# Introduction to Scientific Visualization

*Past, Present and Future*

**Tobias Schiebeck**

*Open to Europe Intensive Programme – TRABHCI*

*29th March - 9th April 2011*

*Universidad Politécnica de Valencia*

# Overview

- History of Visualization
- The Visualization Pipeline
- Data Classification
- Visualization Techniques
- Overview of toolkits available

# What is Visualization?

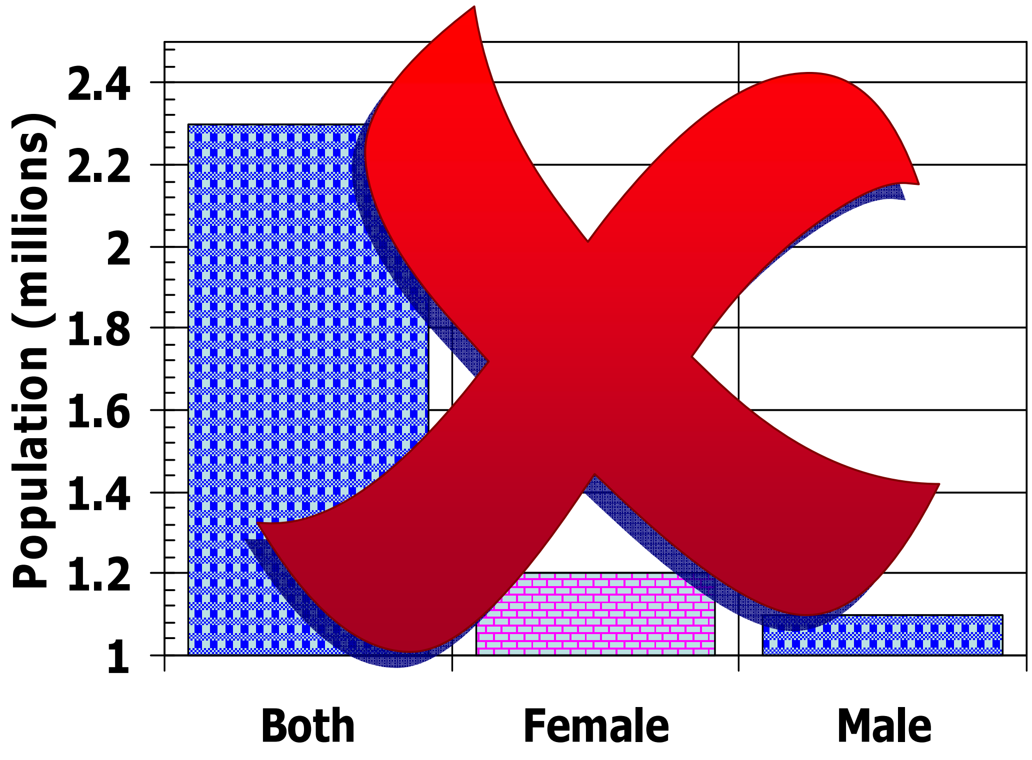
- Using computer-generated pictures to gain information and understanding from data (geometry) and relationships (topology). The impacts of such visualizations effect the methodology of science and engineering.
- Graphically exploring data to gain insight
- R W Hamming, Numerical Methods for Scientists & Engineers, 1962

  *"The purpose of [scientific] computing is insight not numbers"*

  – The goal of visualization is to leverage existing scientific methods by providing new scientific insight through visual methods.
- It differs from presentation graphics … two phases:
  – Exploration: understanding the data
  – Presentation: communicating the results

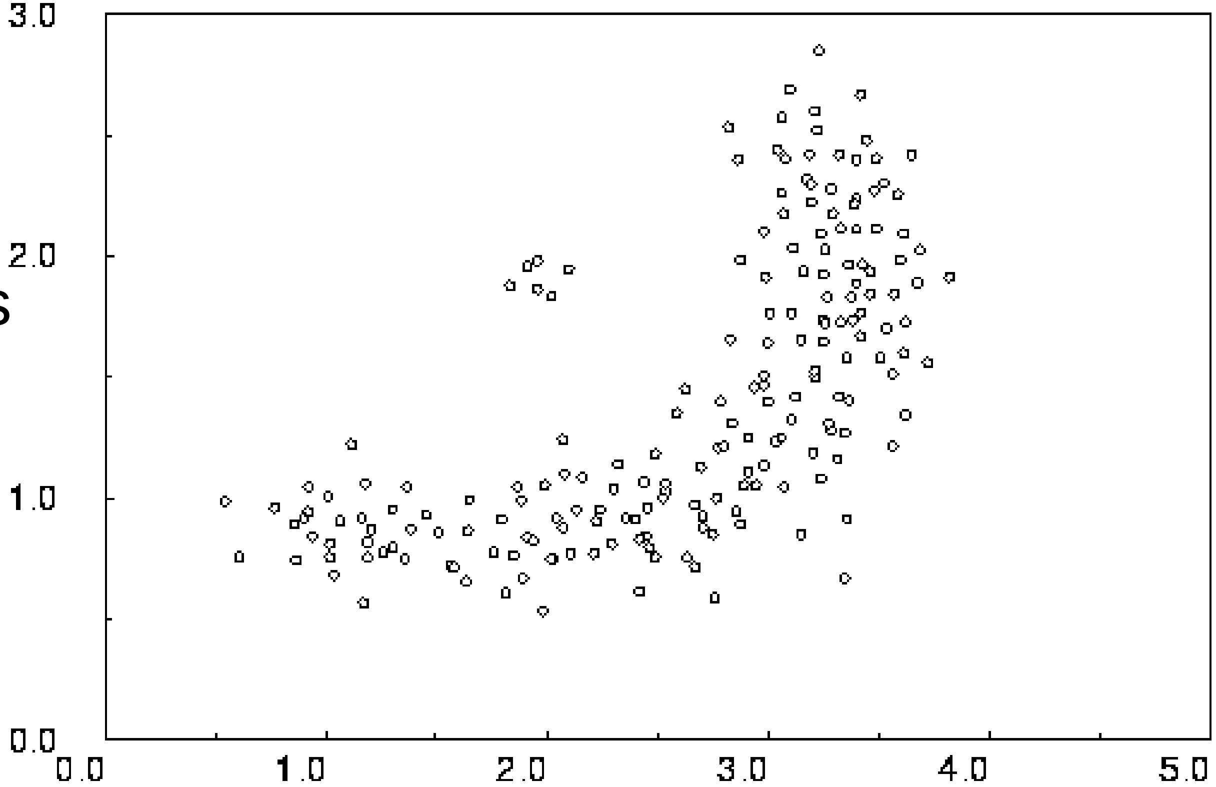
# Why Draw a Graph?

- Only two numbers
- Misleading scale
- Superfluous sum
- Distracting patterns
- Achieves nothing!



