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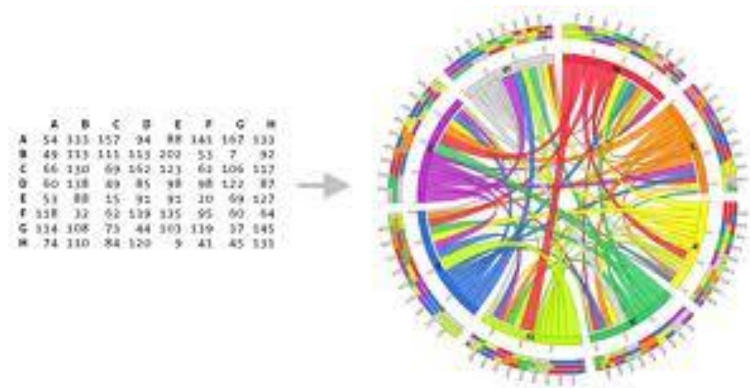
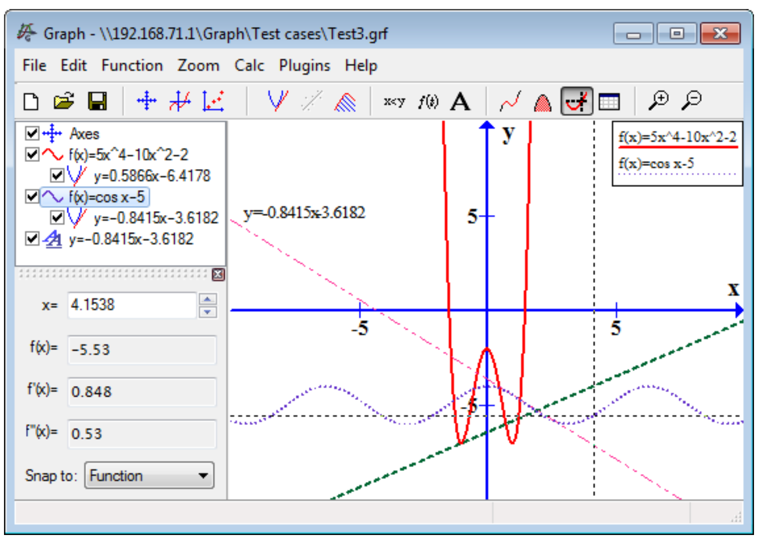
axblog4u.wordpress.com

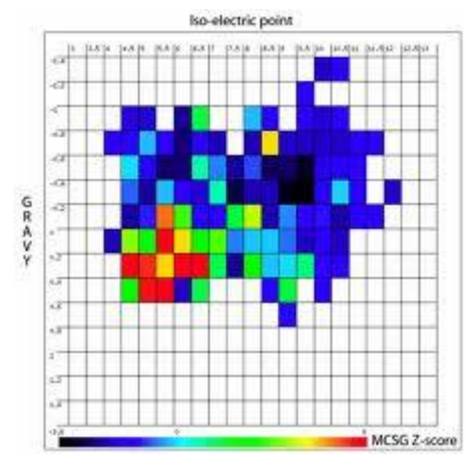


mkweb.bcgsc.ca

2. Input data characteristics



www.padowan.dk



technology.sbkb.org

Process of data visualization

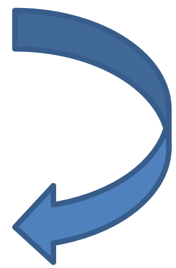
- Generating data
  - Measuring, simulation, modeling
    - Can be lengthy (measuring, simulation) and costly (simulation, modeling)
- Visualization (the rest of the visualization pipeline)
  - Visual mapping, rendering
    - Can be fast or slow, depending on hardware and implementation
- Interaction (user feedback)
  - How the user can interact with the visualization

Passive visualization

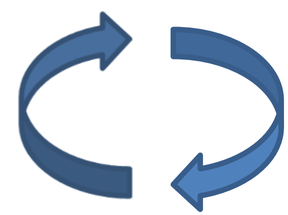
- The following three steps are strictly separated
  - Generating data – after finishing this phase
  - Off-line visualization
    - Displaying the generated data
    - Result is a video or animation
  - Passive visualization
    - Exploration of the results of the previous phase

Interactive visualization

- Here only the generating data phase is separated
  - Off-line data generation



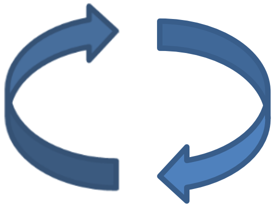
  - Interactive visualization
    - Generated data is available for interactive visualization



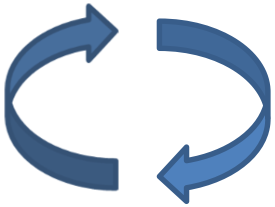
    - Options: selection, parametrization of visualization
    - Currently very popular technique

Interactive steering

- All three steps are connected
  - Generating data on the fly

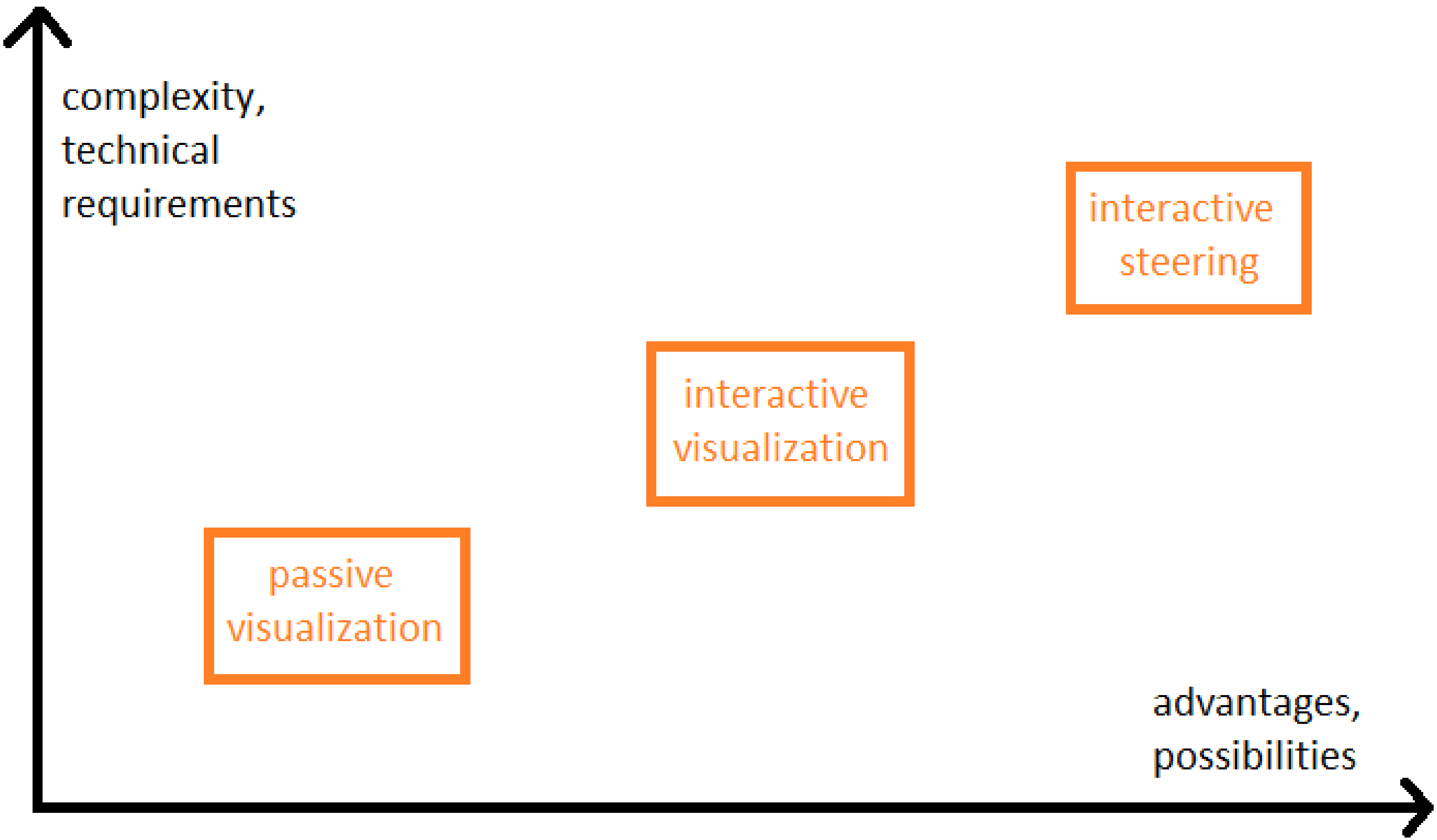


  - Interactive visualization enabling real-time view onto data



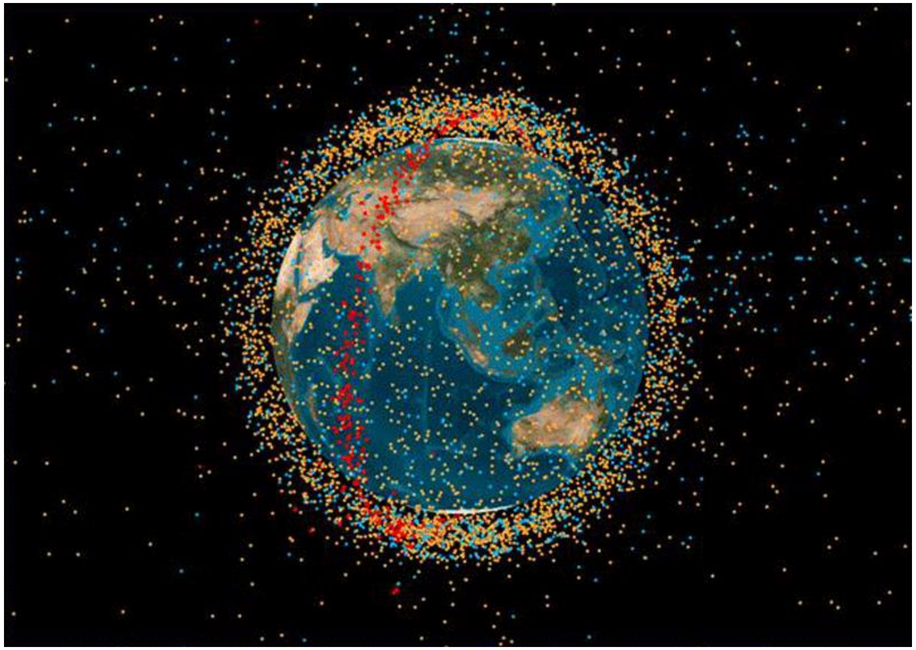
  - Extended interaction
    - The user can control the simulation process, change design when modeling, etc.
    - Very complicated and costly process

Comparison


complexity,
technical
requirements
interactive
steering
interactive
visualization
passive
visualization
advantages,
possibilities

Data

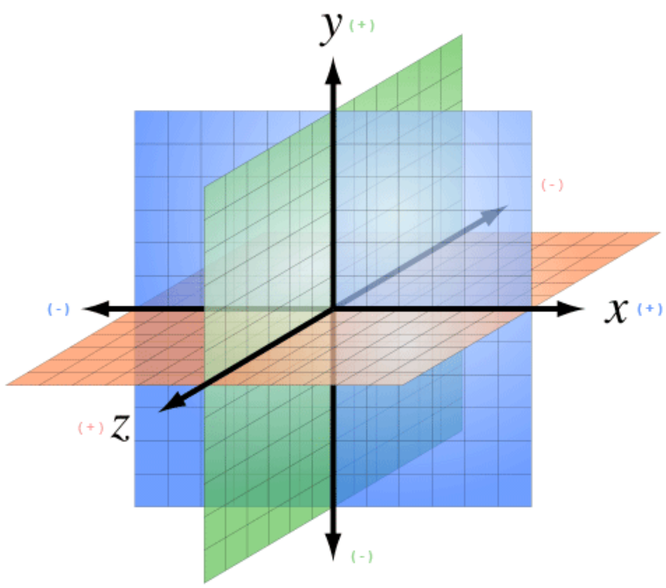
- Central topic of visualization
- Data influences the selection of appropriate visualization technique (along with the user)
- Important questions:
  - Where data „lives" (what is the **data space**)
  - **Type** of data
  - Which **representation** is meaningful



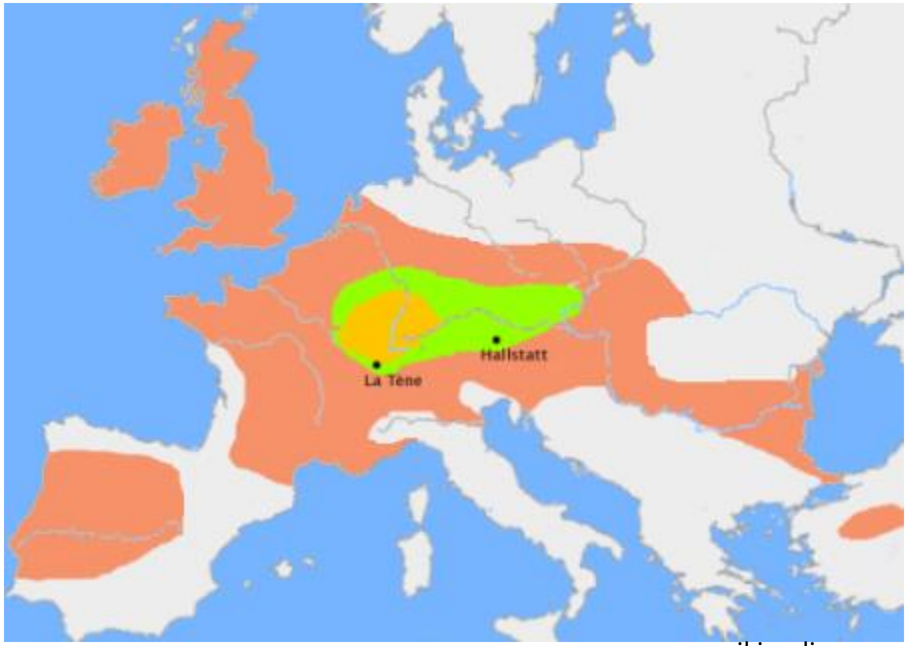
blogs.agi.com

Data space

- Different properties
  - Dimensionality of data space
  - Coordinate system
  - Region of influence (local or global impact)



wiki.brown.edu



en.wikipedia.org

Data definition

- *Raw data x preprocessed data*

- Data item (r_1, r_2, ..., r_n)
- Each r_i record contains *m* variables (v_1, v_2, ..., v_m)
- v_i is often denoted as observation

Definition of variables

- *Independent variable iv_i*
  - not influenced by any other variable (e.g., time)
- *Dependent variable dv_j*
  - is influenced by one or more independent variables (e.g., temperature)

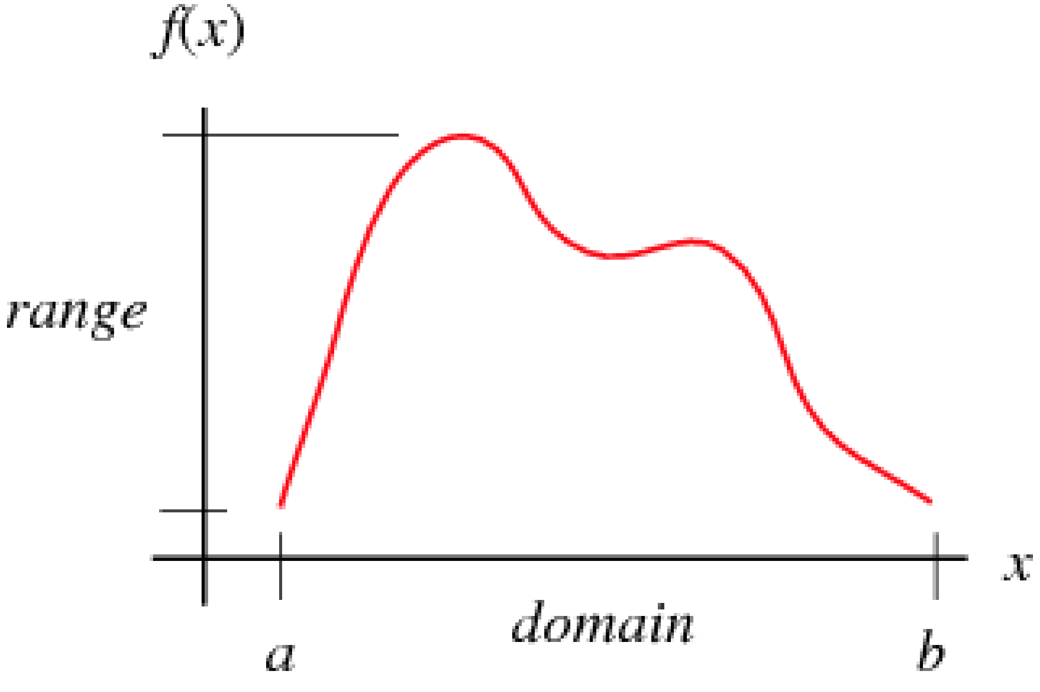
- Record can be represented as

$$r_i = (iv_1, iv_2, \ldots, iv_{m_i}, dv_1, dv_2, \ldots, dv_{m_d})$$

where $m = m_i + m_d$

Data generated by function

- Independent variables = domain
- Dependent variables = range



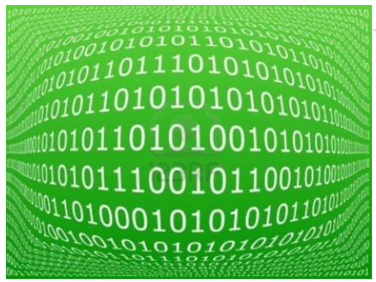
mathworld.wolfram.com

Types of variables

- Physical types
  - Characterized by the input format
  - Characterized by the type of possible operations
  - Example: bool, string, int, float,…
- Abstract types
  - Data description
  - Characterized by methods/attributes
  - Can be hierarchical
  - Example: plants, animals, …

