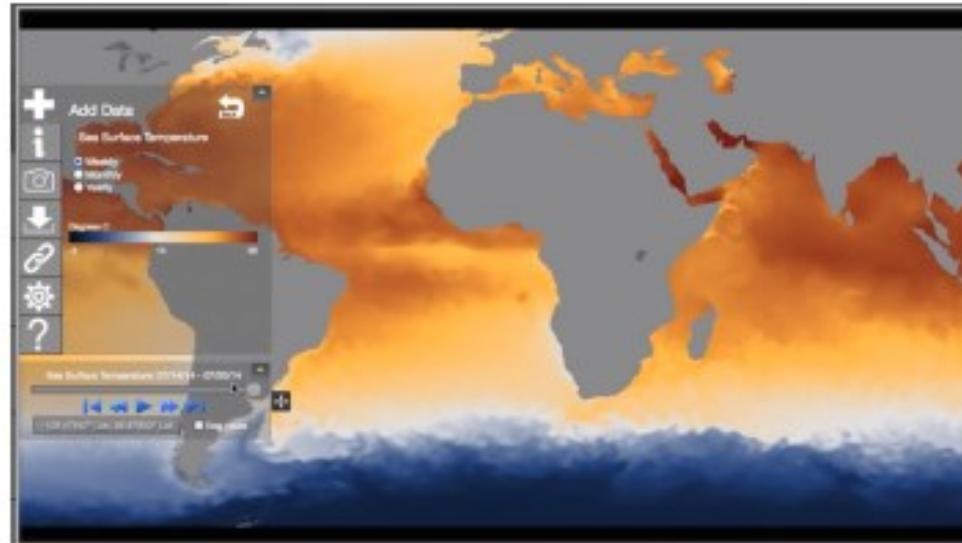
# Meteorology and oceanography



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

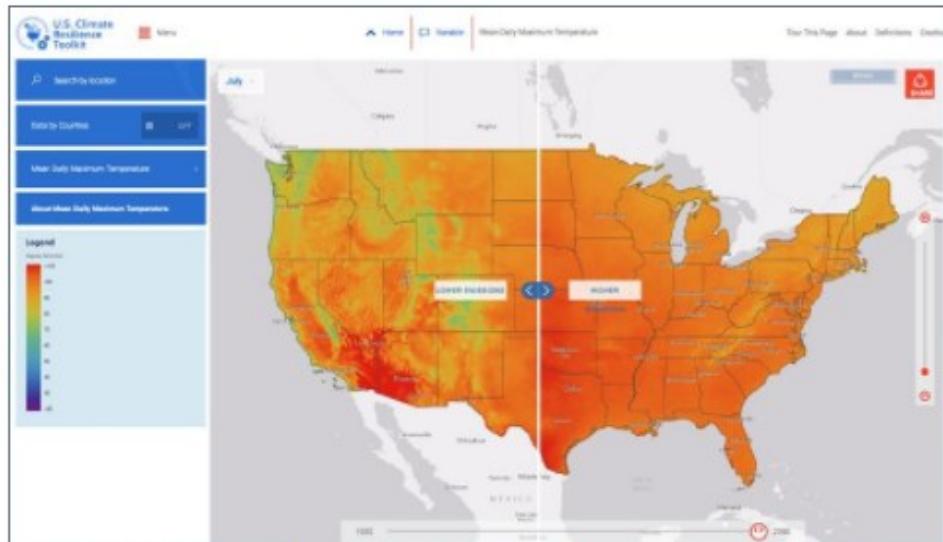
# Climate research (by NOAA)