# A Better Graph

- Summarizes data
- Reveals outliers
- It communicates



MANCHESTER 1824

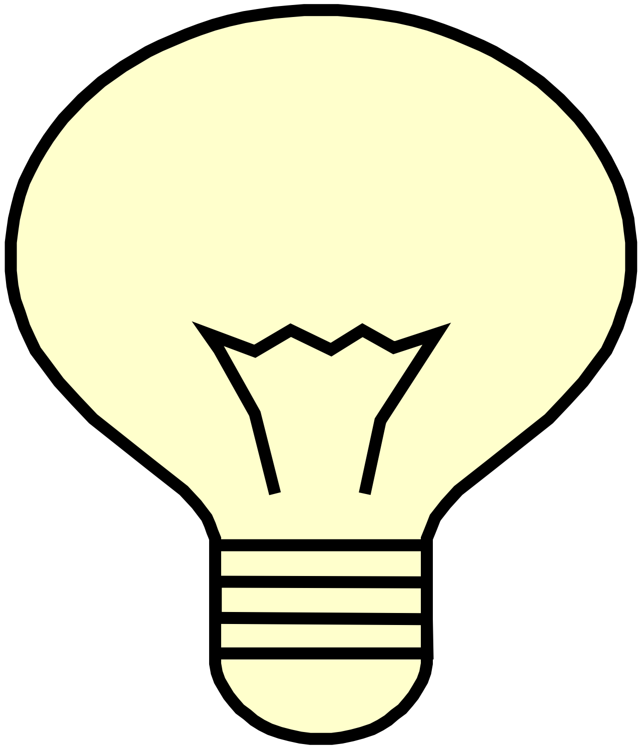
The University of Manchester

# Effective Graphs

- Reasonable amount of data
- Describe behaviour
- Be truthful

*There cannot be too much emphasis on our need to see behaviour... Graphs force us to note the unexpected; nothing could be more important*

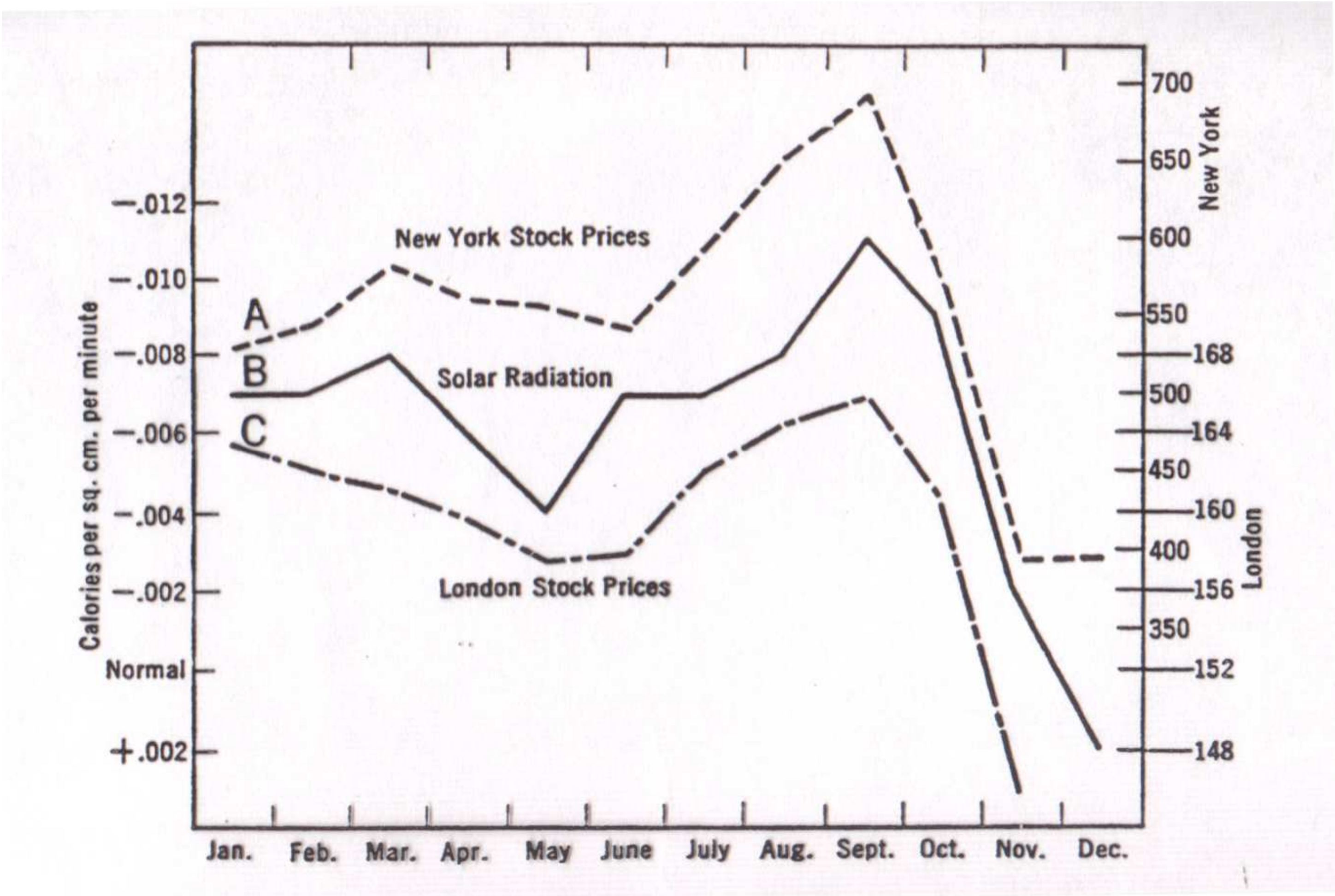
Tukey (1977)



# Excellence in Display

- Show the data
- Induce thought
- Avoid Distortion
- Present Much
- Make large datasets coherent
- Encourage the eye to compare
- Reveal Several Levels
- Serve a purpose
- Integrated with the verbal or text