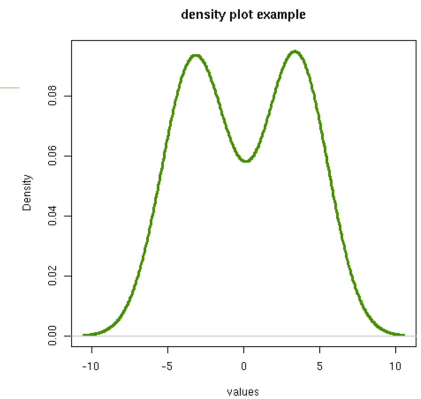
Data types

- ***Ordinal***
  - Binary
  - Discrete
  - Continuous
- ***Nominal***
  - Categorical
  - Sorted
  - Random

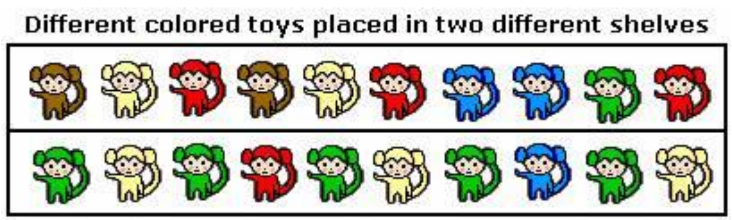


www.123rf.com

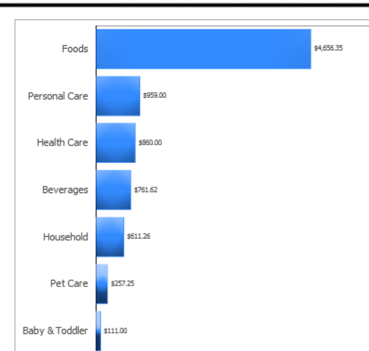
www.forbes.com



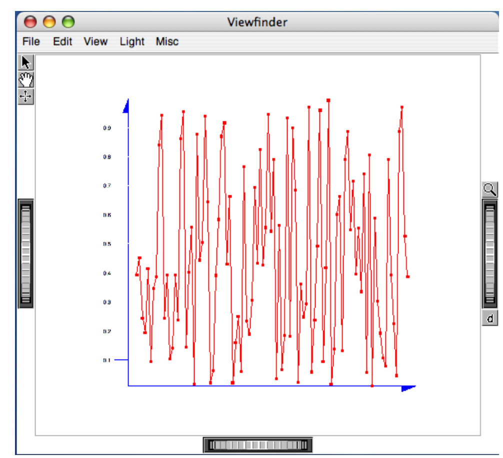
orgmode.org



www.icoachmath.com



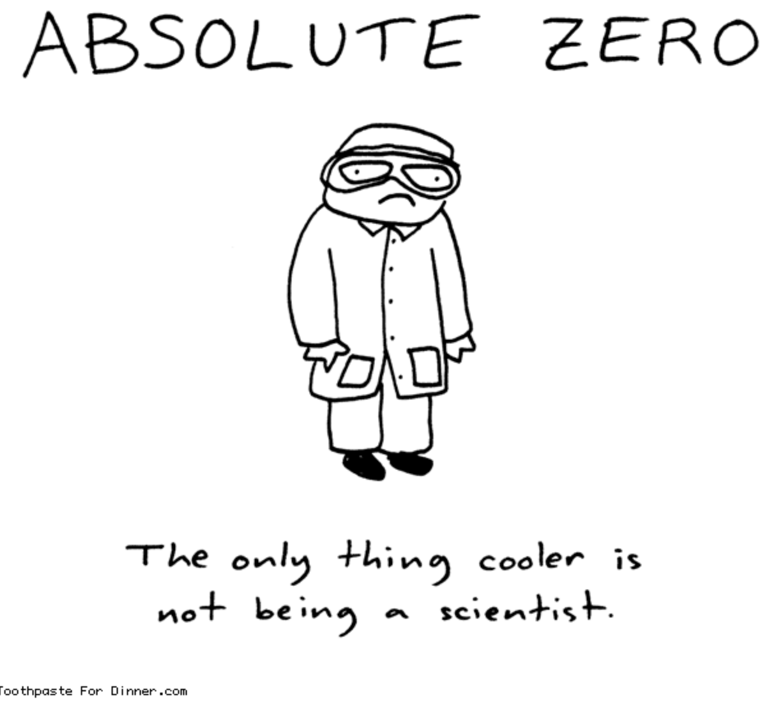
tennysusantobi.blogspot.com



www.cincomsmalltalk.com

Scale

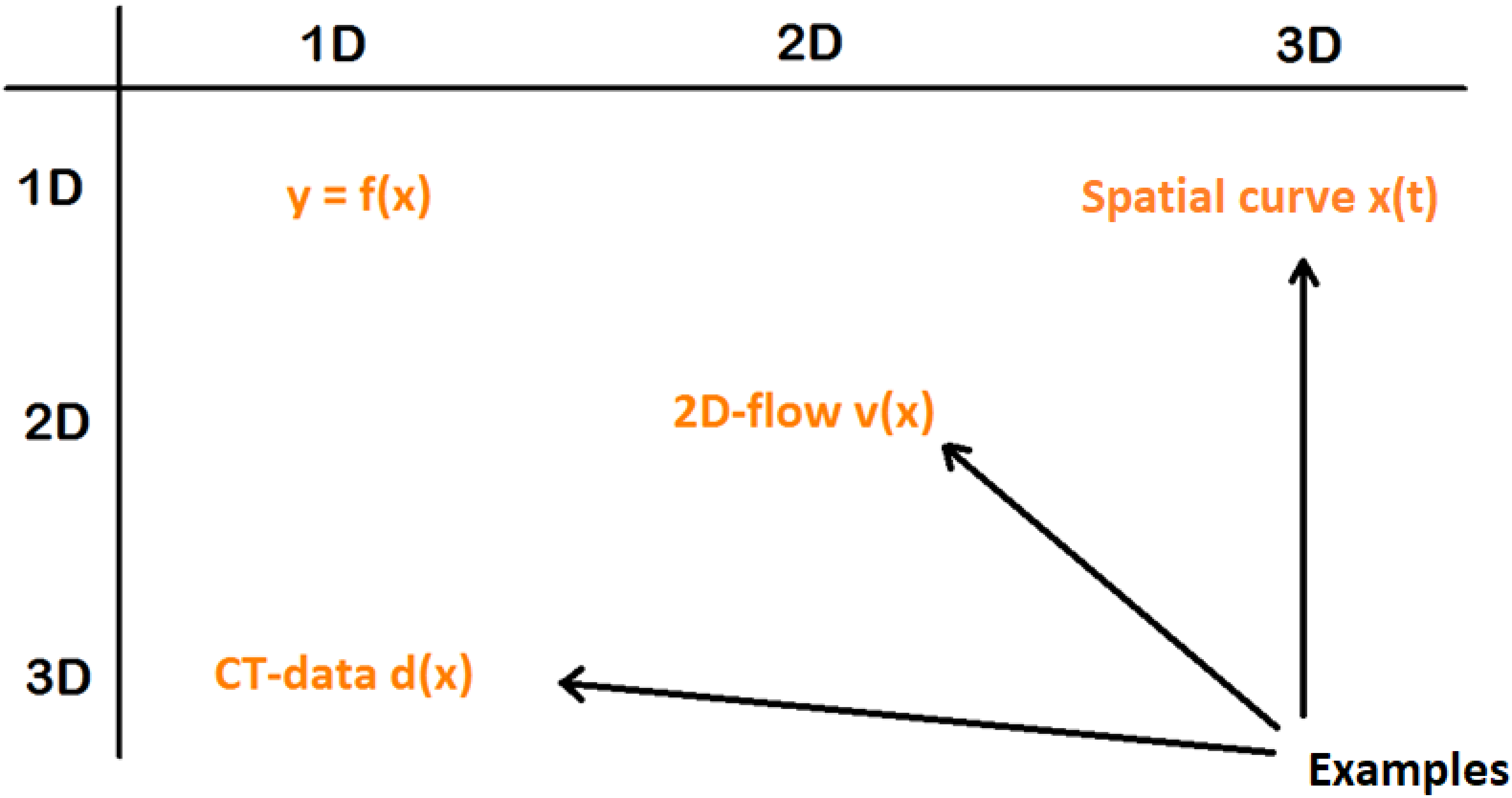
- 3 basic attributes:
  - Ordering relation on data
  - Distance metric
  - Existence of absolute zero
    - Fixing the minimal value of variable



Data representation

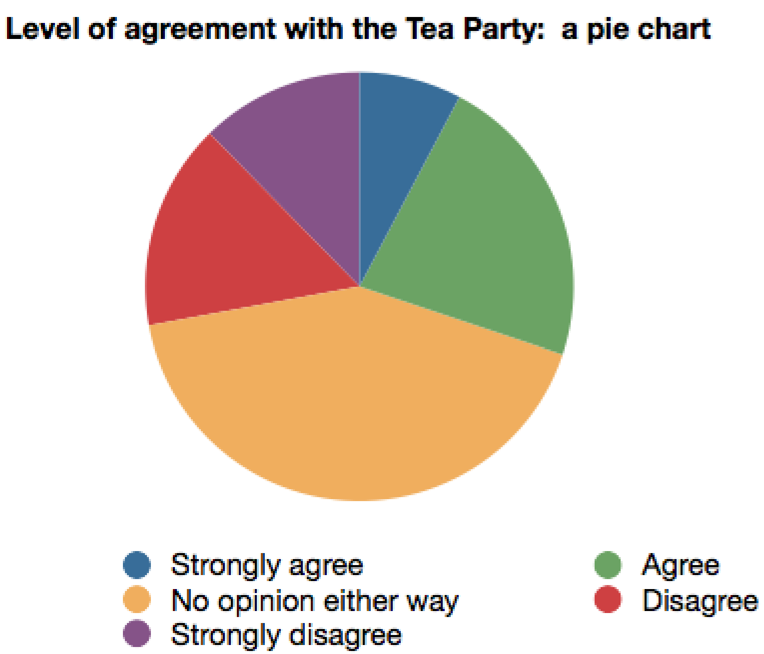
- Depends on:
  - The presence of spatial domain
    - If it is not inherently in data, which domain to choose?
  - How the dimensions are used?
    - Data characteristics
    - Available visualization space (2D/3D)
    - Which part of data is in focus?
    - In which parts we can use more abstracted representation?

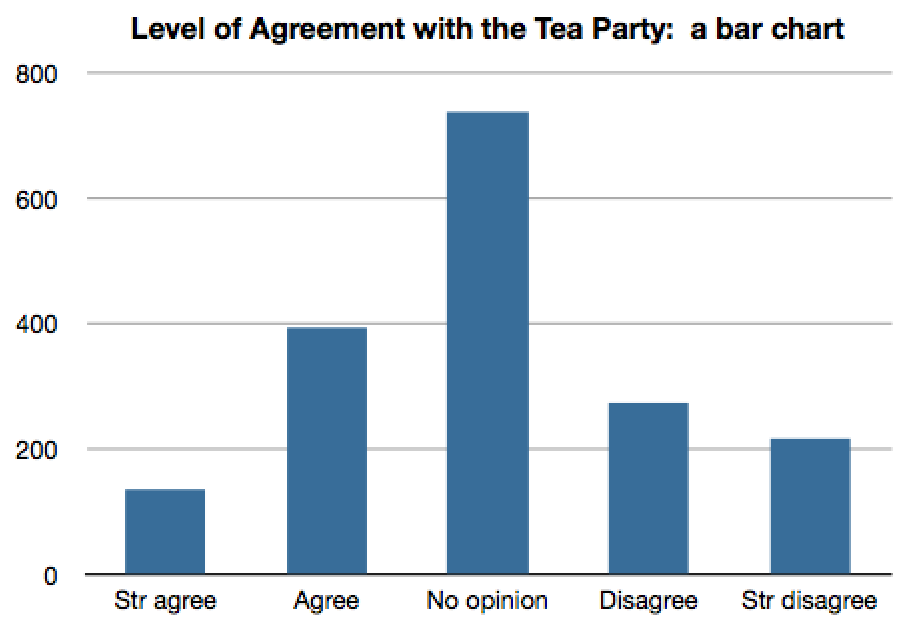
Data space vs. data properties



Examples

- Discrete data – set of values, visualization using bar charts, pie charts, …

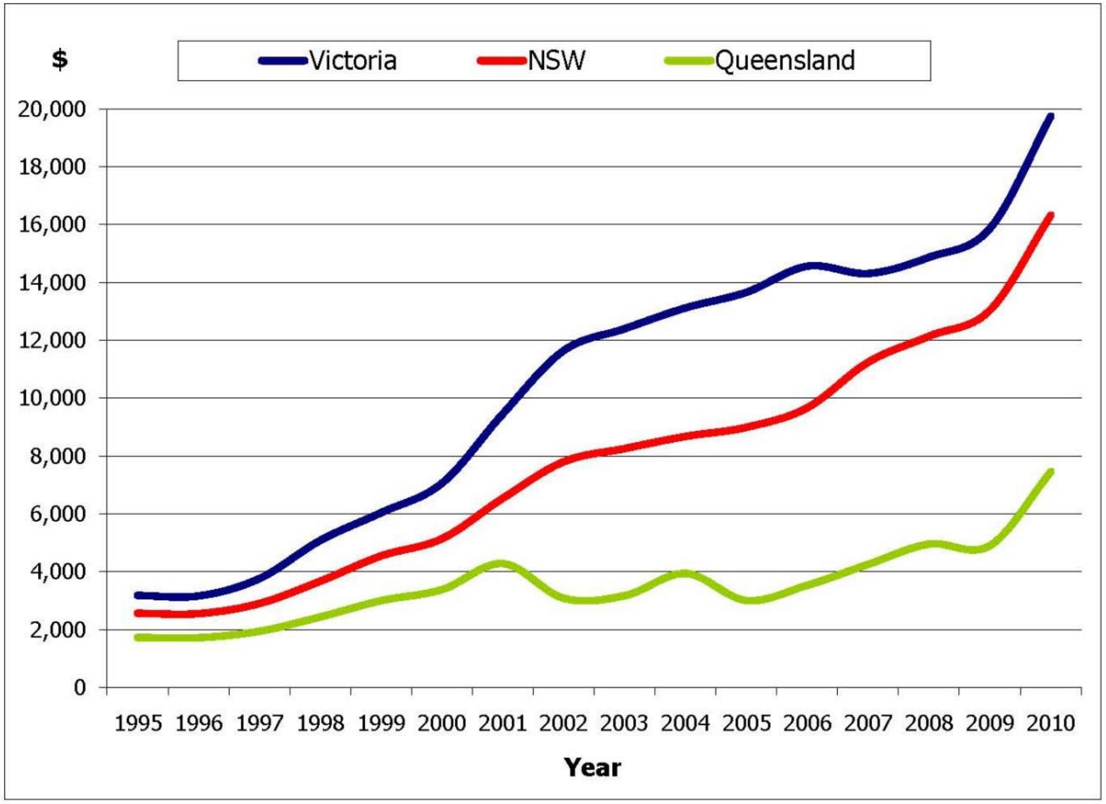




wiki.opossem.org

Examples

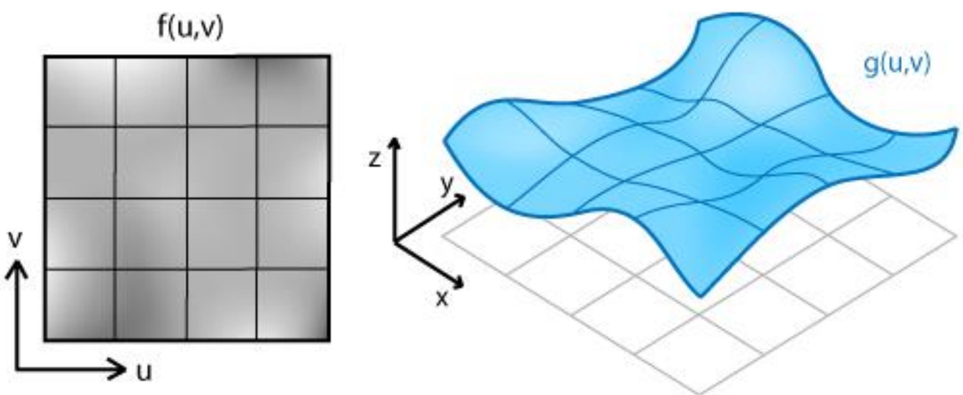
- Continuous data – function, visualization using graphs



www.isanybodylistening.com.au

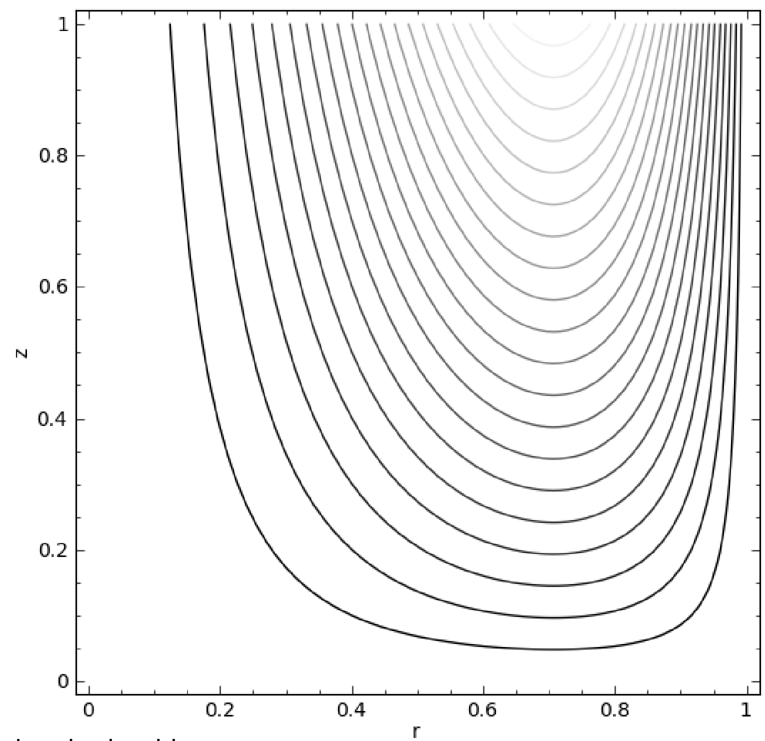
Examples

- 2D real numbers
  - Function of two variables, visualization using 2D height maps, contours in 2D, …



$$g(u,v) \rightarrow (x,y,z) : \begin{cases} x = u \\ y = v \\ z = f(u,v) \end{cases}$$