- 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



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

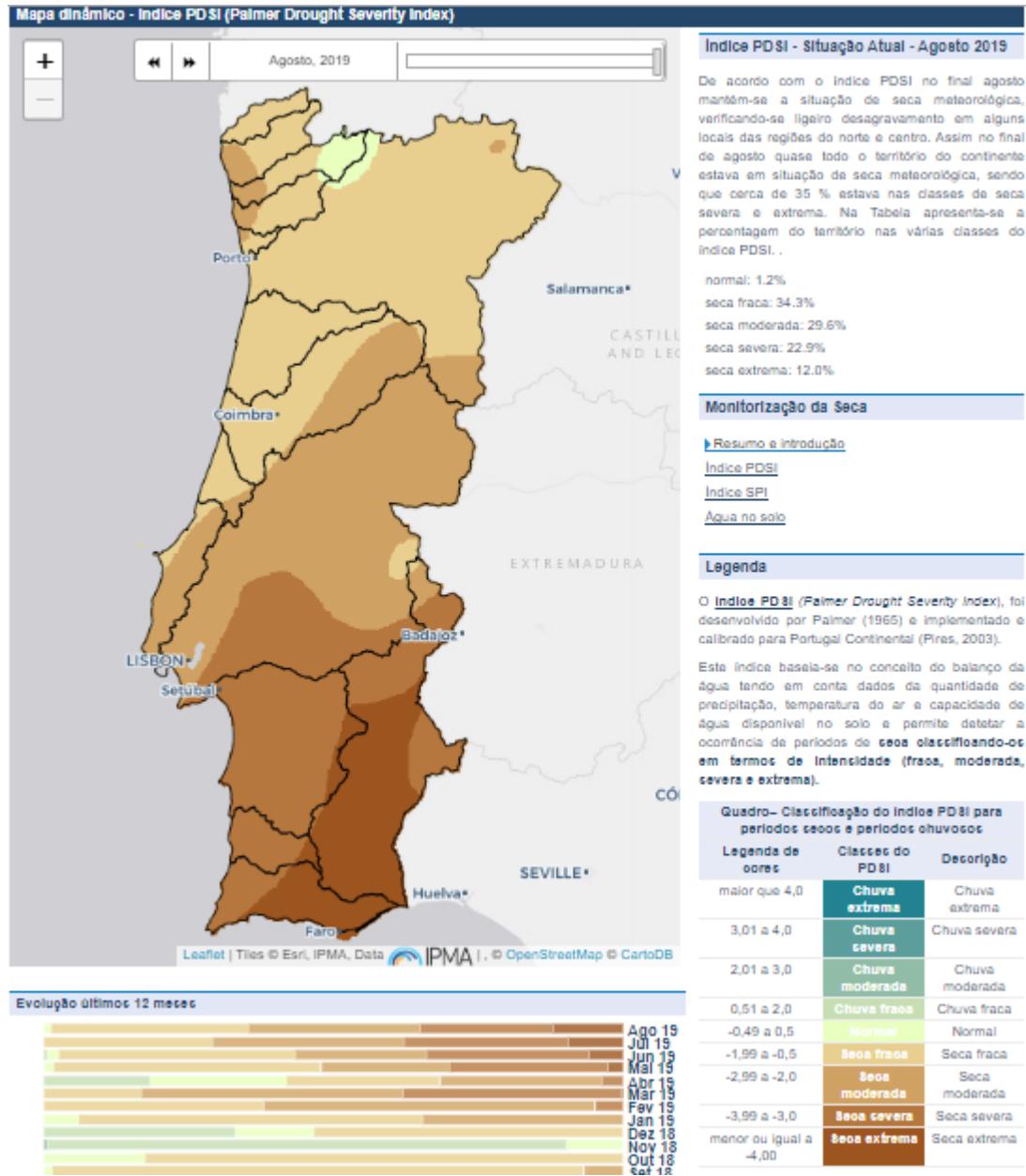
- The tool shows projected conditions for two possible futures:
  - one in which humans make a moderate attempt to reduce global emissions of heat-trapping gases,
  - one in which we go on conducting business as usual.



View by Variable interface. [View Maximum Daily Temperature variable in Climate Explorer](#).