# Silly Theories



MANCHESTER
1824

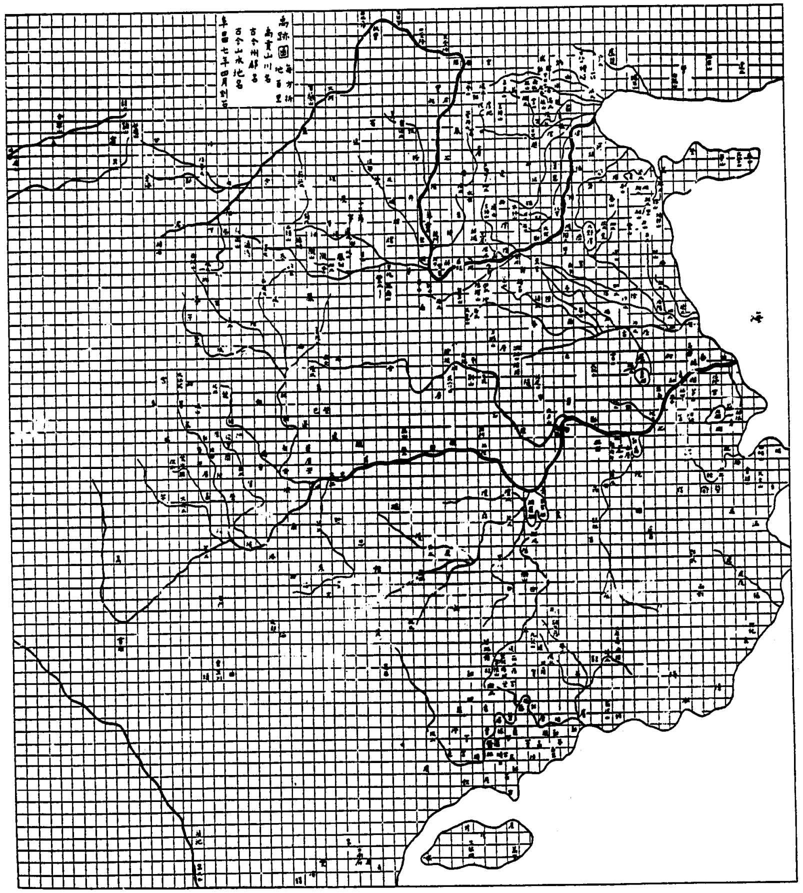
The University of Manchester

# Some History

# The History of Visualization

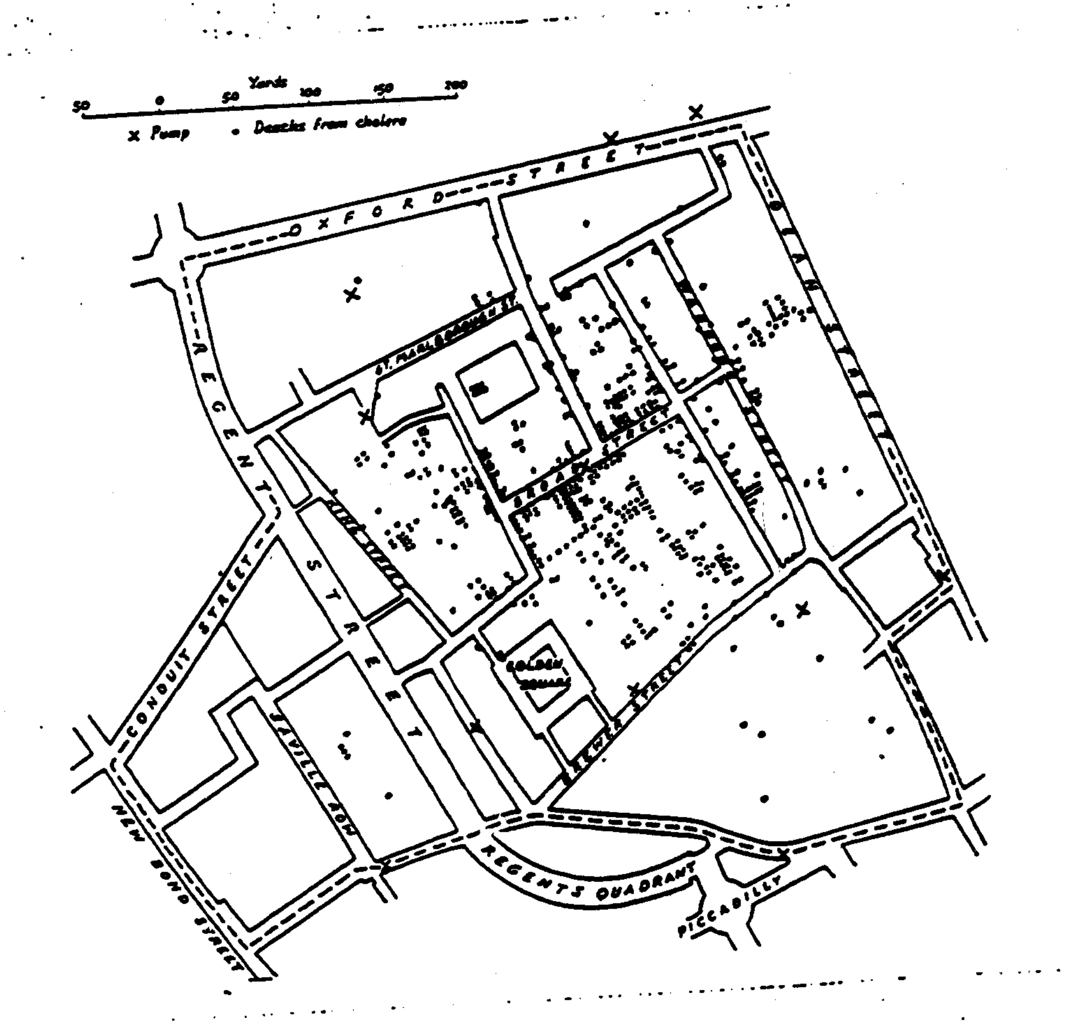
- The most cited paper is McCormick et al, Visualization in Scientific Computing. Computer Graphics 21(6), 1987
- It was concerned with the large amounts of data being produced from simulations on supercomputers
- It introduced the terms:
  - Fire hoses of data from simulations
  - Vast warehouses of data left unused