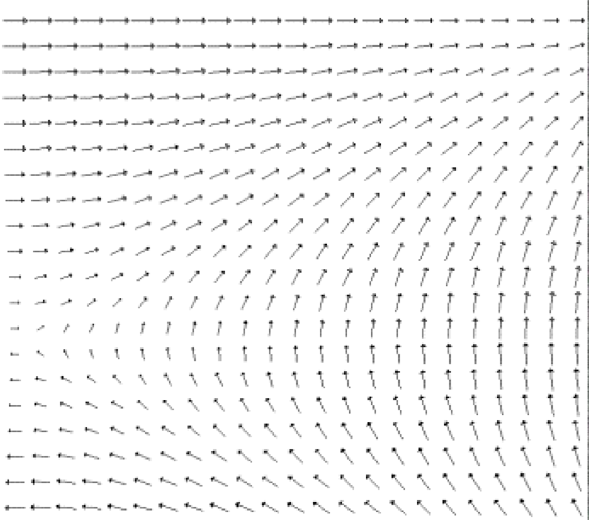
acko.net



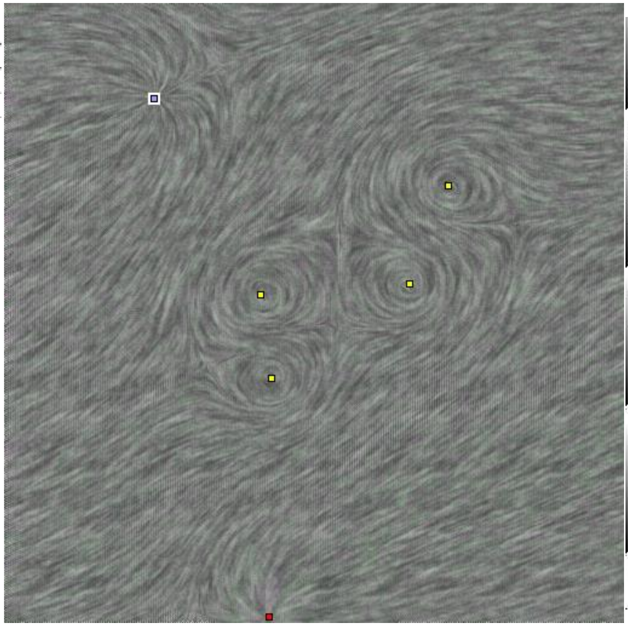
timothyandrewbarber.blogspot.com

Examples

- 2D vector fields, visualization using hedgehog plots, LIC (line integral convolution), streamlets, …



csis.pace.edu

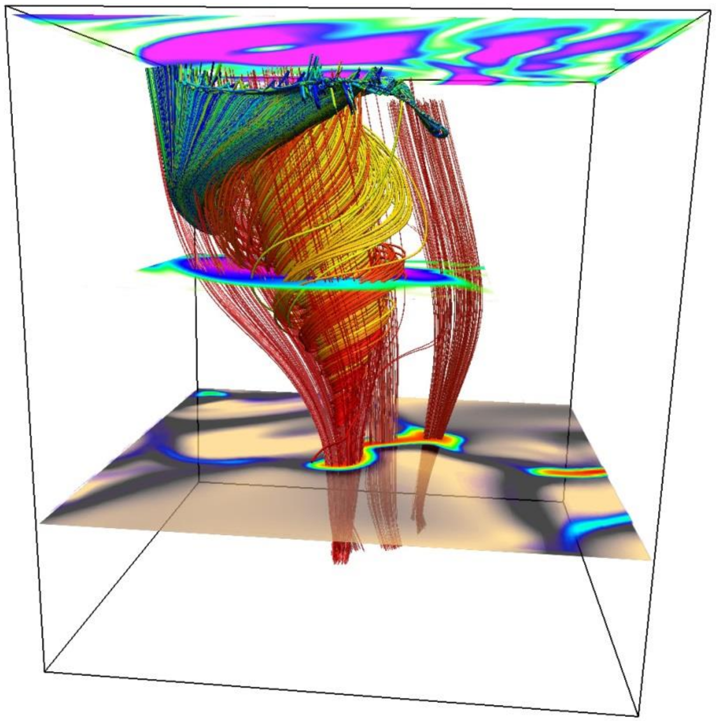


en.wikipedia.org

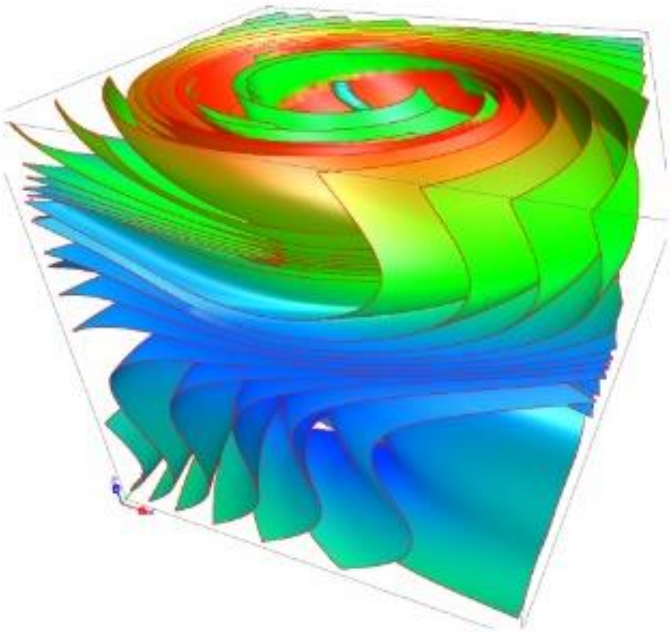
www.cg.tuwien.ac.at

Examples

- Spatial data + time
  - 3D flow, visualization using streamlines, streamsurfaces



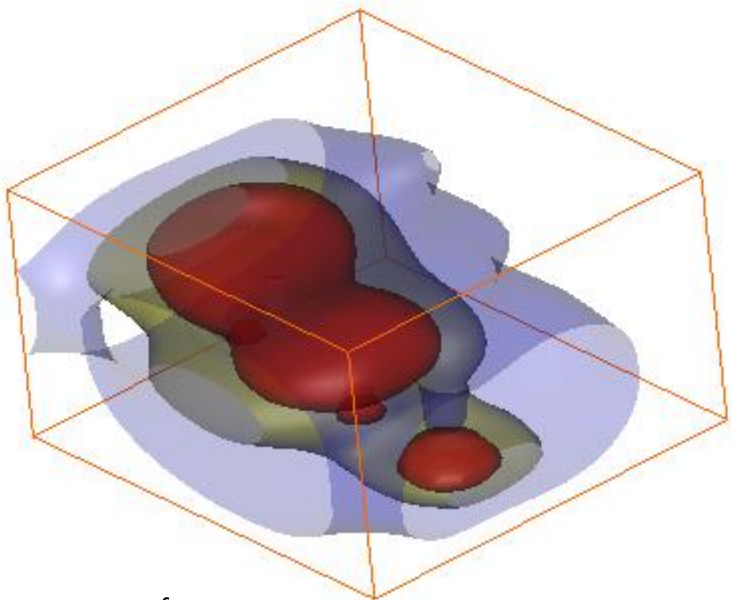
www.solartornado.info



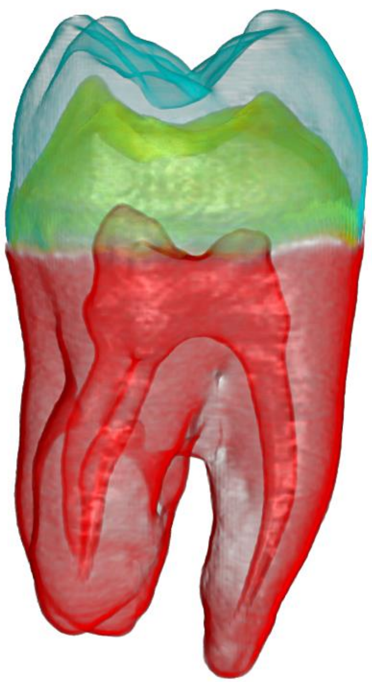
www2.cs.uh.edu

Examples

- Spatial data
  - 3D density, visualization using isosurfaces, volume rendering



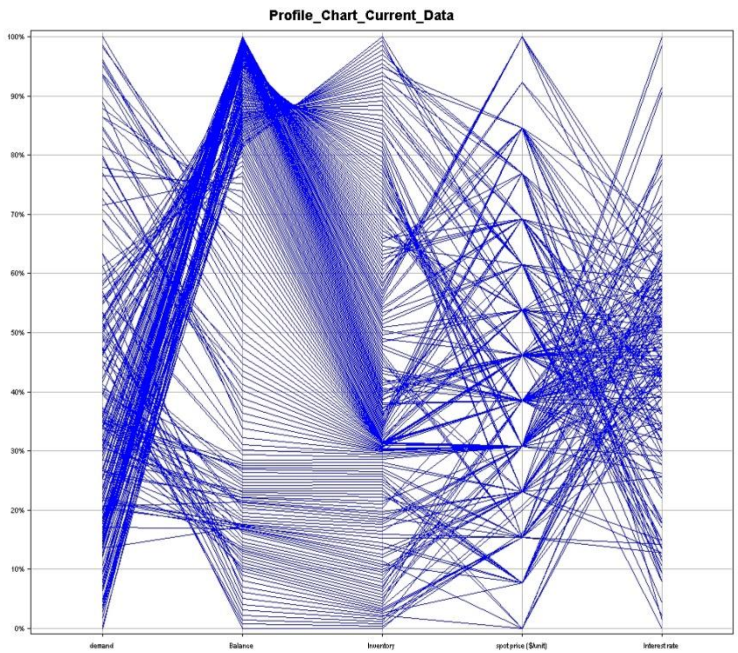
www.ssg-surfer.com



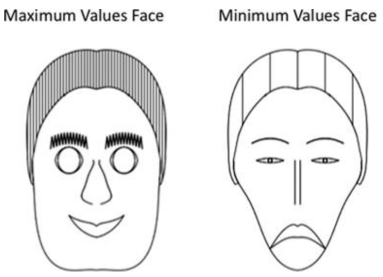
viscg.uni-muenster.de

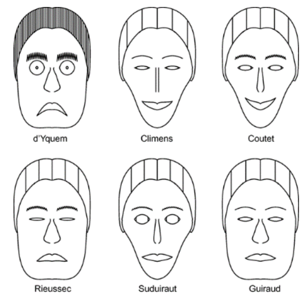
Examples

- Multidimensional data
  - Set of n dimensions, visualization using parallel coordinates, glyphs, icons, …

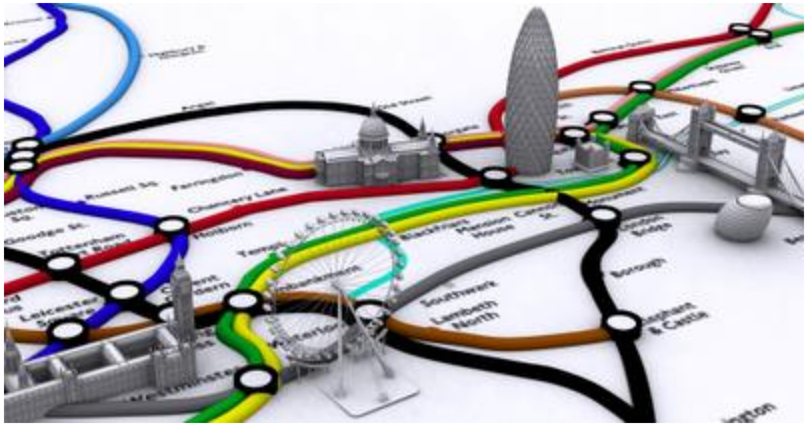


www.cs.umd.edu





www.emeraldinsight.com



datamining.typepad.com

Structure inside and between records

- Data sets consist of:
  - **Syntax** – data representation (so called data model)
  - **Semantics** – relationships within one record or between records (so called conceptual model)
- Types of structures:
  - Scalars, vectors, tensors
  - Geometry and grids
  - Other forms

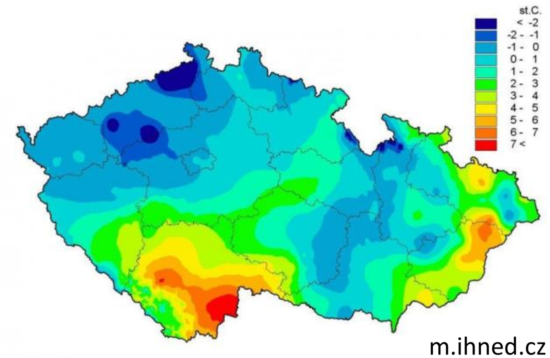
.ca

Scalars, vectors, and tensors

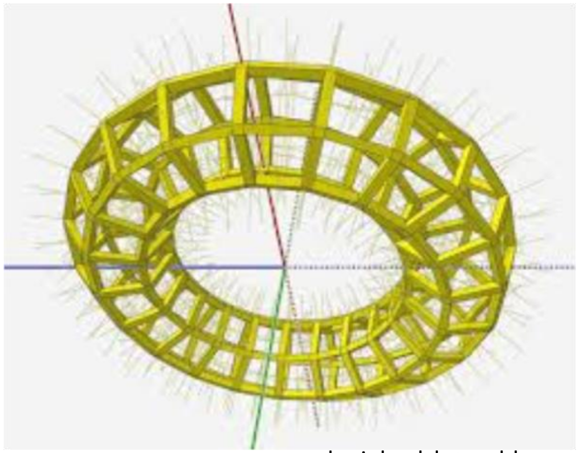
- **Scalar** = individual number in record
  - e.g., age
- **Vector** = composition of several variables to one record
  - e.g., point in 2D space, RGB
- **Tensor** = defined by its order and space dimension. Represented by field or matrix.
  - e.g., transformation matrix in 3D

Geometry and grids

- Geometry is represented using coordinates of records



m.ihned.cz

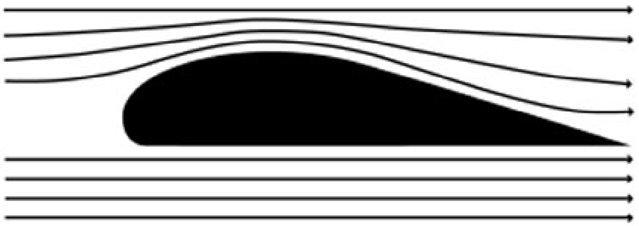


danielwalsh.tumblr.com

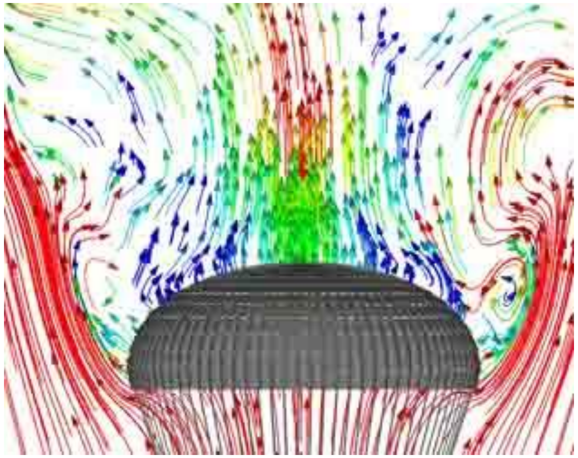
- Grid – geometry can be derived from the starting position, orientation, and step size in horizontal and vertical direction

Non-uniform geometry

- We need to store coordinates of all records – they cannot be derived

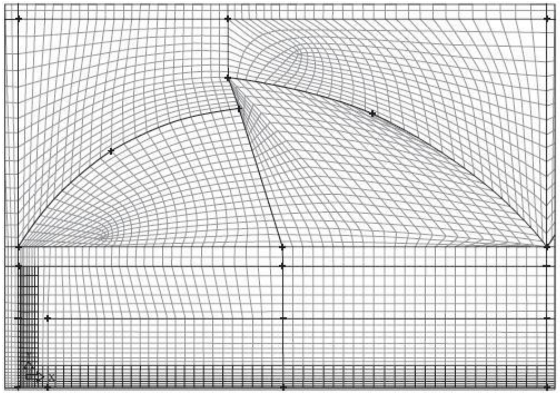


blog.nasm.si.edu



www.tafsm.org

- Non-uniform grid

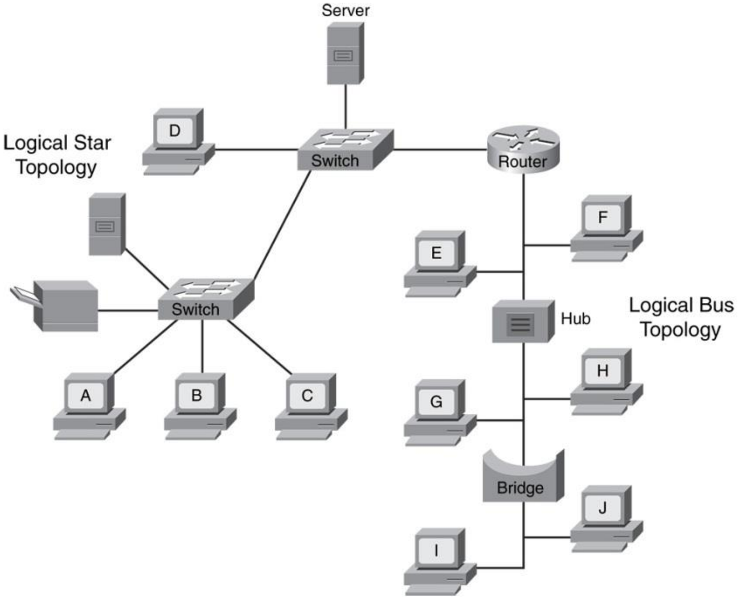


www.scielo.org.mx

Other types of structures

- Another important structure is **topology**
- It defines so called **connectivity**

www.bugman123.com



xpertnetworking.wordpress.com

- Important in resampling and interpolation

Time

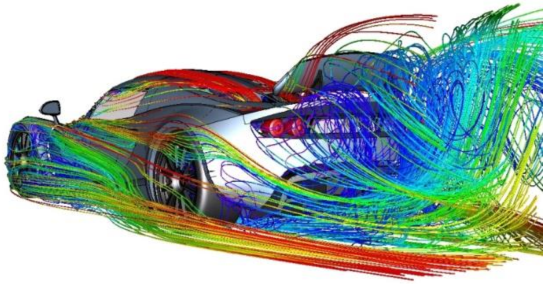
megworden.com

- Enormous range of values (picosecs vs. millenia)
- Expressed absolutely or relatively
- Data sets containing time can have regular distribution (regular sampling) or irregular one (e.g., transaction processing – according to the time stamp of its execution)