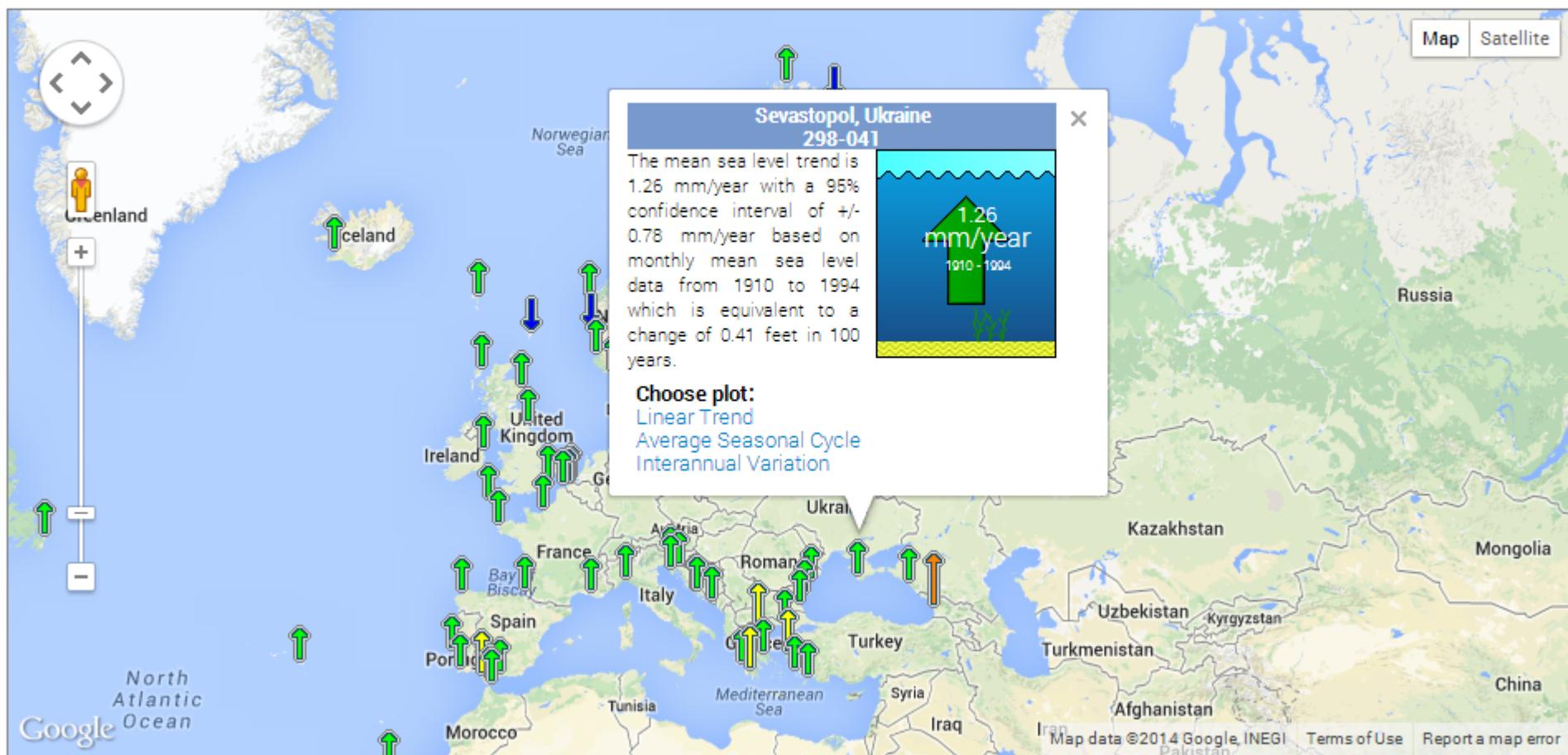
<https://toolkit.climate.gov/tools/climate-explorer>

# Example in Climate monitoring: Drought Severity Index (by IPMA)



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

# Sea Level Trends

[East Coast](#)[West Coast](#)[Gulf Coast](#)[Alaska](#)[Hawaii](#)[Global](#)[View in Google Earth](#)[Map](#) [Satellite](#)

The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

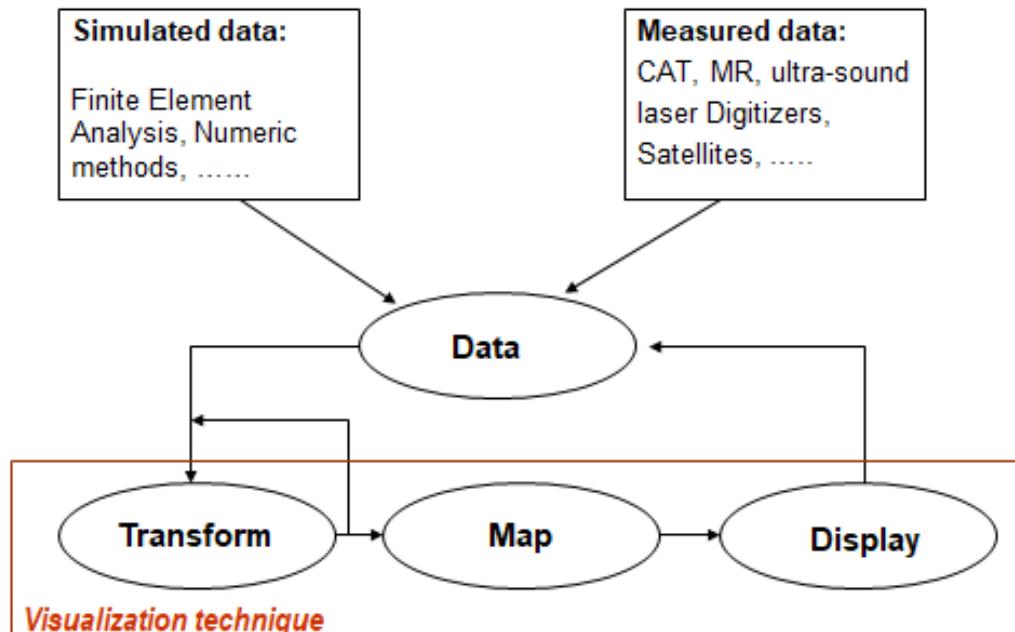
## Sea Level Trends mm/yr (feet/century)