# Yu the Great (1137)

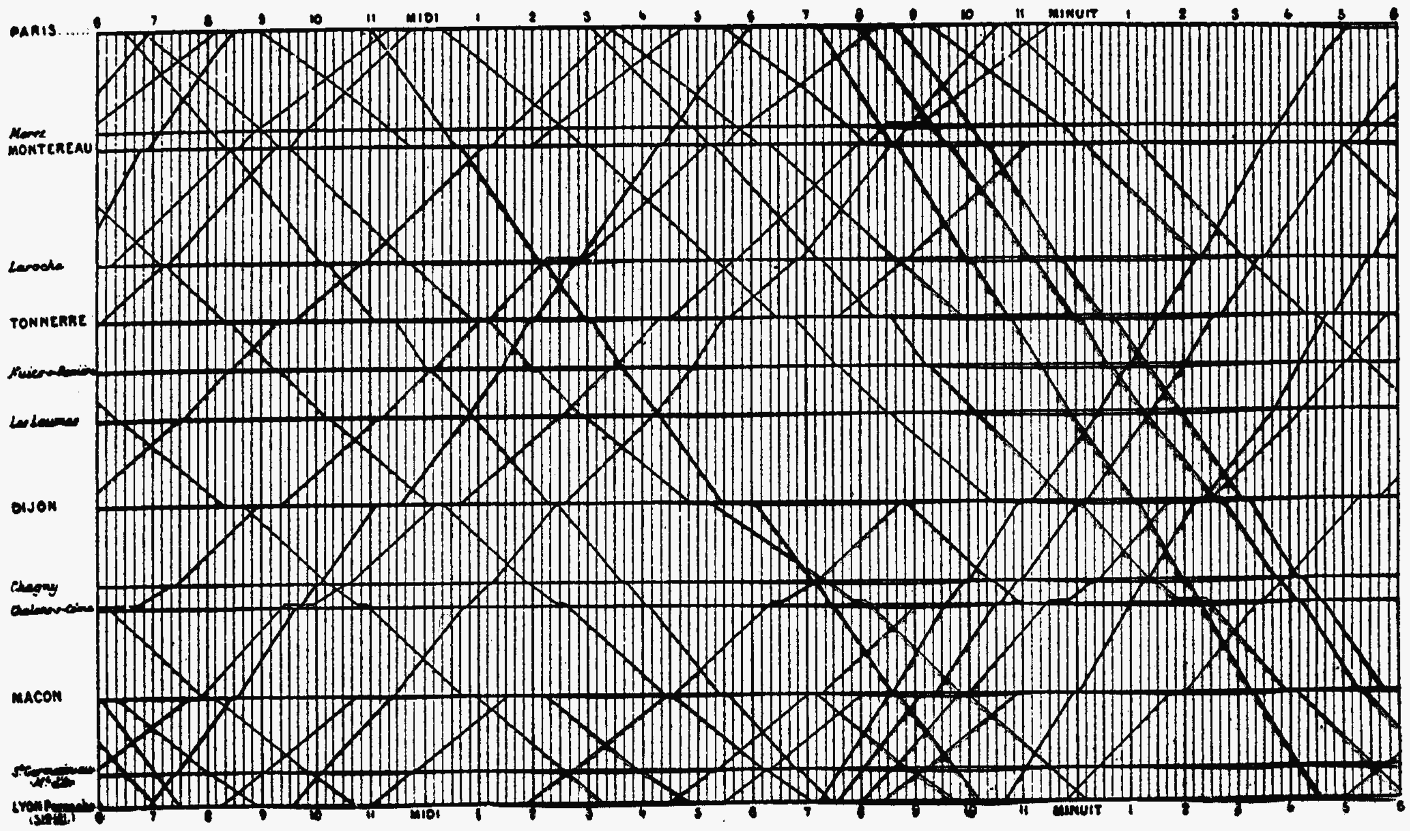


E. Chavannes, "Les Deux Plus Anciens Spécimens de la Cartographie Chinoise," *Bulletin de l'École Française de l'Extrême Orient*, 3 (1903), 1–35, Carte B.