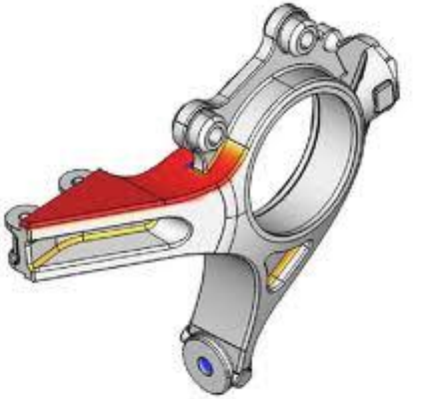
Other examples of structured data

www.impactlab.net

- Magnetic Resonance Imaging (MRI)
- Computational fluid dynamics (CFD)
- Financing
- CAD systems
- Counting people
- Social networks

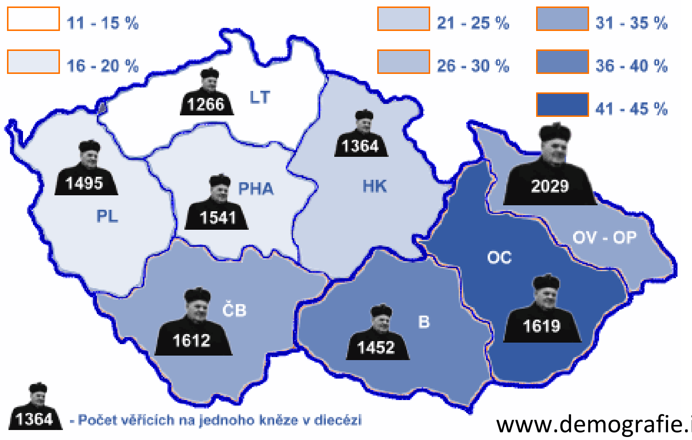


lotusenthusiast.net



www.mjmdesigns.co.uk

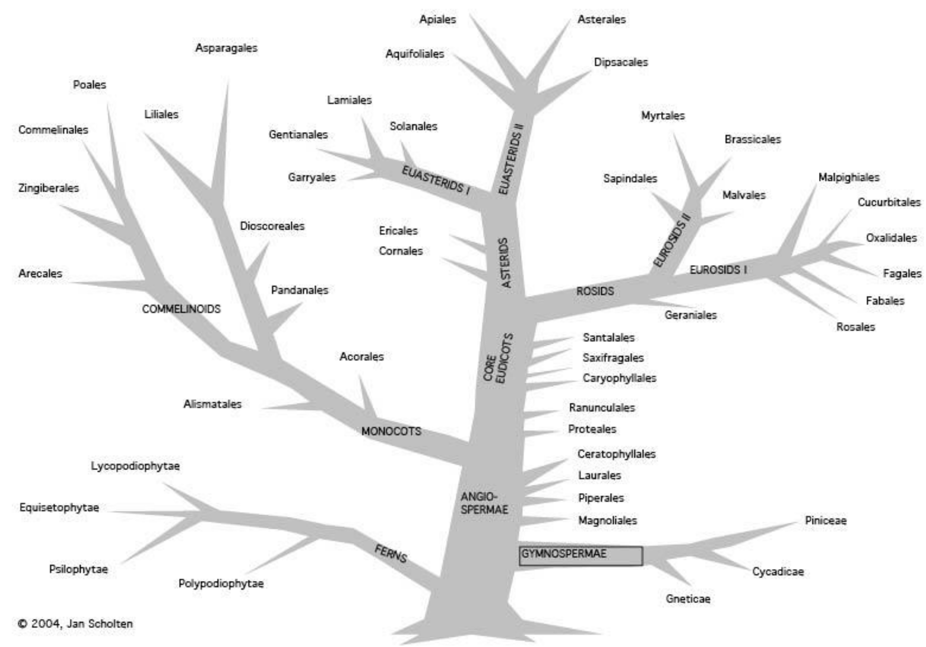
successfulworkplace.com



www.demografie.info

Taxonomy – 7 types of data

- 1D (linear sets and sequences)
- 2D (maps)
- 3D (objects, shapes)
- nD (relations)
- Trees (hierarchy)
- Networks (graphs)
- Temporal data

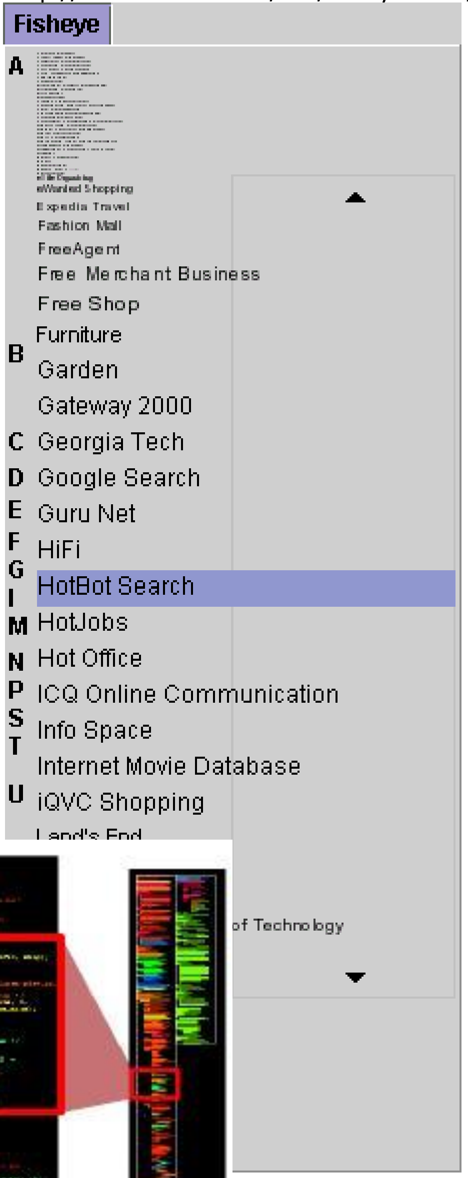


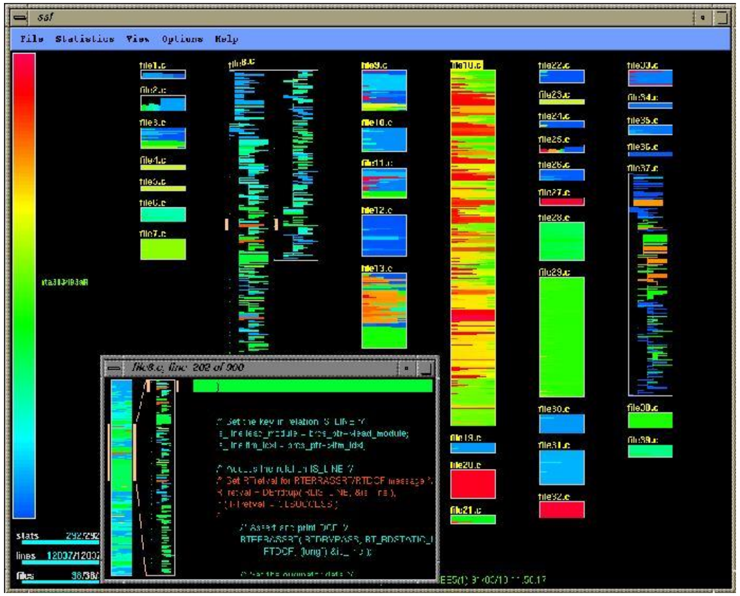
www.janscholten.com

Linear data

- Long lists of items
  - – Menu items
  - – Source code
- Fisheye displays

http://www.cs.umd.edu/hcil/fisheyemenu/





http://ds.cc.yamaguchi-u.ac.jp/~ichikay/pfp7/iv/pics/SeeSoft-line.jpg

http://ds.cc.yamaguchi-u.ac.jp/~ichikay/pfp7/iv/pics/SeeSoft-line.jpg

2D data - maps

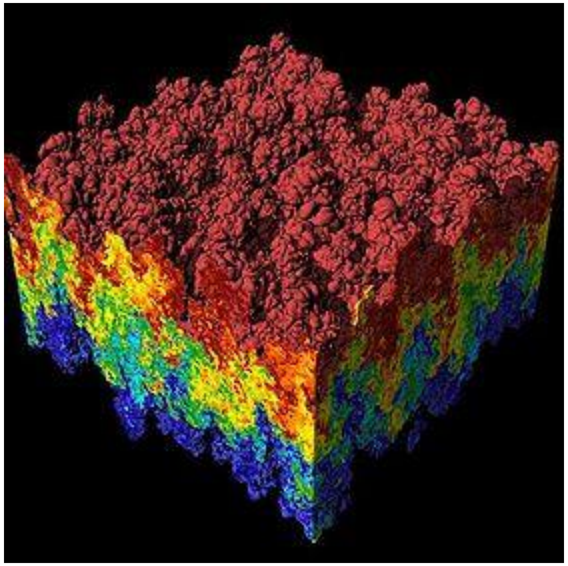
- GIS (Geographical Information Systems)
  - Maps (e.g., Google Earth)

    http://www.wimp.com/unusualplaces/
  - Spatial queries
  - Spatial data analysis

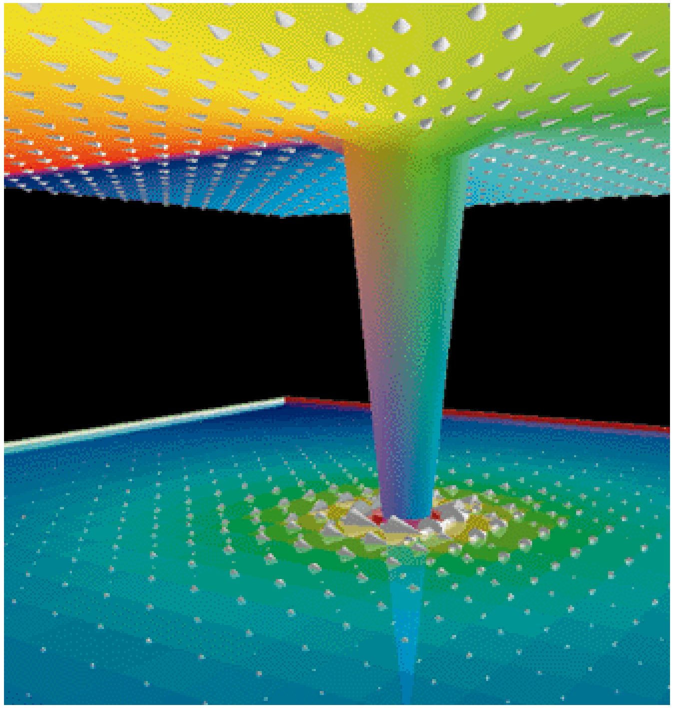
www.bowdoin.edu

3D data

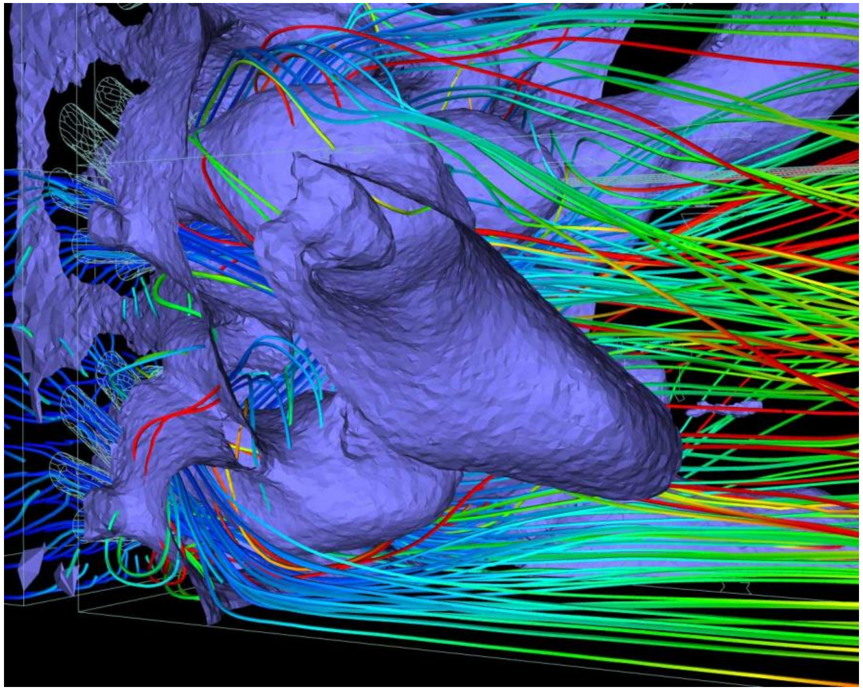
- Different types of 3D data vis
- Scientific visualization



en.wikipedia.org



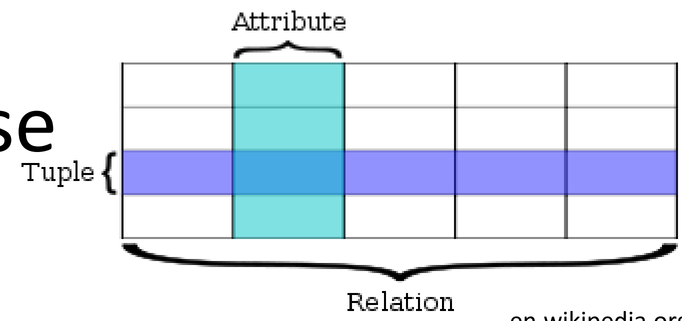
www.ornl.gov



gvis.grc.nasa.gov

Multidimensional data

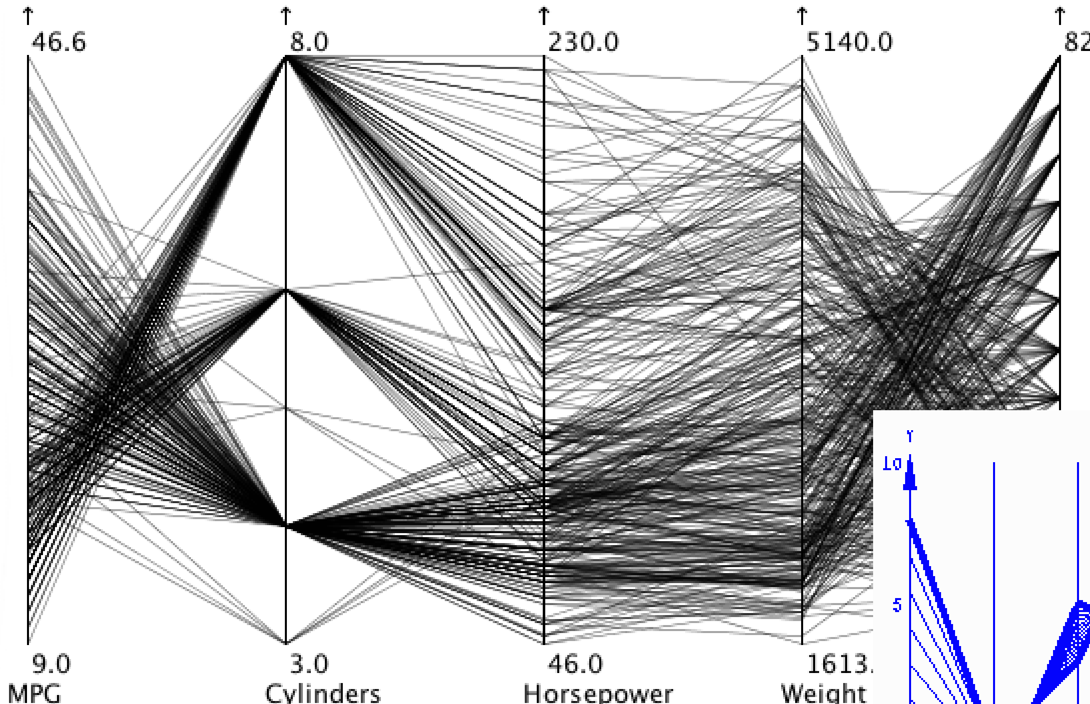
- Records in relational database



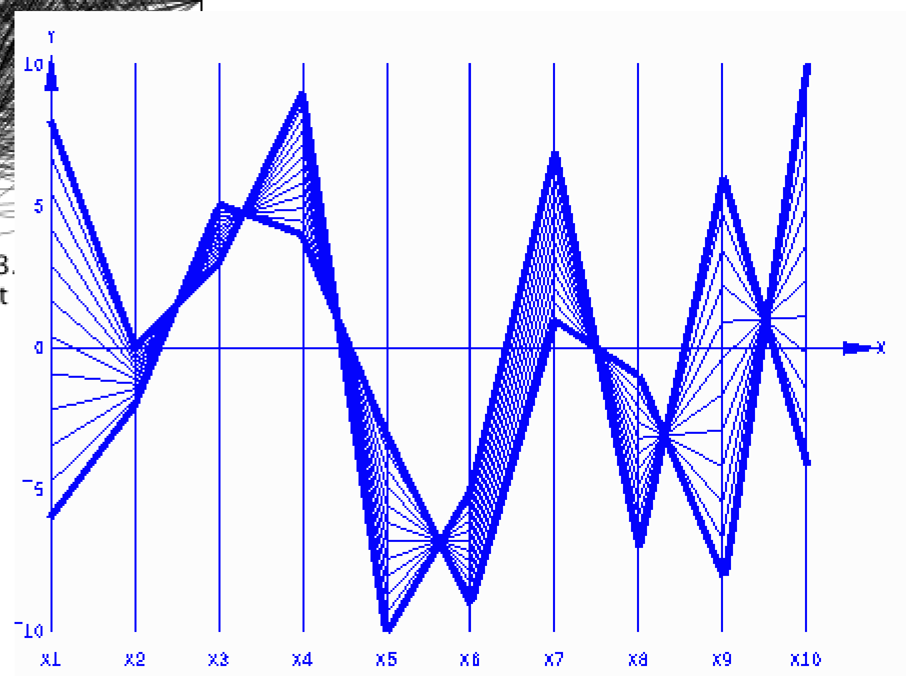
en.wikipedia.org

- Two solutions:
  - Drawing all possible pairs of variables in 2D graph
    - Simple but unusable for general overview of the data
  - „Parallel coordinates“
    - Method for displaying multidimensional data (Alfred Inselberg)