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/sltslrends/regionalcomparison.html?region=GNEATL>

- “***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

# Scientific Visualization reference model



(adapted from Schroeder et al., 2006)

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

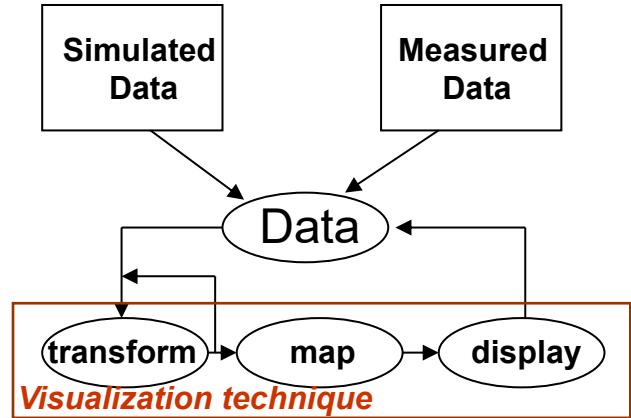


The user should get insights from the visualization



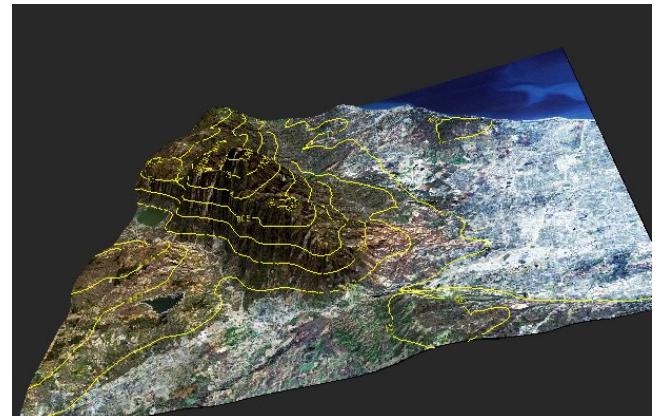
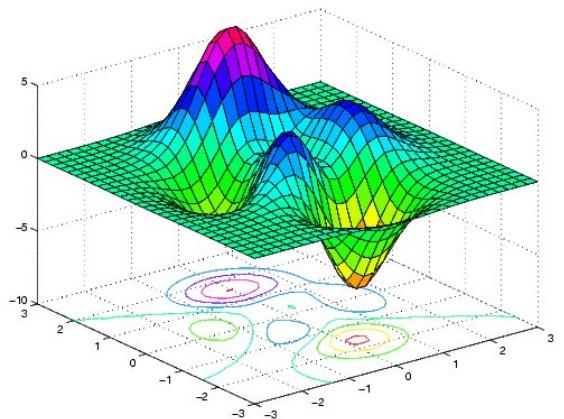
- Data can be

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



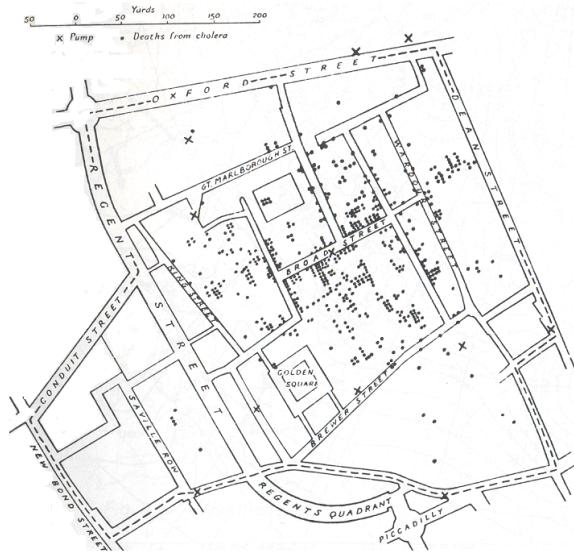
- Then a **visualization technique** is applied, involving:
  - data **transformation** through several methods
    - (e.g. scale transformation, noise filtering, outlier elimination, changing resolution, etc.)
  - **mapping** to an adequate form to represent data visually
    - (e.g. lines, points, 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)