# Cholera in Ye Old London (1854)

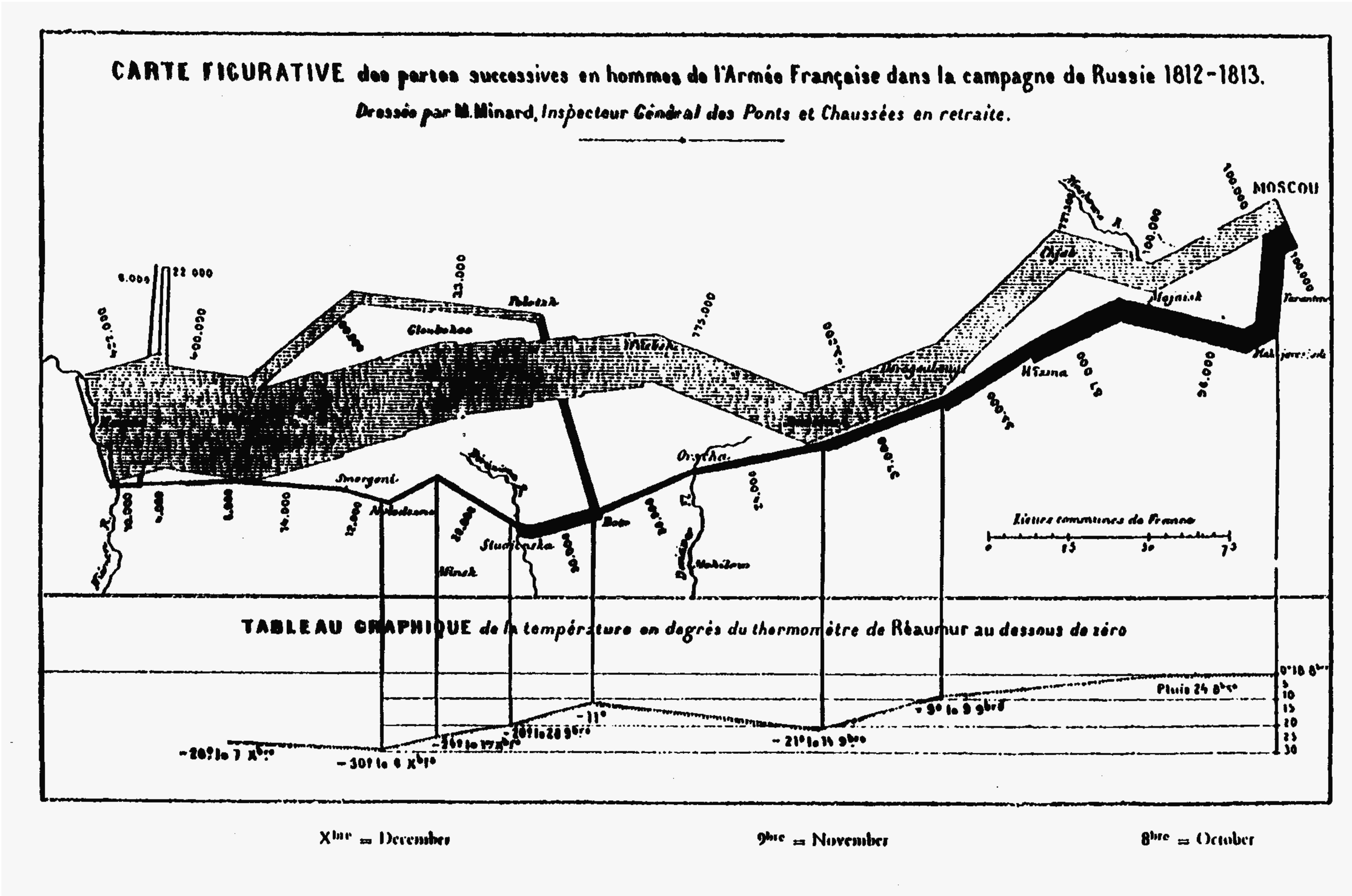


# French Train Timetable (1885)




E. J. Marey, *La Méthode Graphique* (Paris, 1885), p. 20. The method is attributed to the French engineer, Ibry.

# Fate of Napolean’s Army in Russia

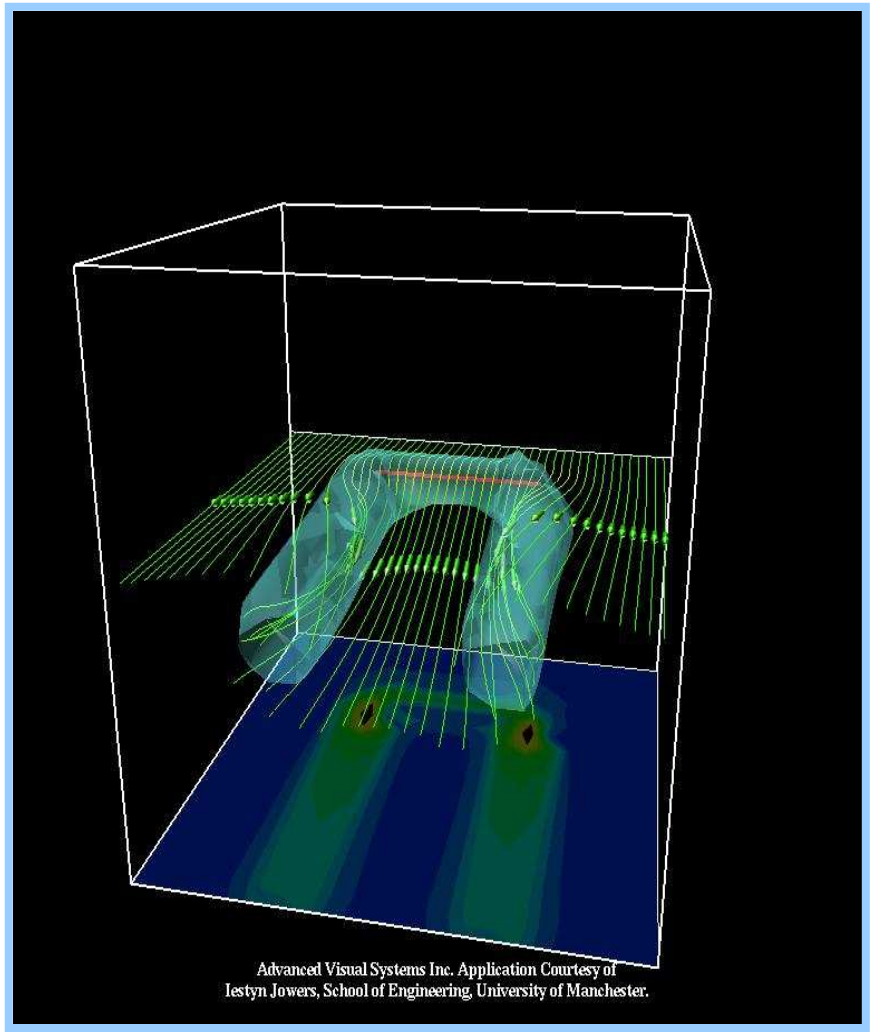


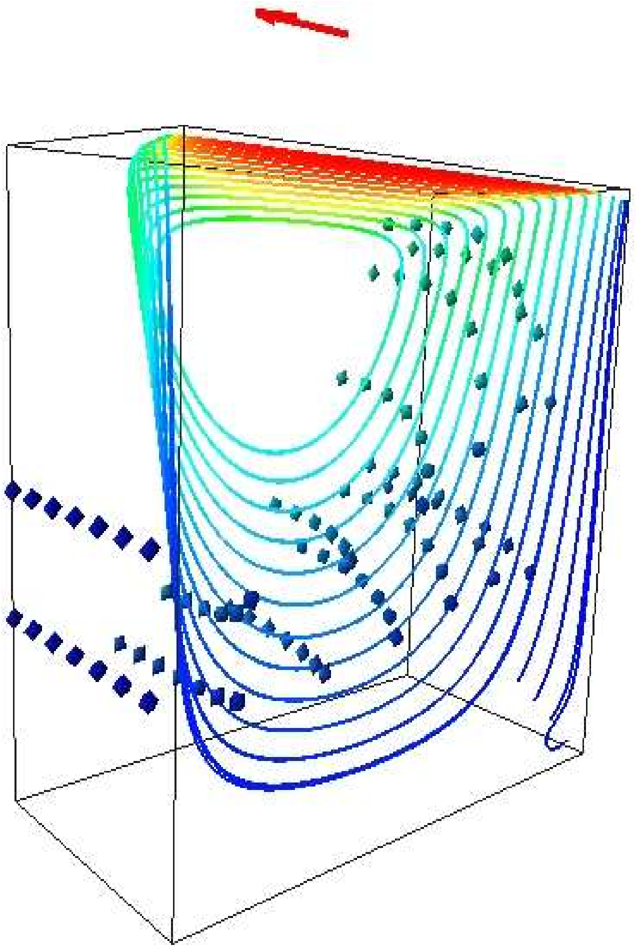
# The History of Visualization (2)

- Americans discovered it in 1987!
- But it didn't all begin in 1987...
- There are many examples of visualization before 1987 and some of these pre-date the invention and use of computers:
  - 1137 - Maps of the tracks of Yu the Great
  - 1686 - E. Halley, worldwide trade winds and monsoons
  - 1782 - M Du Carla, Use of isolines for representing height
  - 1854 - Dr J Snow, location of deaths from cholera in central London
  - 1885 – Marey, Train timetables