Parallel coordinates



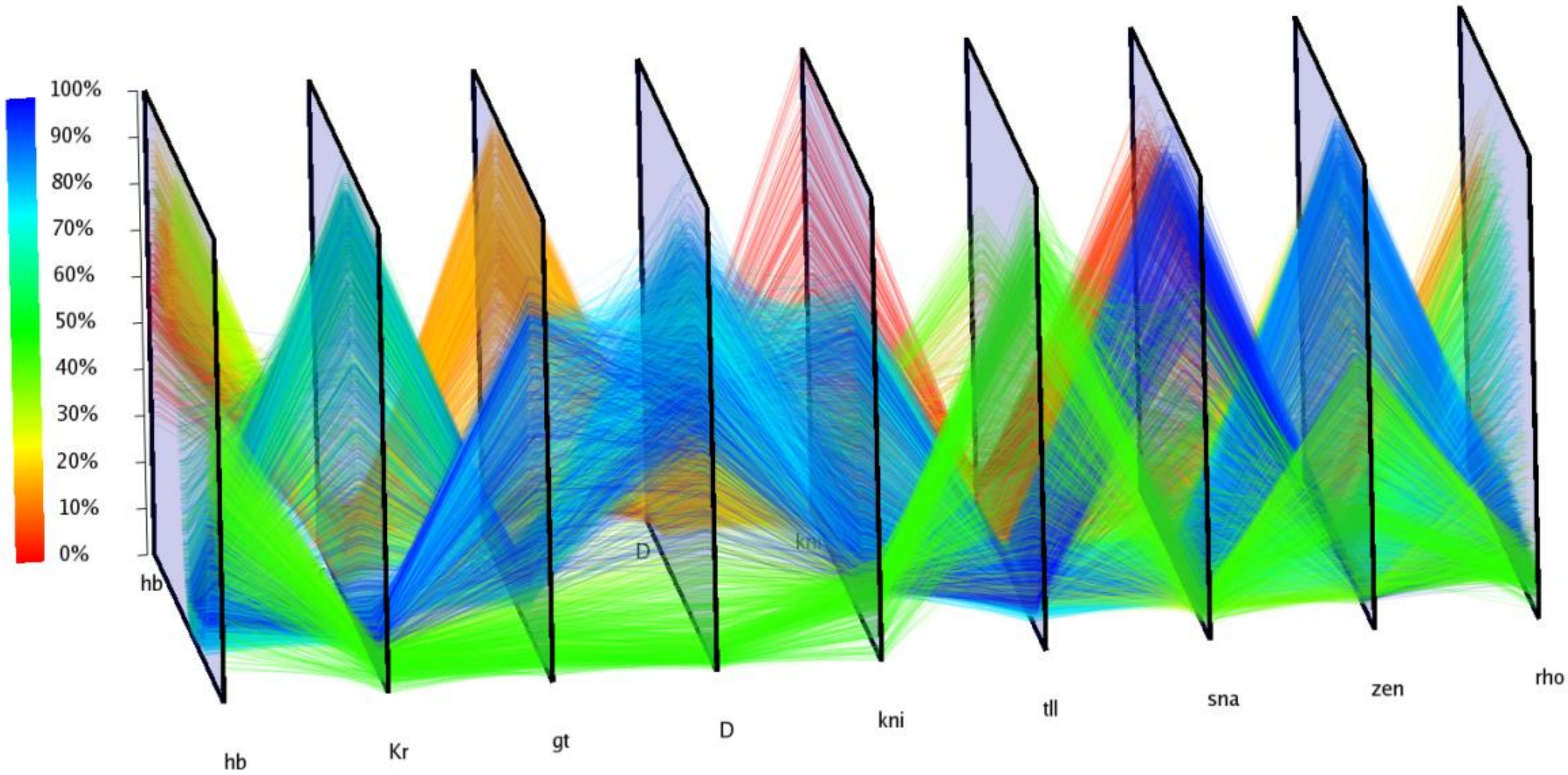
eagereyes.org



andrewgelman.com

Parallel coordinates

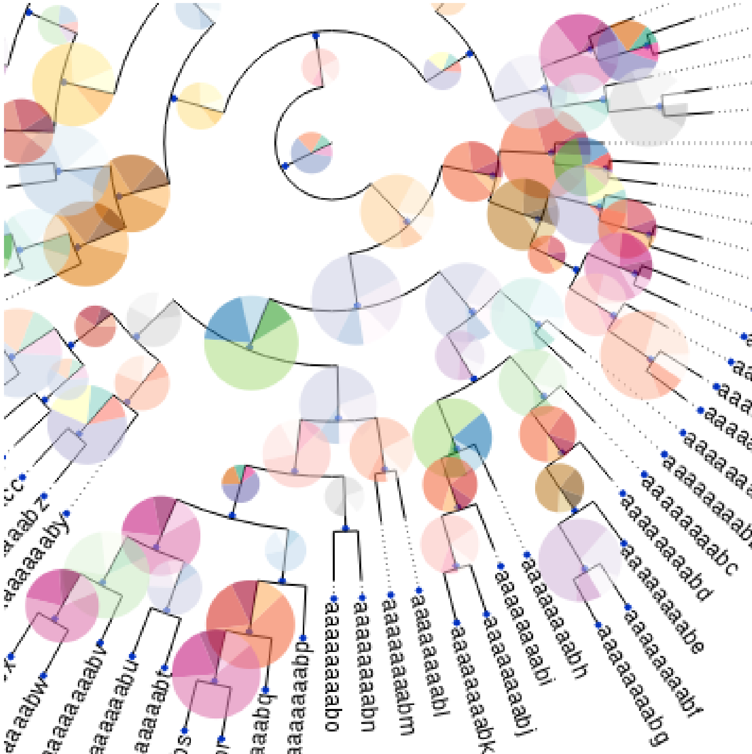
whyevolutionistrue.wordpress.com

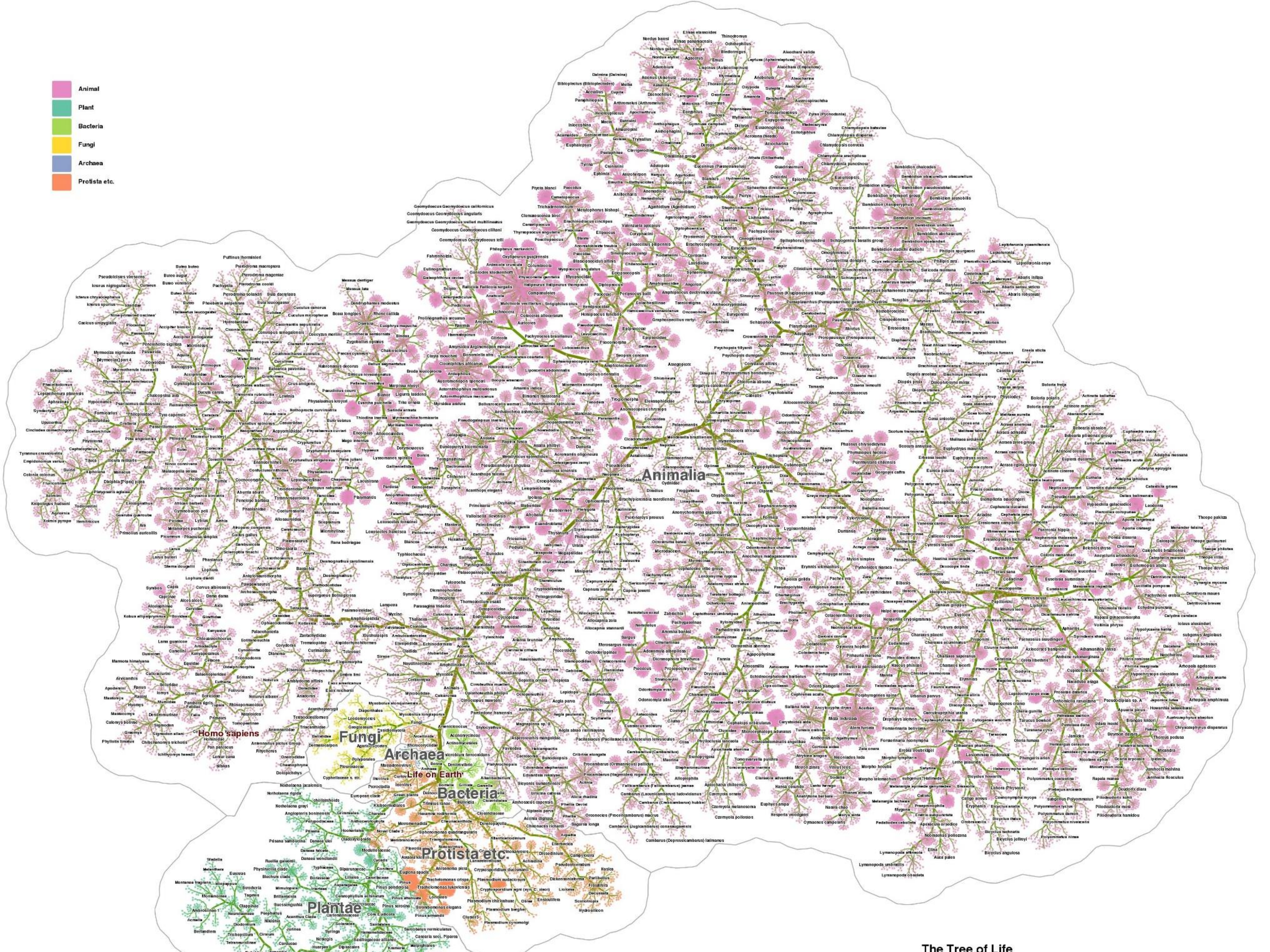


vis.lbl.gov

Trees

- Displays not only data itself but also their structure
  - e.g., genetic trees, file systems
- Number of items increases significantly in lower levels of tree

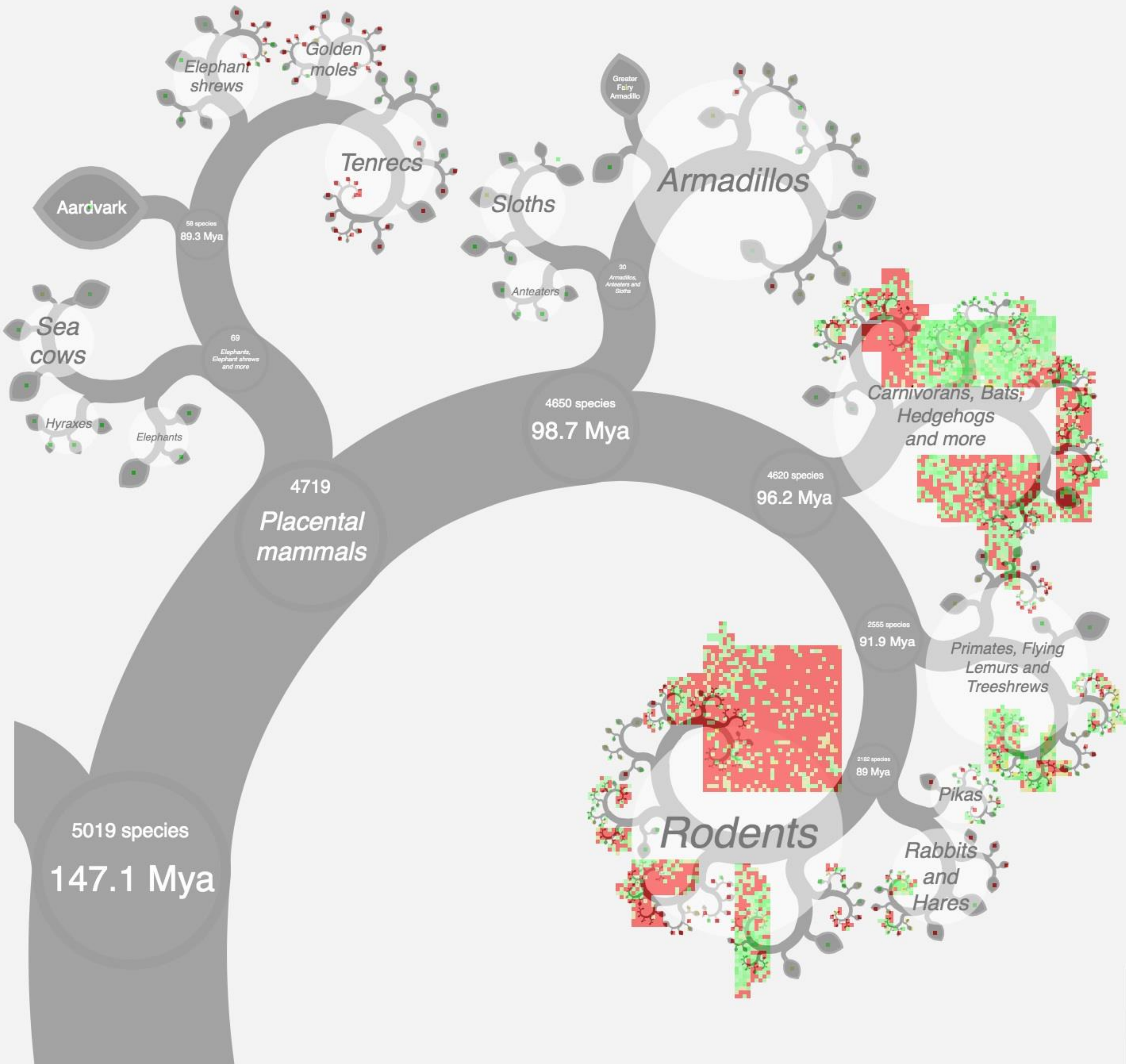




The Tree of Life

This drawing illustrates the phylogeny of organisms, i.e., the history of organismal lineages as they change through time, as documented by the Tree of Life Web Project. Each dot represents a species or a group, and is linked to its containing group by an edge. Data collected from the project website (http://www.tolweb.org) on 9/19/2011. A total of 93891 species and groups were found on the site, a small sample of the estimated millions of species on Earth today.