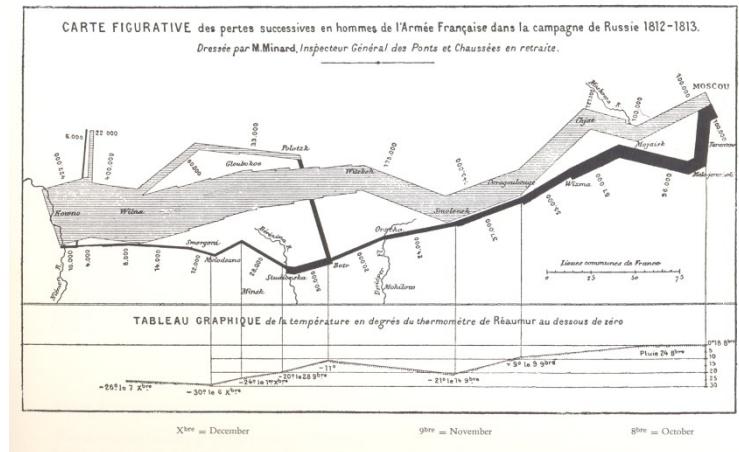


- Visualization may be used with different purposes:
  - personal exploration
  - discussion with colleagues
  - presentation to other people

a)



b)



Classical examples for:

- exploration
- presentation

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 °C):

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?

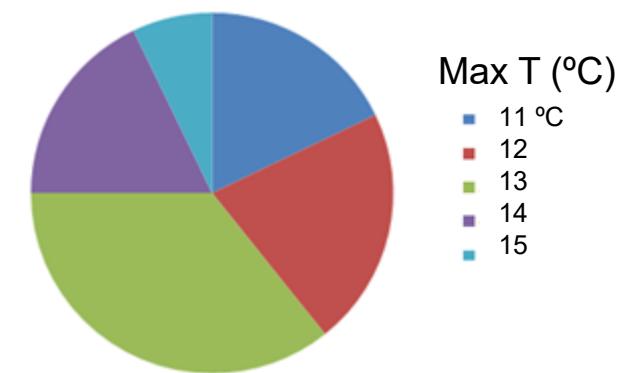
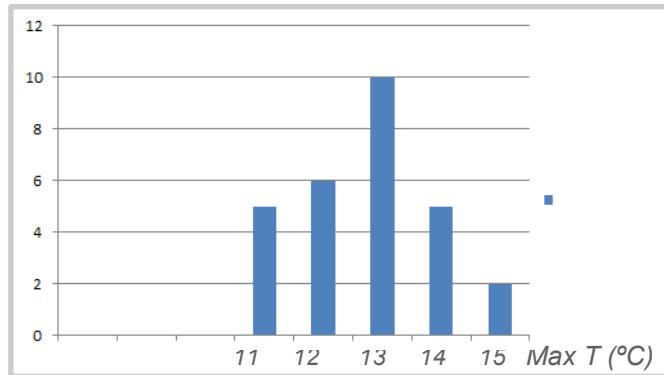
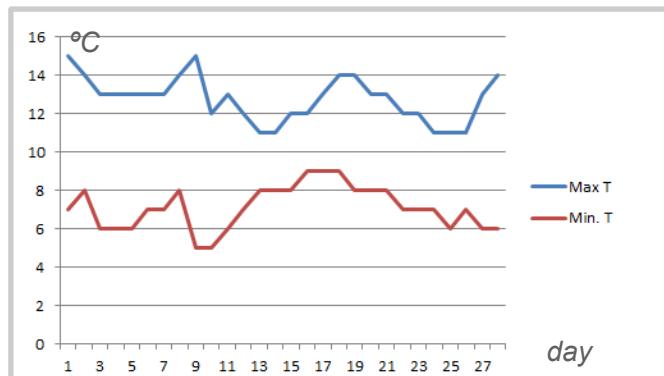
- What type of chart would you use to answer Q1?