# Examples of Manchester Work

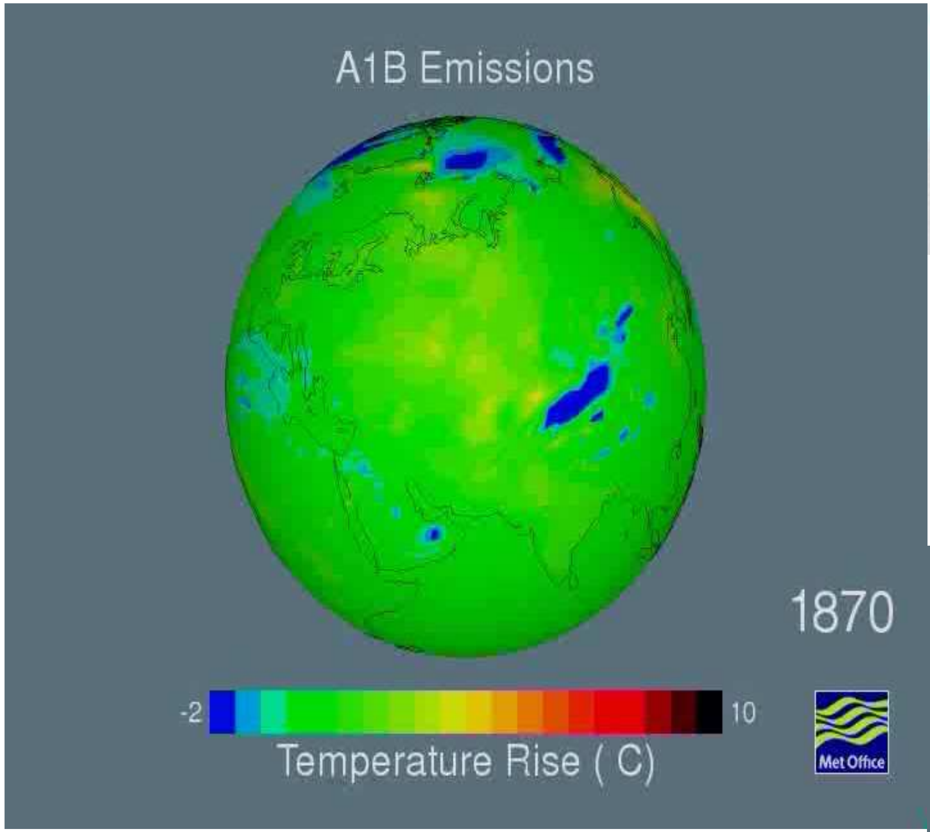
# Virtual Wind Tunnel

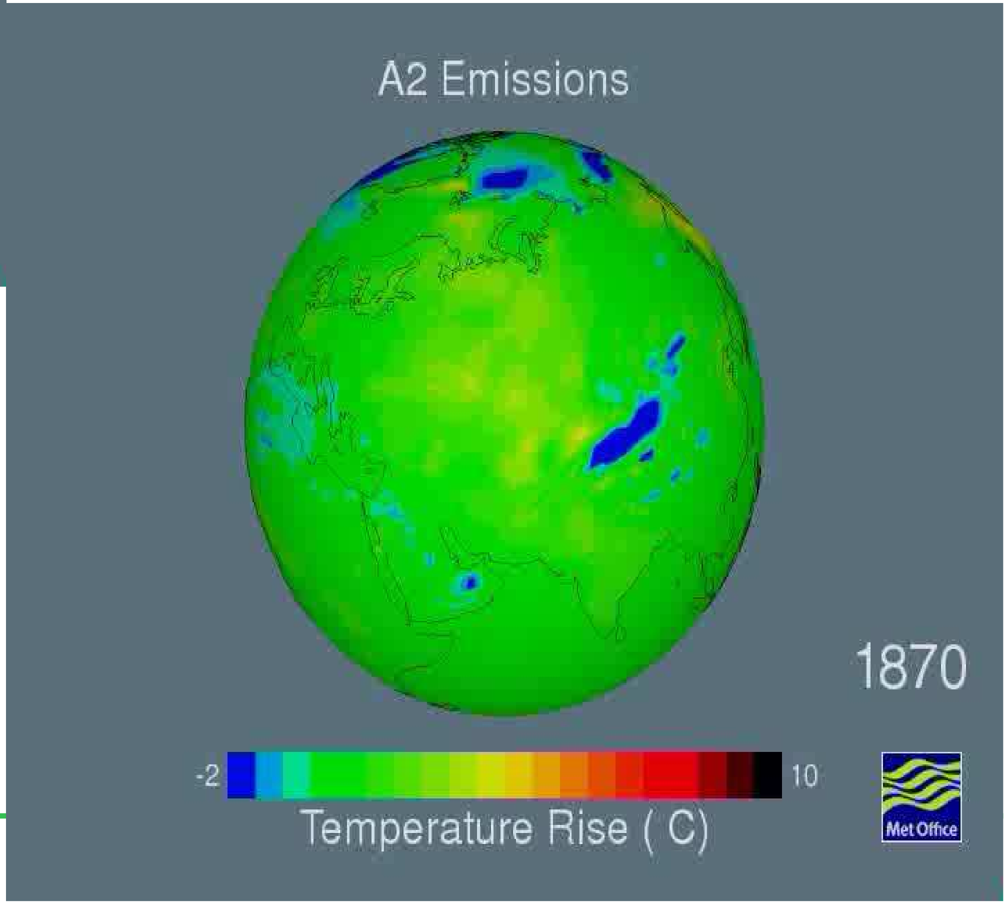


# Little Island in the Sun

# Climate warming?



# Do the Dishes

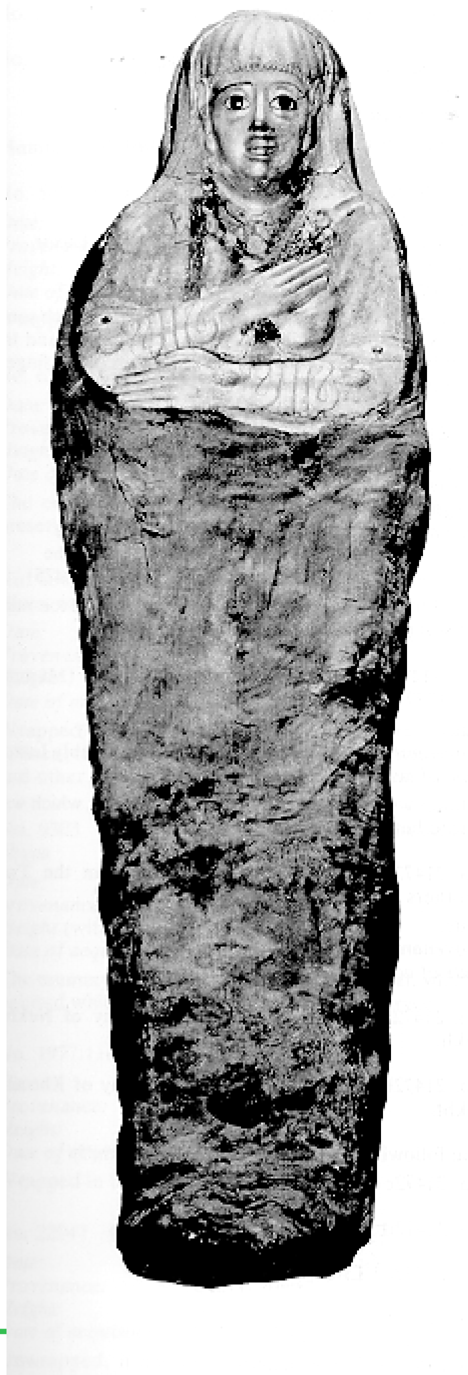
MANCHESTER 1824

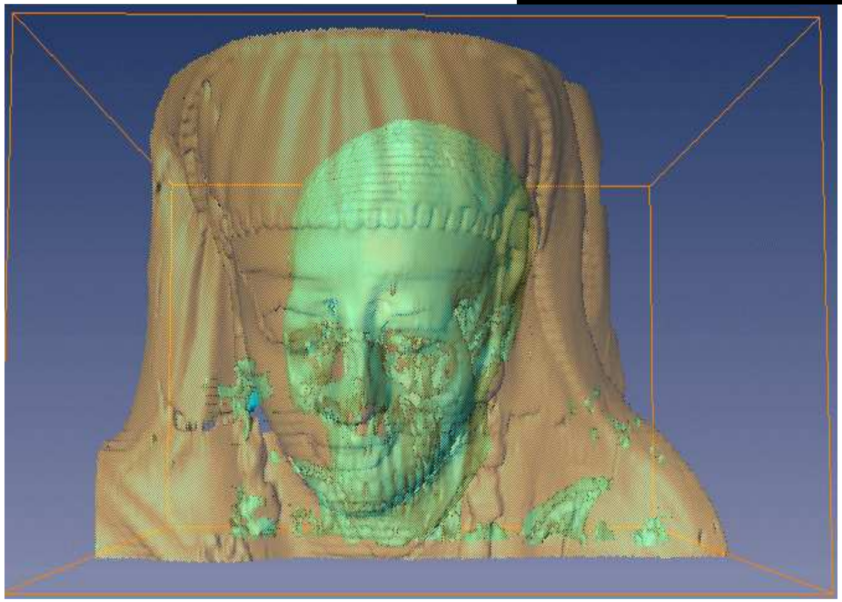
The University of Manchester

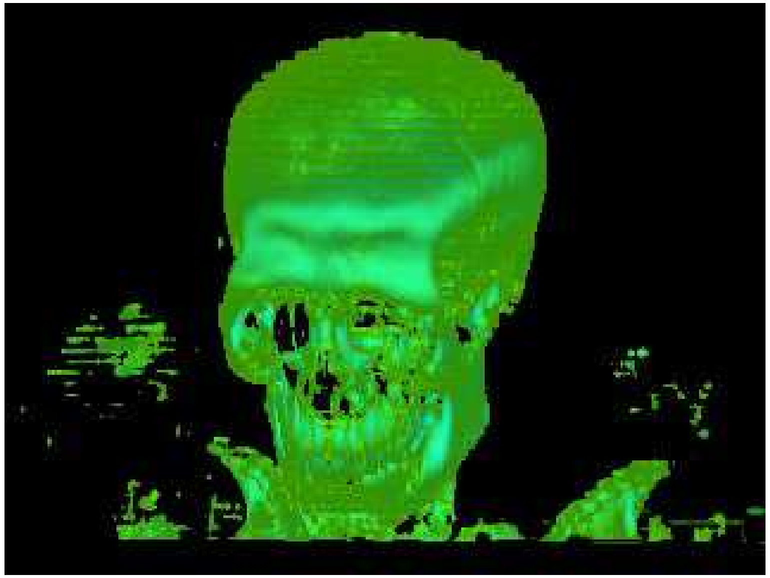
# My TV Aerial

# Non Destructive Testing on My Mummy

# My Mummy







# Types of Visualization

- Information Visualization
  - Data is abstract (financial, statistical)
  - physical entities do not contribute to (or possibly distract from) the properties of the effect shown
  - Example:
    - *The transfer of £1,000,000 between two bank accounts does not need to be shown using £10 notes*

# Types of Visualization

- Scientific Visualization
  - Data is related to physical coordinates
  - Visualization of the object without the physical environment, reduces or defeats the objective
  - Example:
    - *A flow through a valve cannot be shown without at least indicating the location of the edges of the valve*