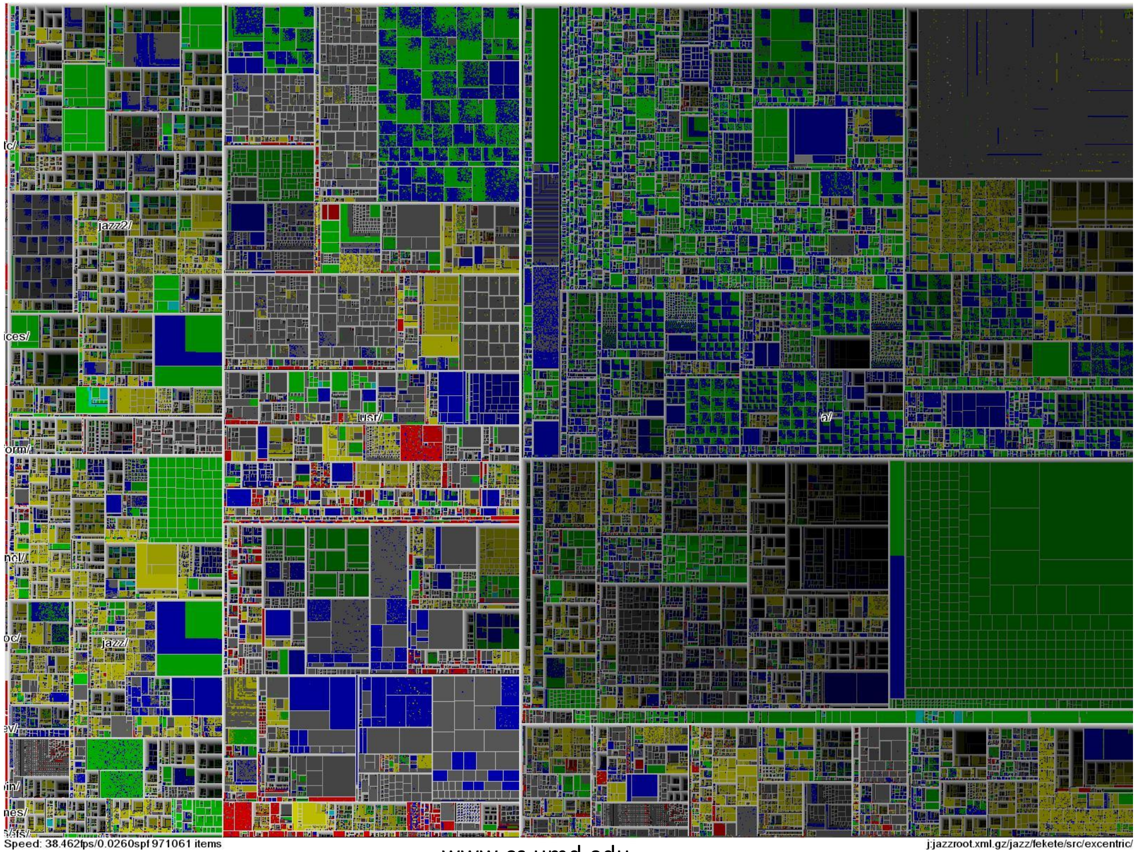
Illustration created by Yifan Hu, AT&T Labs – Research



Elephant shrews
Golden moles
Tenrecs
Greater Fairy Armadillo
Armadillos
Sloths
Anteaters
30
Armadillos, Anteaters and Sloths
Aardvark
58 species
89.3 Mya
Sea cows
69
Elephants, Elephant shrews and more
Hyraxes
Elephants
4719
Placental mammals
4650 species
98.7 Mya
Carnivorans, Bats, Hedgehogs and more
4620 species
96.2 Mya
2555 species
91.9 Mya
Primates, Flying Lemurs and Treeshrews
2182 species
89 Mya
Pikas
Rodents
Rabbits and Hares
5019 species
147.1 Mya

Trees

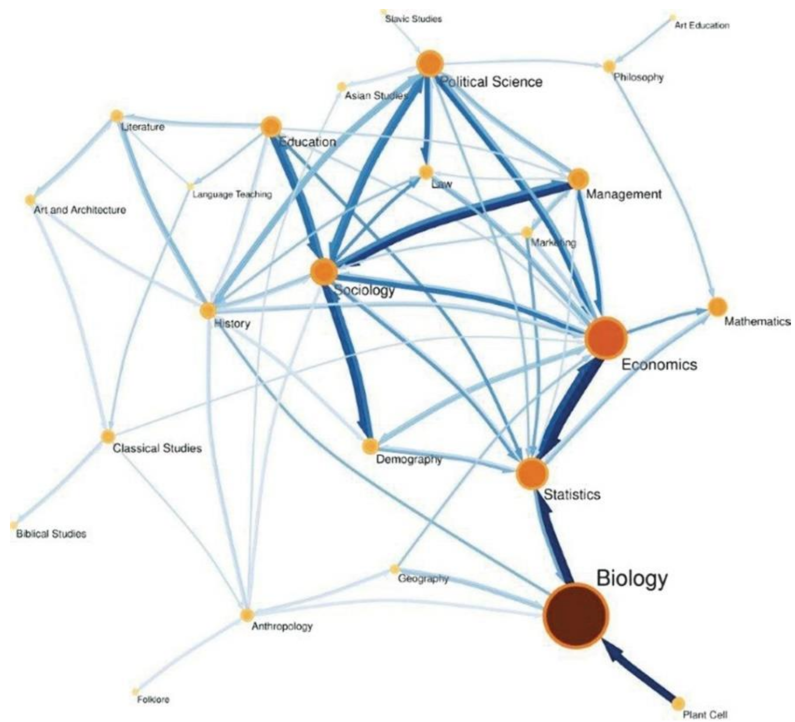
- Tree Maps
  - Displaying the tree data as nested rectangles
  - Tree with a million records:



www.cs.umd.edu

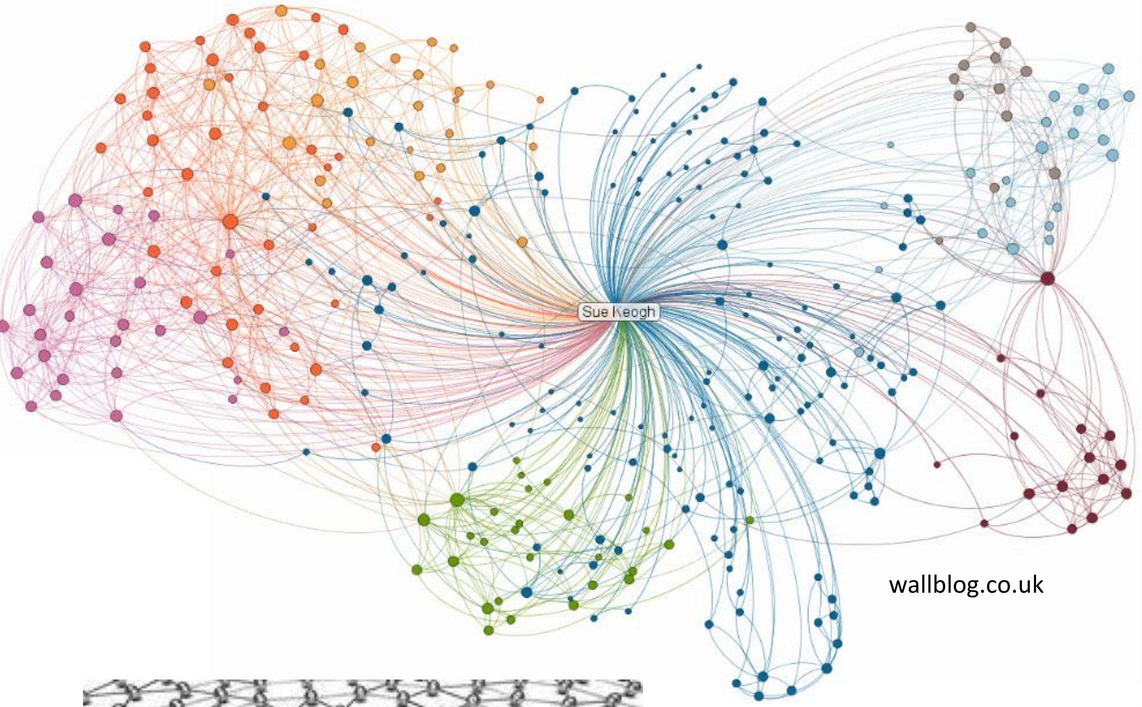
Networks

- Similar to trees – we aim to display the data structure
- Networks = nodes + edges
- Design should contain:
  - Minimal edge crossings
  - Minimal edge length
  - Minimal edge bending

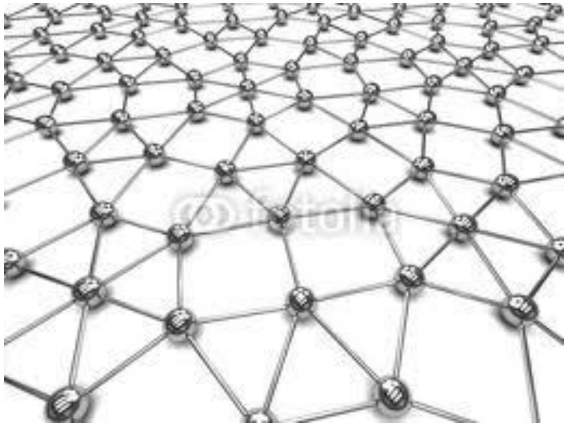


archaeologicalnetworks.wordpress.com

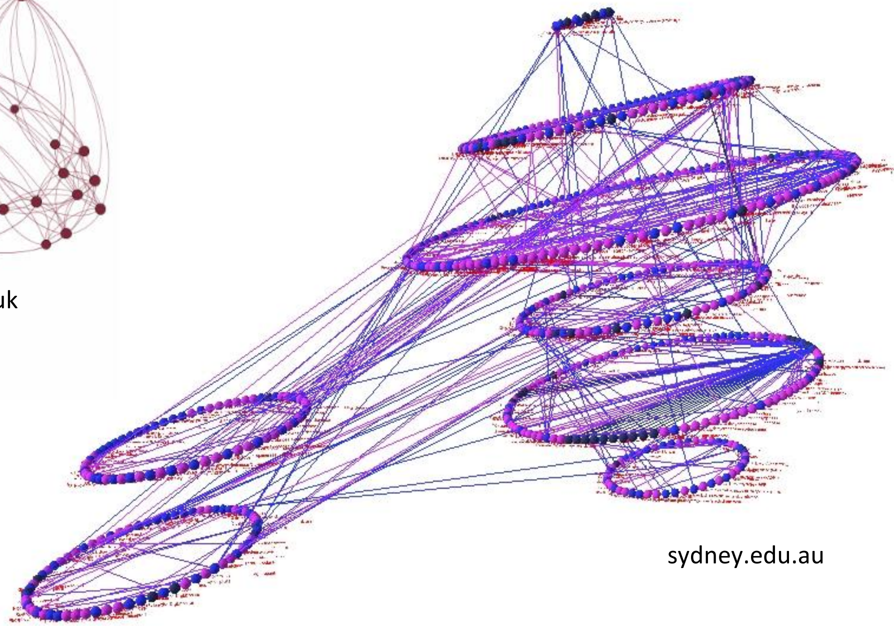
Networks



wallblog.co.uk



us.fotolia.com

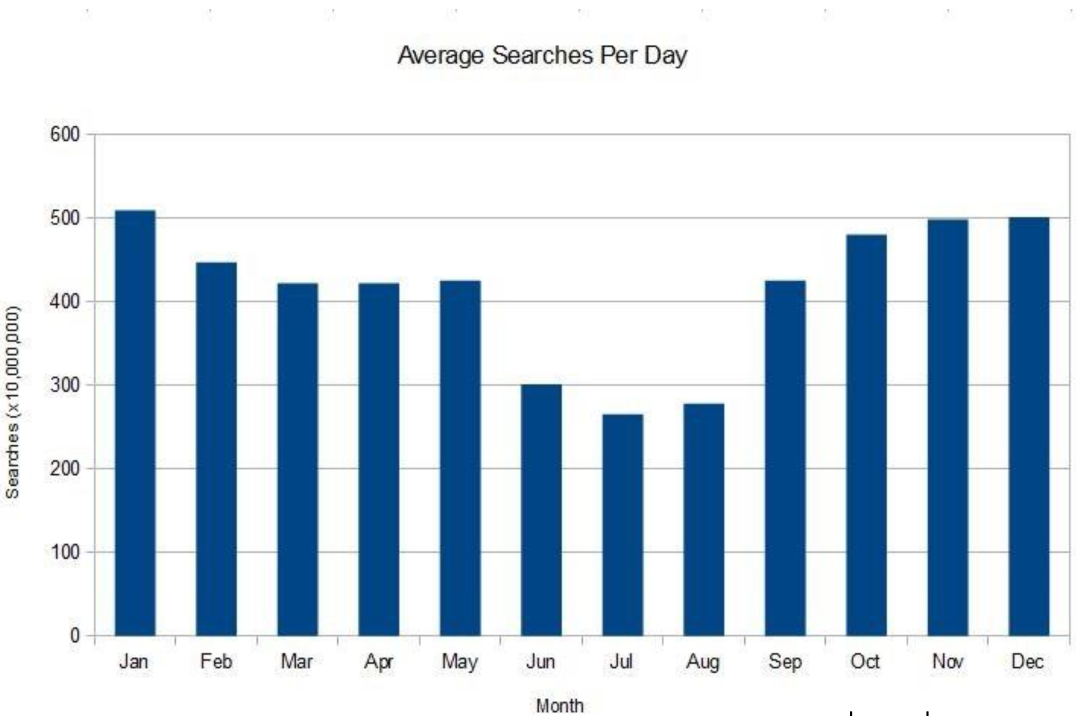


sydney.edu.au

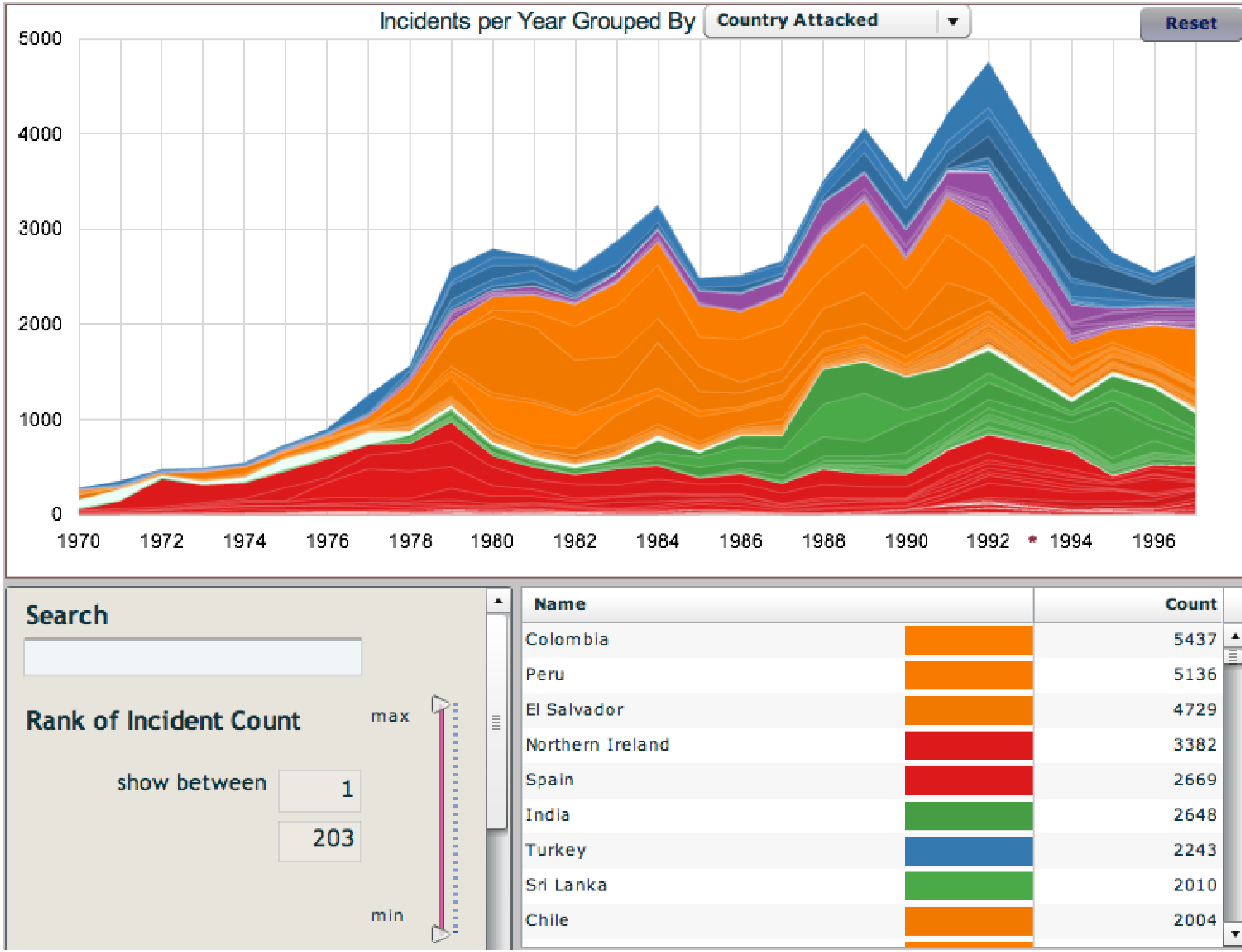
Temporal data

- Displaying data dependent on time
  - Trend and seasonal graphs

www.psdgraphics.com

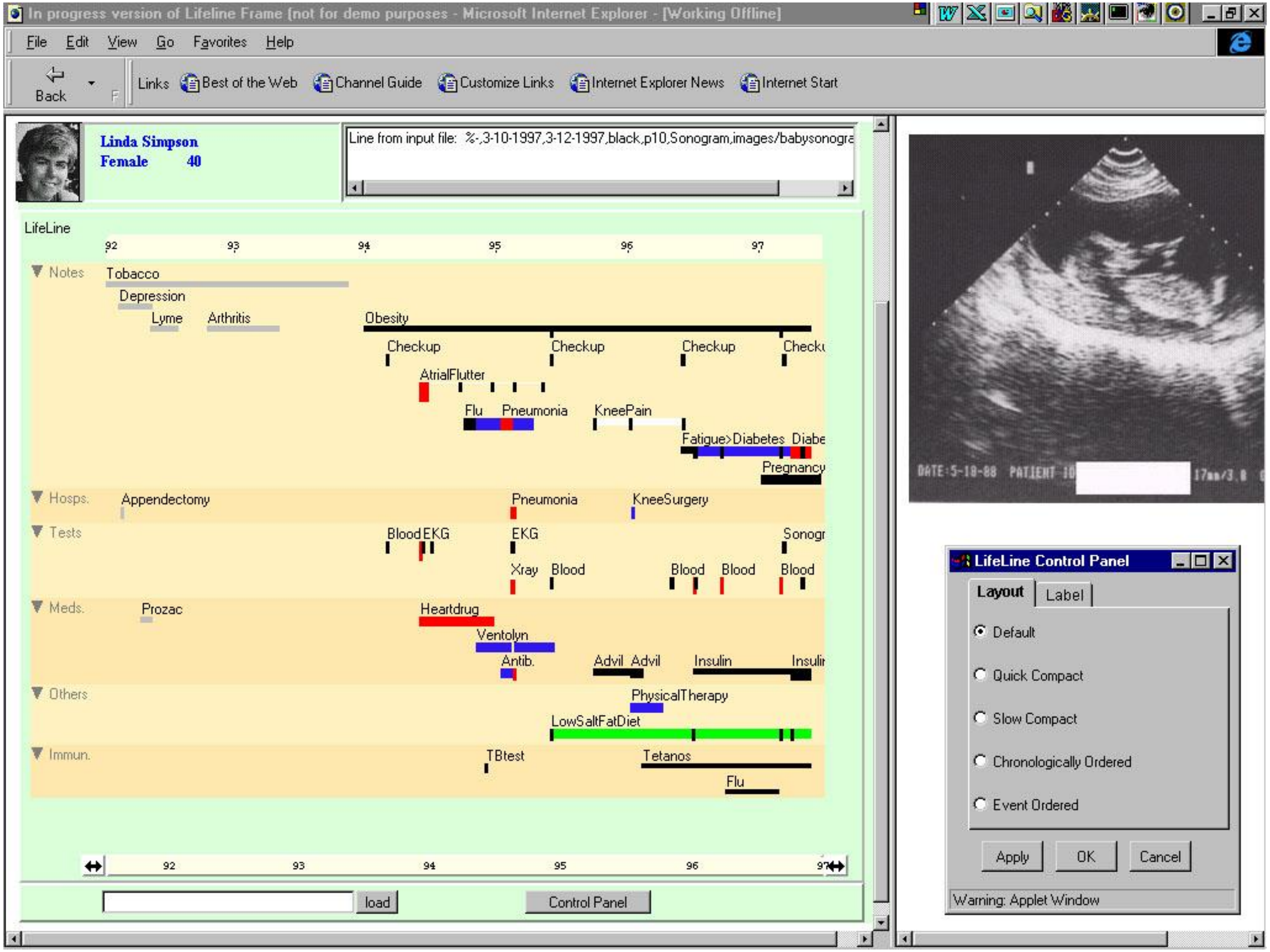


www.demondemon.com



Incidents per Year Grouped By
Country Attacked
Reset
5000
4000
3000
2000
1000
0
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Search
Rank of Incident Count
show between
1
203
max
min
Name
Count
Colombia 5437
Peru 5136
El Salvador 4729
Northern Ireland 3382
Spain 2669
India 2648
Turkey 2243
Sri Lanka 2010
Chile 2004