- And the other questions?

# Example: how to select simple charts?

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

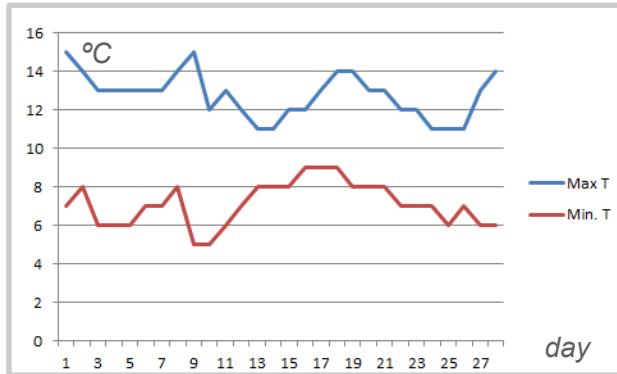
day	Max T	Min. T
1	15	7
2	14	8
3	13	6
4	13	6
5	12	6
6	13	7
7	13	7
8	14	8
9	15	5
10	12	5
11	13	6
12	12	7
13	11	8
14	11	8
15	12	8
16	12	9
17	13	9
18	14	9
19	14	8
20	13	8
21	13	8
22	12	7
23	12	7
24	11	7
25	11	6
26	11	7
27	13	6
28	14	6



# Simple example

Temperatures along the month of February (in °C):

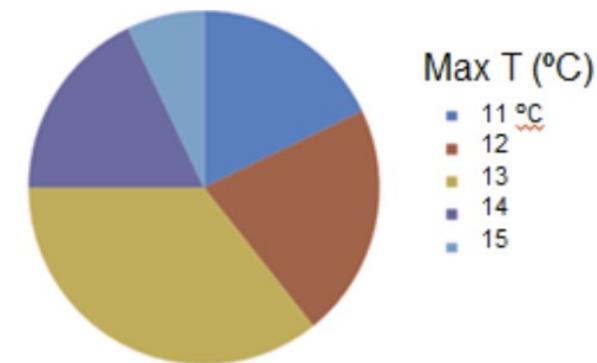
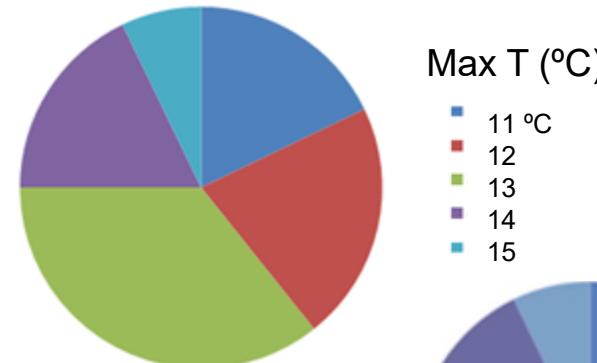
Anything “odd” about this chart?



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

# Bibliography

- Munzner, T., *Visualization Analysis and Design*, A K Peters/CRC Press, 2014
- Kirk, A., *Data Visualisation: A Handbook for Data Driven Design*, 2nd. Ed., Sage, 2019
- Kirk, A., *Data Visualization : a successful design process*. Packt Publishing., 2012
- Spence, R., *Information Visualization, Design for Interaction*, Prentice Hall, 2007
- Tufte, E., *The Visual Display of Quantitative Information*, Graphics Press, 1983
- Tufte, E., *Envisioning Information*, Graphics Press, 1990
- Friendly, M., "Milestones in the history of thematic cartography, statistical graphics, and data visualization", 2008

Images of the 1rst slide:

B. Marques, S. Silva, J. Alves, T. Araújo, P. Dias, B. Sousa Santos, “A conceptual model and taxonomy for collaborative Augmented Reality”, *IEEE Transactions on Visualization and Computer Graphics*, 2021.

V. Gonçalves, P. Dias, M. J. Fontoura, R. Moura, and B. Sousa Santos, “Investigating landfill contamination by visualizing geophysical data.,” *IEEE Comput. Graph. Appl.*, vol. 34, no. 1, pp. 16–21, 2015.

S. Silva, B. Sousa Santos, J. Madeira, “Exploring different parameters to assess left ventricle global and regional functional analysis from coronary CT angiography”. *Computer Graphics Forum*, vol. 31, n. 1, 146–159, 2012.