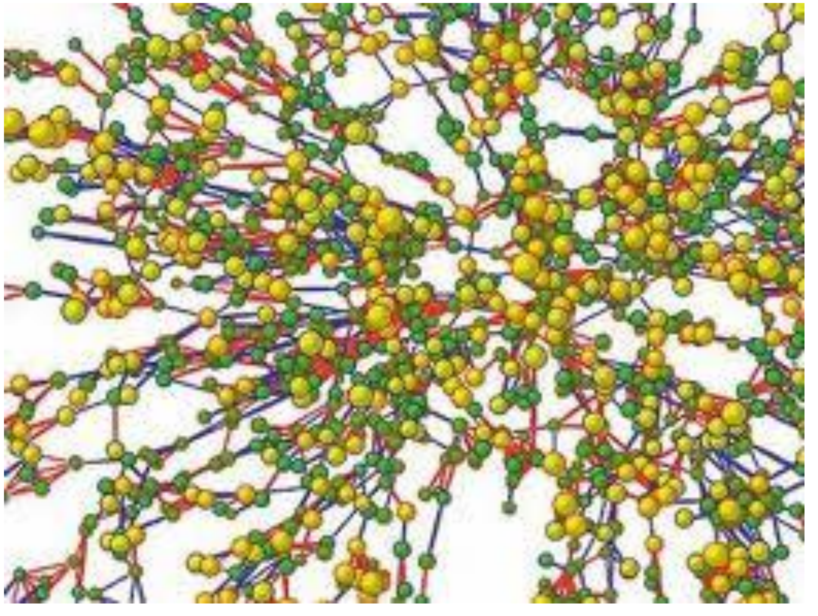
Temporal data - LifeLines



http://www.cs.umd.edu/hcil/lifelines/

Data preprocessing

- Displaying raw data = precise, identification of outliers, missing data, …
- Sometimes preprocessing is required



blog.wpfwonderland.com

Preprocessing – techniques

- Metadata and statistics
- Missing values and data “cleaning“
- Normalization
- Segmentation
- Sampling and interpolation
- Dimension reduction
- Data aggregation
- Smoothing and filtration
- Raster to vector

Metadata and statistics

- Metadata – information for preprocessing
  - Reference point for measurement
  - Unit of measurement
  - Symbol for missing values
  - Resolution
- Statistical analysis
  - Detection of missing records
  - Cluster analysis
  - Correlation analysis

If you had two cans without labels, which would you eat?

Without a label, how would you know which was tuna and which was cat food?

Missing values and data “cleaning“

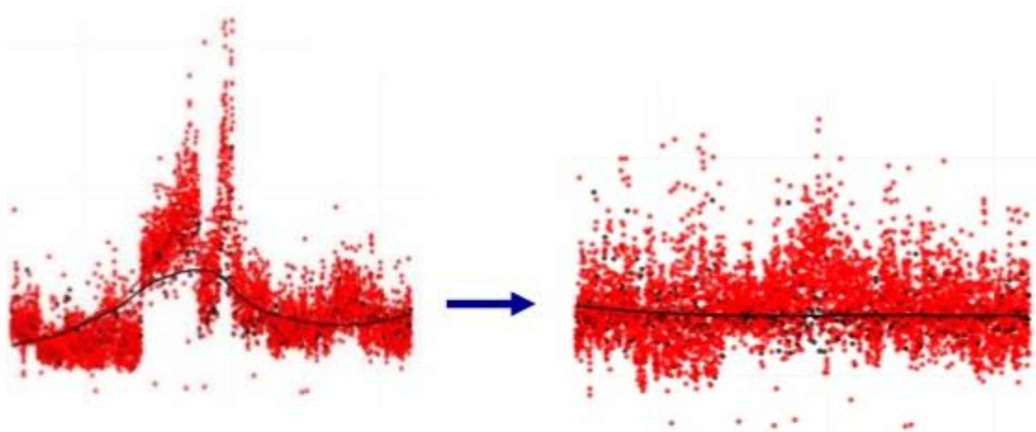
- Removing wrong records
- Assigning a given value
- Assigning an average value
- Assigning a value derived from the nearest neighbor value
- Calculating the value (imputation)

Normalization

- Transformation of the input dataset
- Adjusting values measured on different scales to a notionally common scale
- Normalization to interval [0.0, 1.0]:

$$d_{normalized} = (d_{original} - d_{min}) / (d_{max} - d_{min})$$

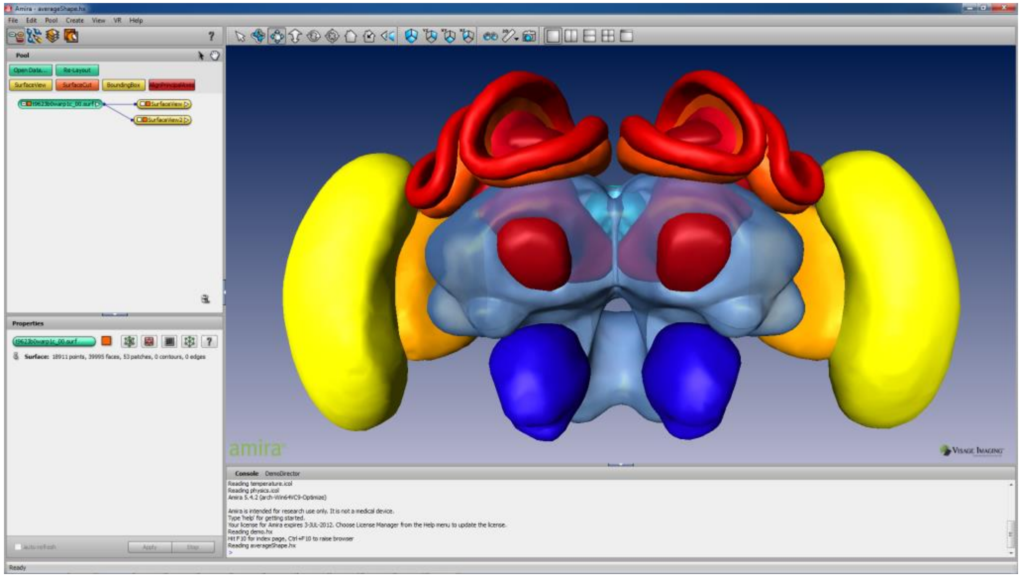
- Clamping according to the threshold values

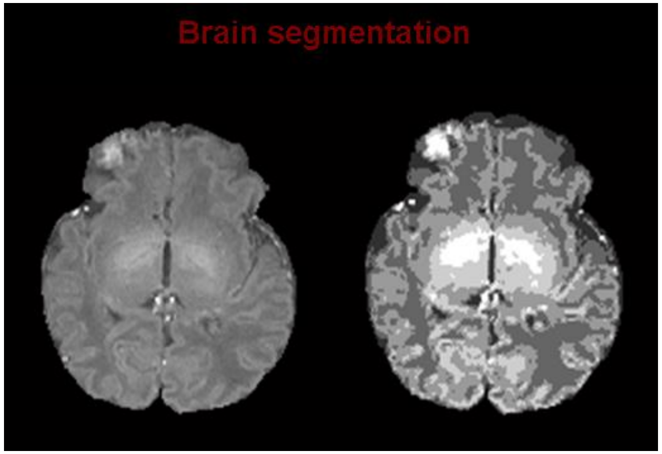


Segmentation

- Classification of input data into given categories

- Split-and-merge iterative algorithm





blog.campaigner.com

Split-and-merge

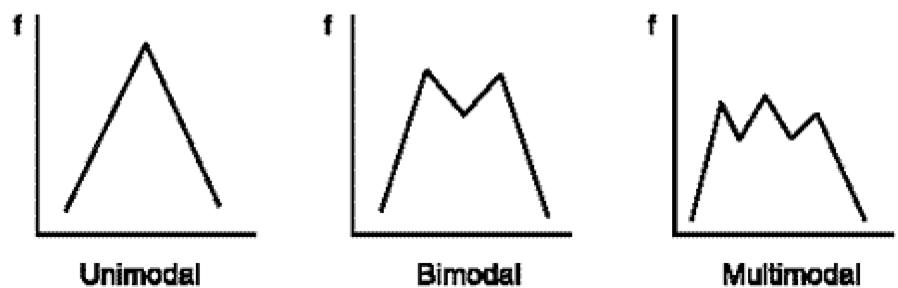
- similarThresh = defines the similarity of two regions with given characteristics
- homogeneousThresh = defines the region homogeneity (uniformity)

```
do {
        changeCount = 0;
        for each region {
                compare region with neighboring ones and find the most similar one;
                if the most similar one is within similarThresh of the current region {
                        connect these two regions;
                        changeCount++;
                }
                evaluate the homogeneity of the region;
                if homogeneity of region is smaller than homogeneousThresh  {
                        split the region to two parts;
                        changeCount++;

        }
} until changeCount  == 0
```

Complex parts of the algorithm

- Determining the similarity of two regions
- Evaluating the homogeneity of a region – histogram



www.statcan.gc.ca

- Splitting the region

Possible problem

- Infinite loop by repeating split and merge steps of the same region

- Solution:
  - Changing the threshold value for similarity or homogeneity
  - Taking into account other region properties (e.g., size and shape of regions)

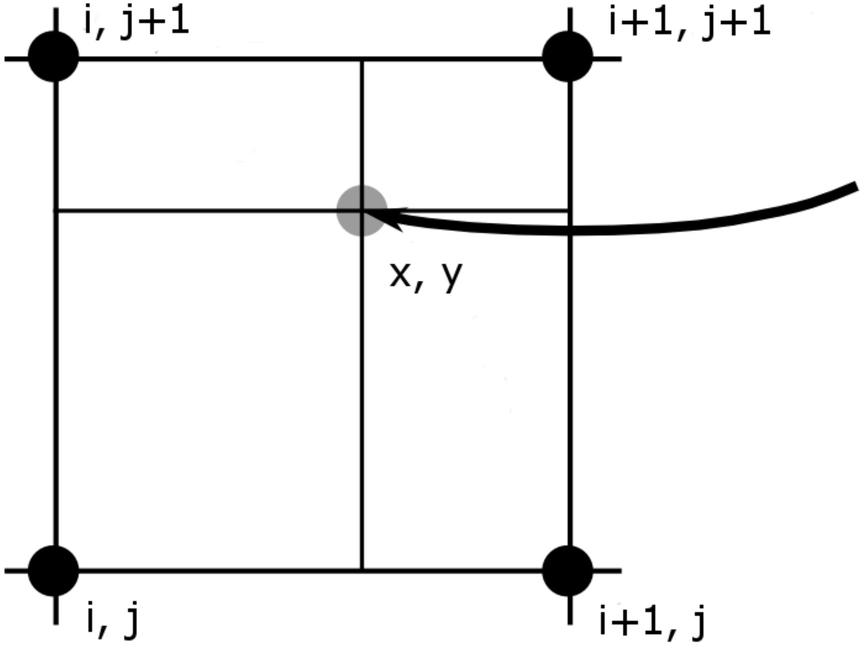
Sampling and interpolation

- Transformation of input data
- Interpolation = sampling method
  - Linear interpolation
  - Bilinear interpolation
  - Non-linear interpolation

inperc.com

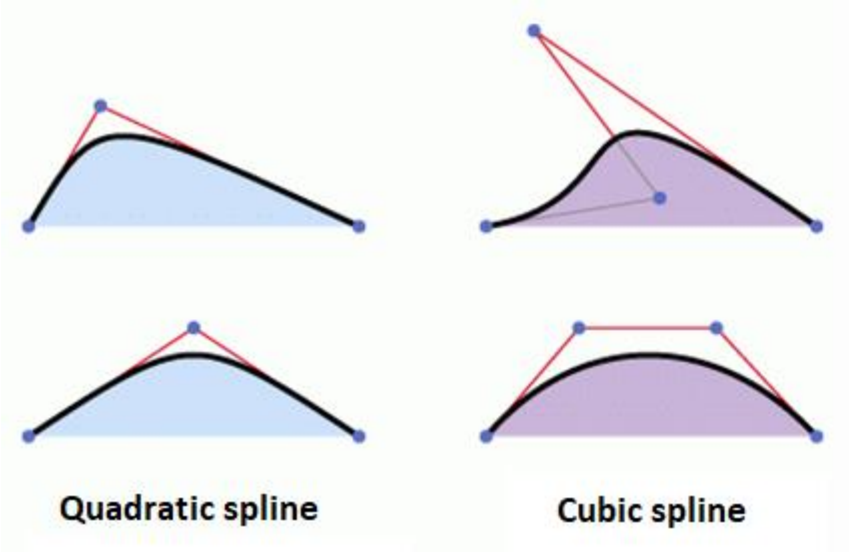
Bilinear interpolation

- Uniform grid
- Horizontal + vertical interpolation



Non-linear interpolation

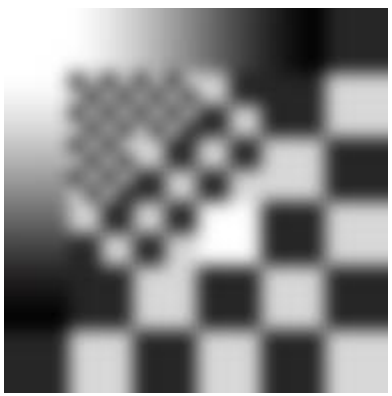
- Problems with linear interpolation – zero connectivity in grid points
- Solution = using quadratic and cubic splines



Result

- Original image (24x24 pixels)

cubic B-spline filter

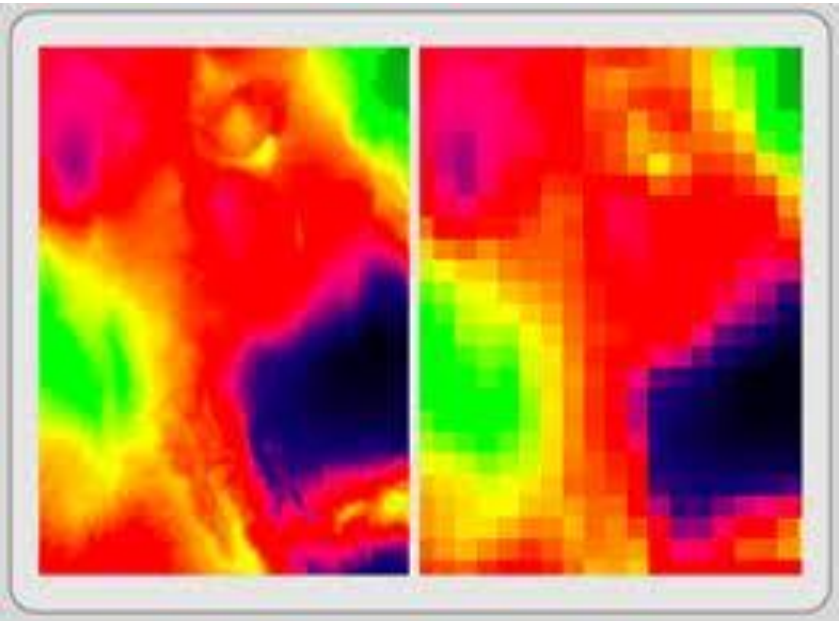


Catmull-Rom

research.cs.wisc.edu

Resampling

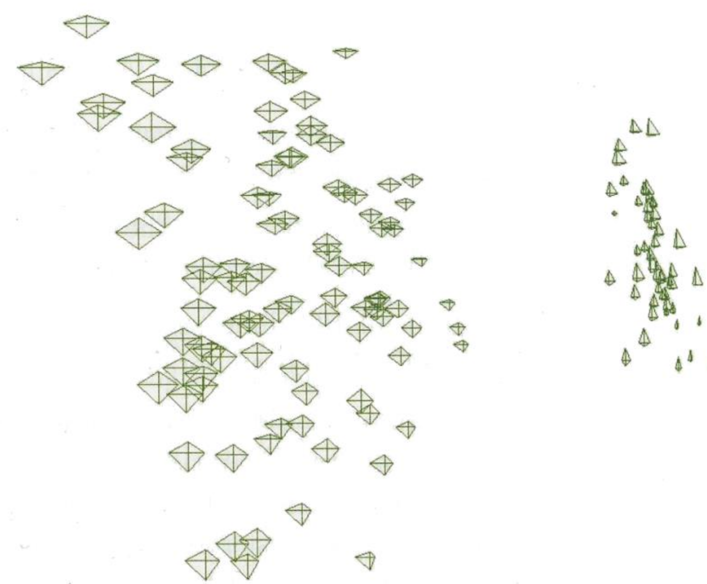
- Pixel replication
- Neighbor averaging
- Data subsetting



giscommons.org

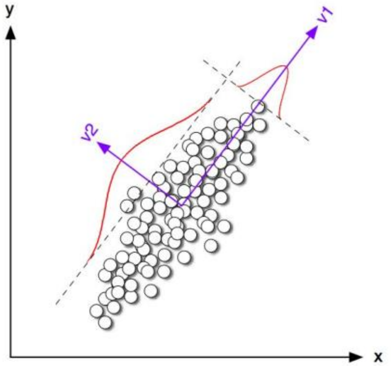
Dimension reduction

- Preparing multidimensional data for displaying
- Keep as much original information as possible
- Techniques:
  - **PCA** (principal component analysis)
  - **MDS** (multidimensional scaling)
  - **SOMs** (Kohonen self-organizing maps)



Interactive Data Visualization - Fondations, Techniques and Applications. Matthew Ward

PCA intuitively

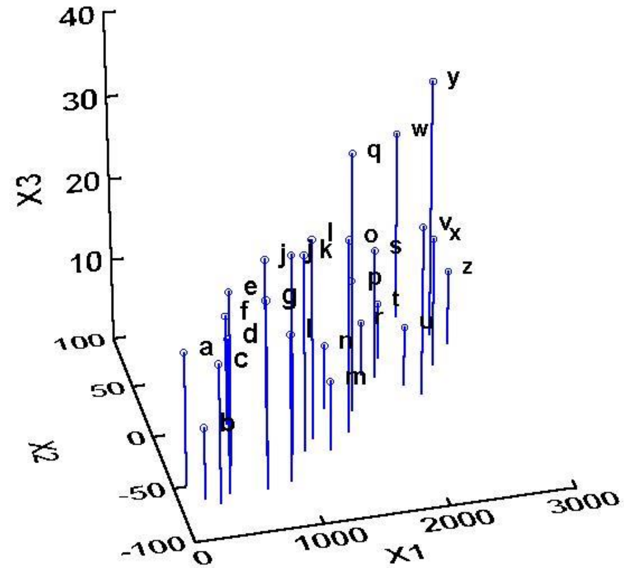


web.media.mit.edu

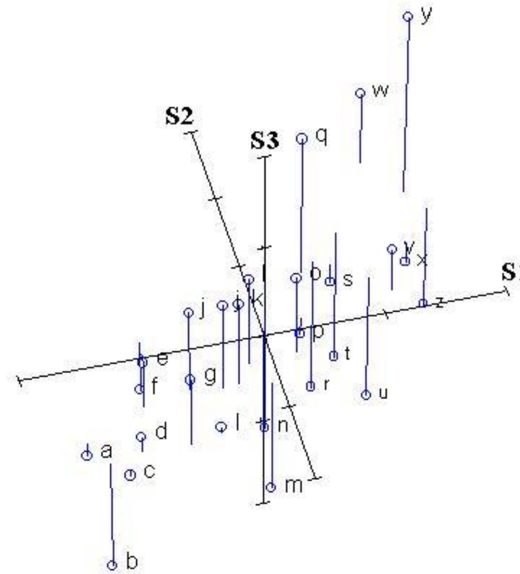
1. We select a line in space visualizing n-dimensional data. This line covers the most of the input data items and is called the first principal component (PC).
2. We select a second line perpendicular to the first PC, this forms the second PC.
3. We repeat this until we proces all PC dimensions or until we reach a desired number of principle components.

PCA – principal component analysis

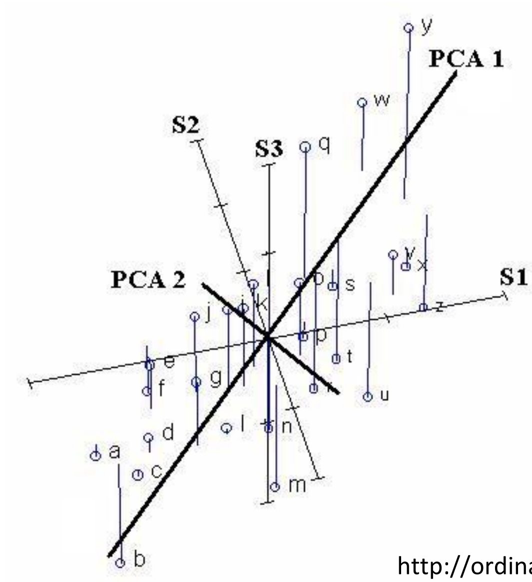
1)



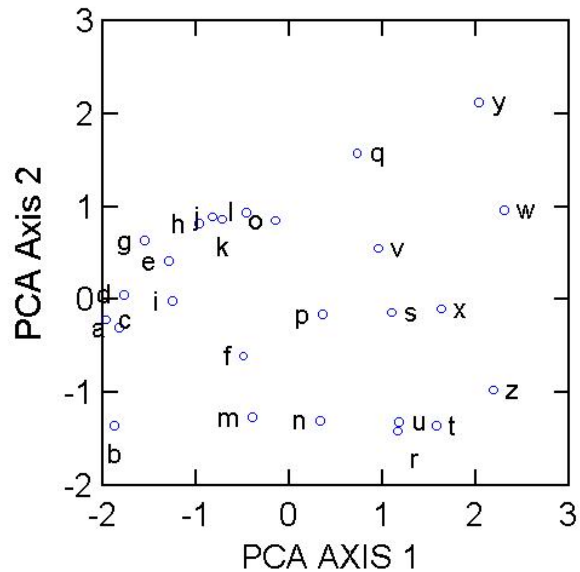
2)



3)



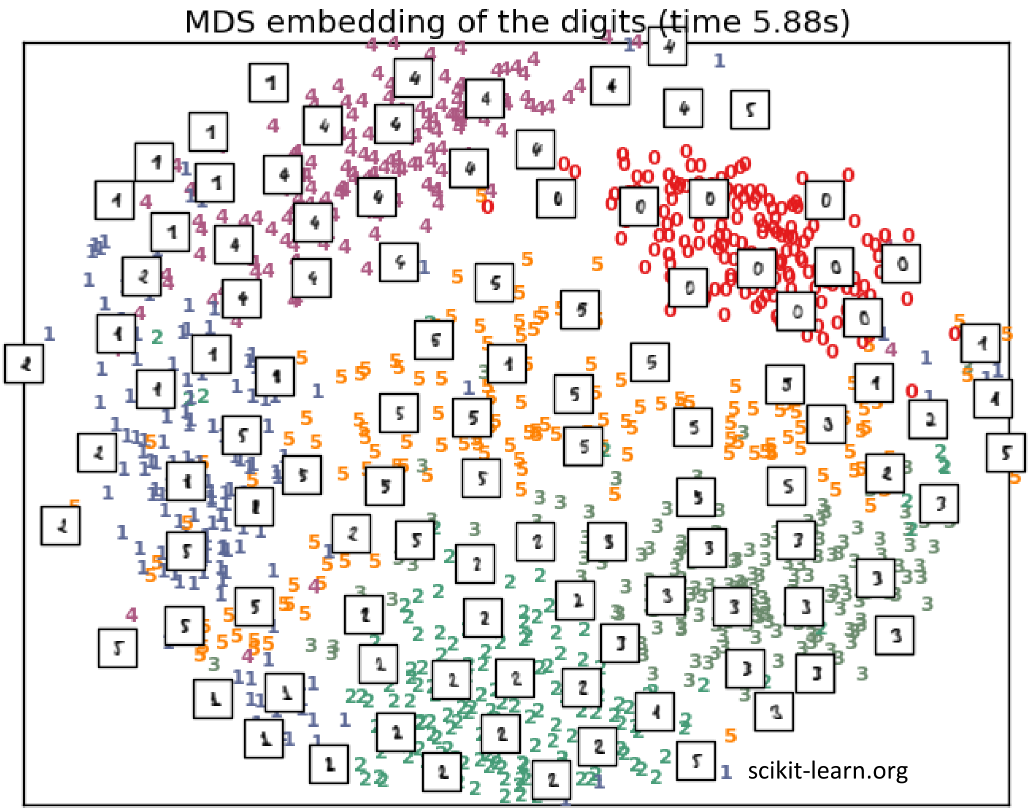
4)



http://ordination.okstate.edu/PCA.htm

MDS – multidimensional scaling

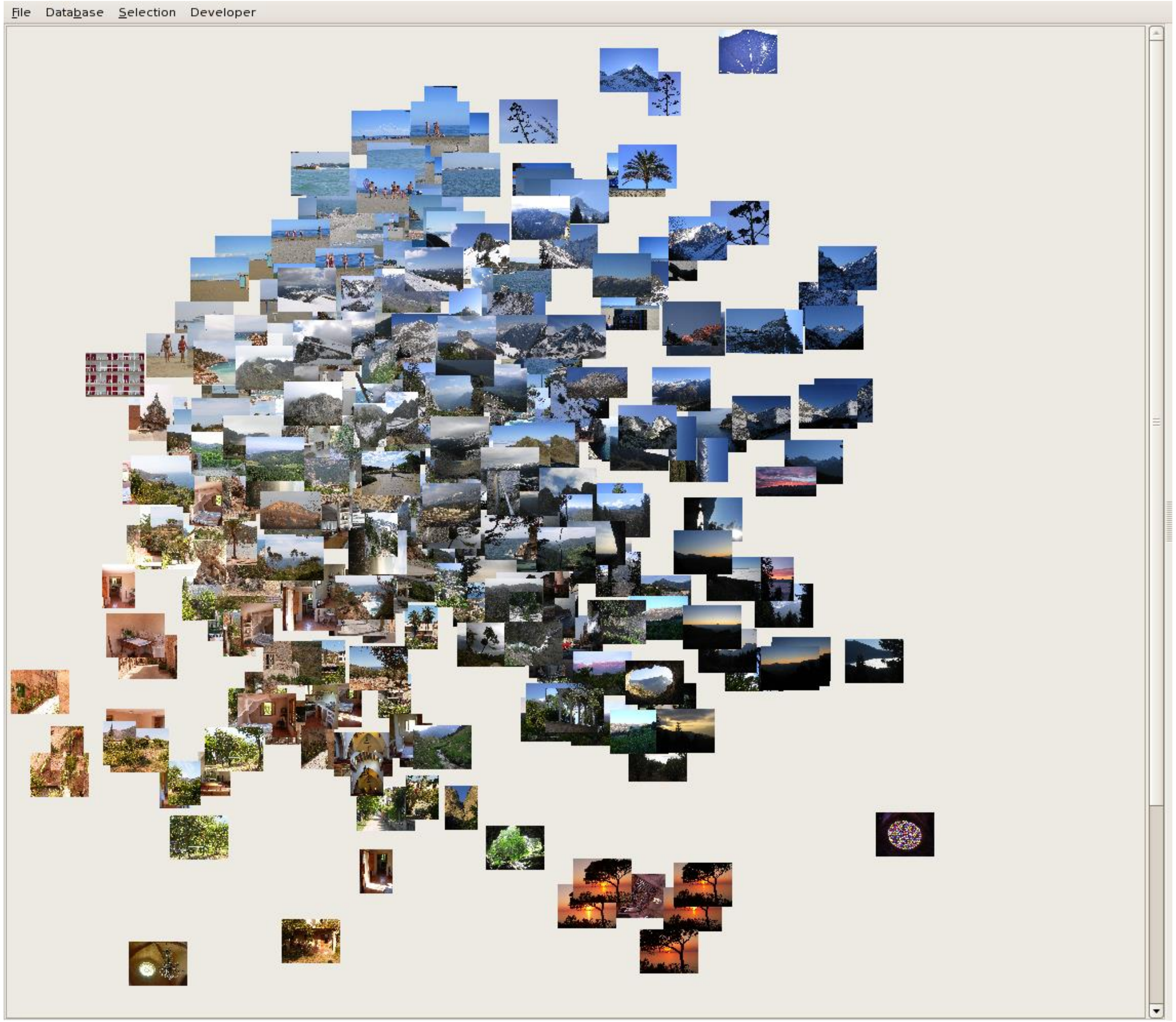
- Based on comparing the distances between individual data items in original and reduced space



MDS – multidimensional scaling

1) We calculate the distances between all pairs of data points in the original space. If we have *n* points as an input, this step requires n(n – 1)/2 operations.
2) We transfer all input data points to points in the reduced dimension space (often randomly).
3) We calculate *stress*, i.e., difference in distance between points in the original and reduced space. This can be done using different approaches.
4) If the average and cummulated *stress* value is smaller than the user-defined threshold, the algorithm ends and returns the result..
5) If the *stress* value is higher than the threshold, for each point we calculate a directional vector pointing to the desired shift direction in order to reduce *stress* between this point and the other points. This is determined as the weighted average of vectors between this point and its neighbors and its weight is derived from *stress* value calculated between individual pairs. Positive *stress* value repulses the points, negative one attracts them. The higher the absolute value of *stress,* the bigger movement of point.
6) Based on these calculations we transform tha data points to the target reduced dimension, according to the calculated vectors. Return to step 3 of the algorithm.

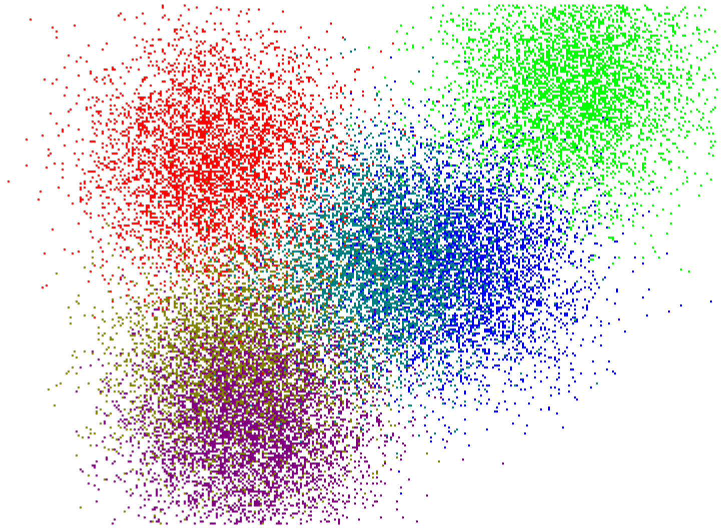
MDS – multidimensional scaling

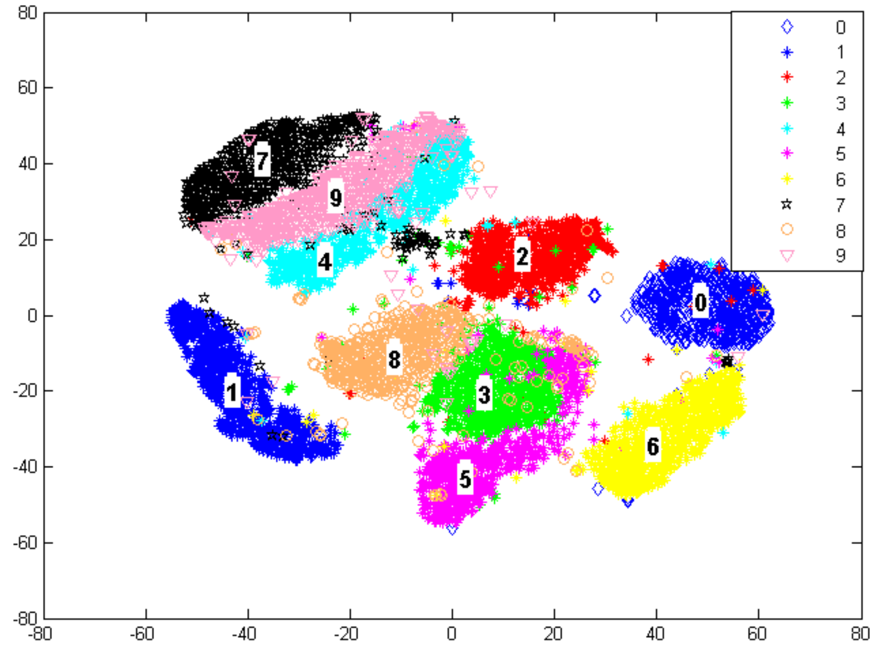


lear.inrialpes.fr/src/yorg/doc/index.html

Data aggregation

- Aggregation = clustering of similar data to groups.





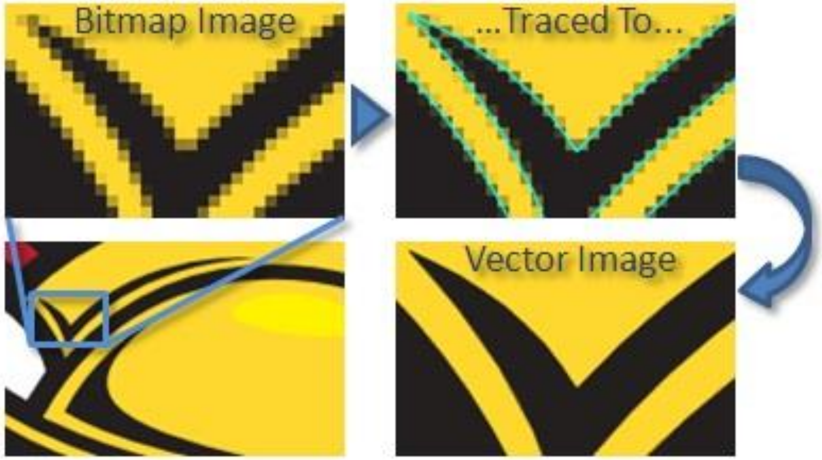
Smoothing and filtration

- Signal processing techniques – noise removal
- **Convolution** in 1D:

$$p_i = \frac{p_{i-1}}{4} + \frac{p_i}{2} + \frac{p_{i+1}}{4}$$

Converting rasters to vectors

- Used for:
  - Data compression
  - Image comparison
  - Data transformation
- Methods:
  - Thresholding
  - Region growing
  - Edge detection
  - …



Conclusion

- The techniques mentioned improve the efficiency of visualization
- We have to inform the user that the data has been transformed!!!