# Information Visualization

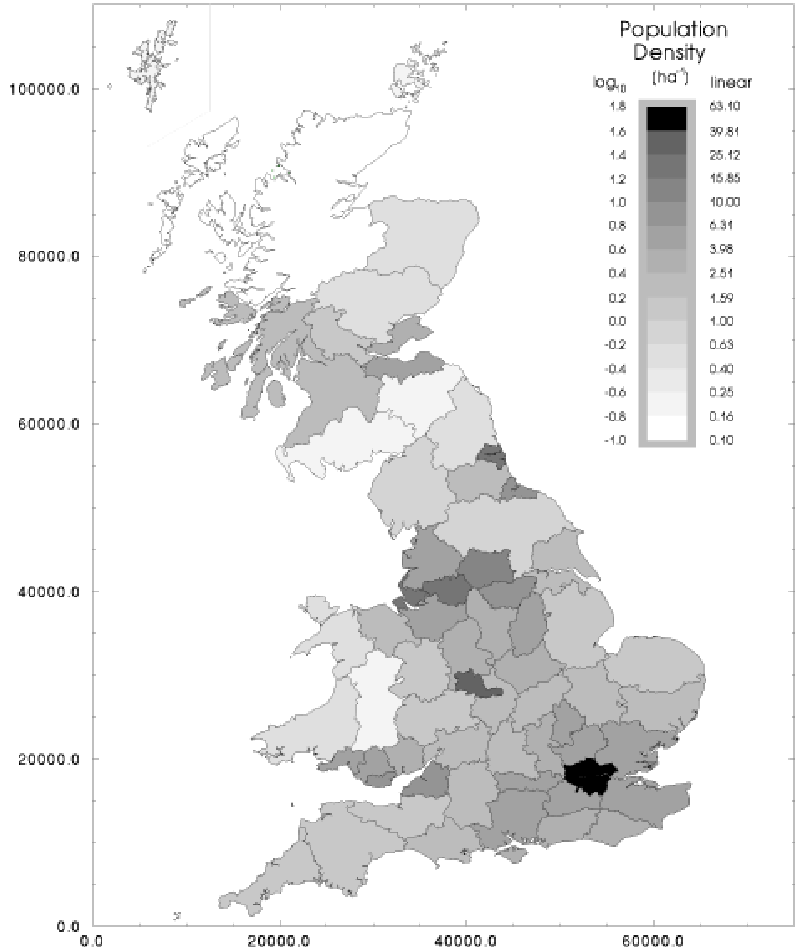
Data Maps

Time series

Relational

Narrative

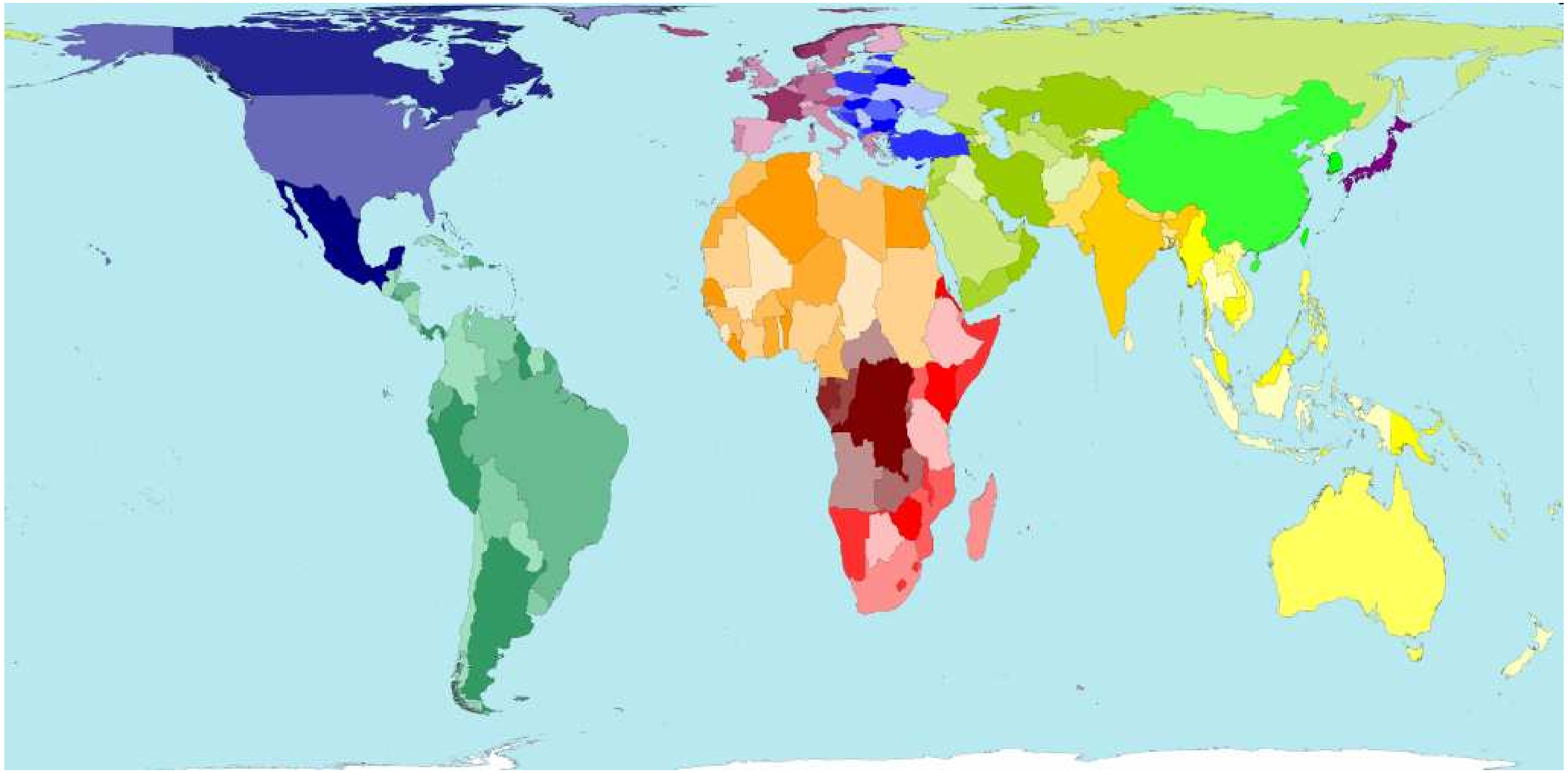
# Data Maps



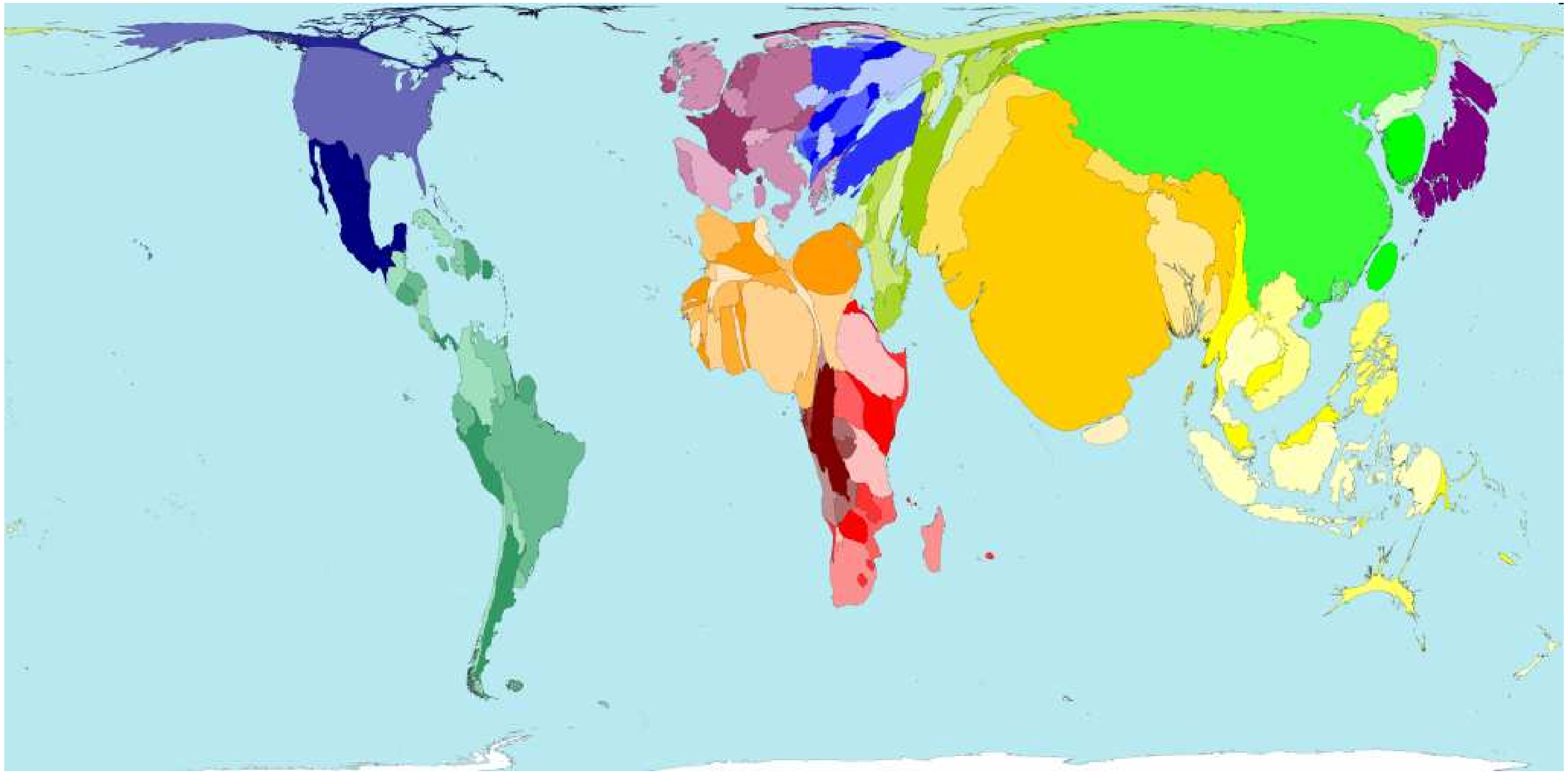
Population Density
(ha$^{-1}$)
log$_{10}$
linear
1.8 63.10
1.6 39.81
1.4 25.12
1.2 15.85
1.0 10.00
0.8 6.31
0.6 3.98
0.4 2.51
0.2 1.59
0.0 1.00
-0.2 0.63
-0.4 0.40
-0.6 0.25
-0.8 0.16
-1.0 0.10
100000.0
80000.0
60000.0
40000.0
20000.0
0.0
0.0
20000.0
40000.0
60000.0

# Land Area

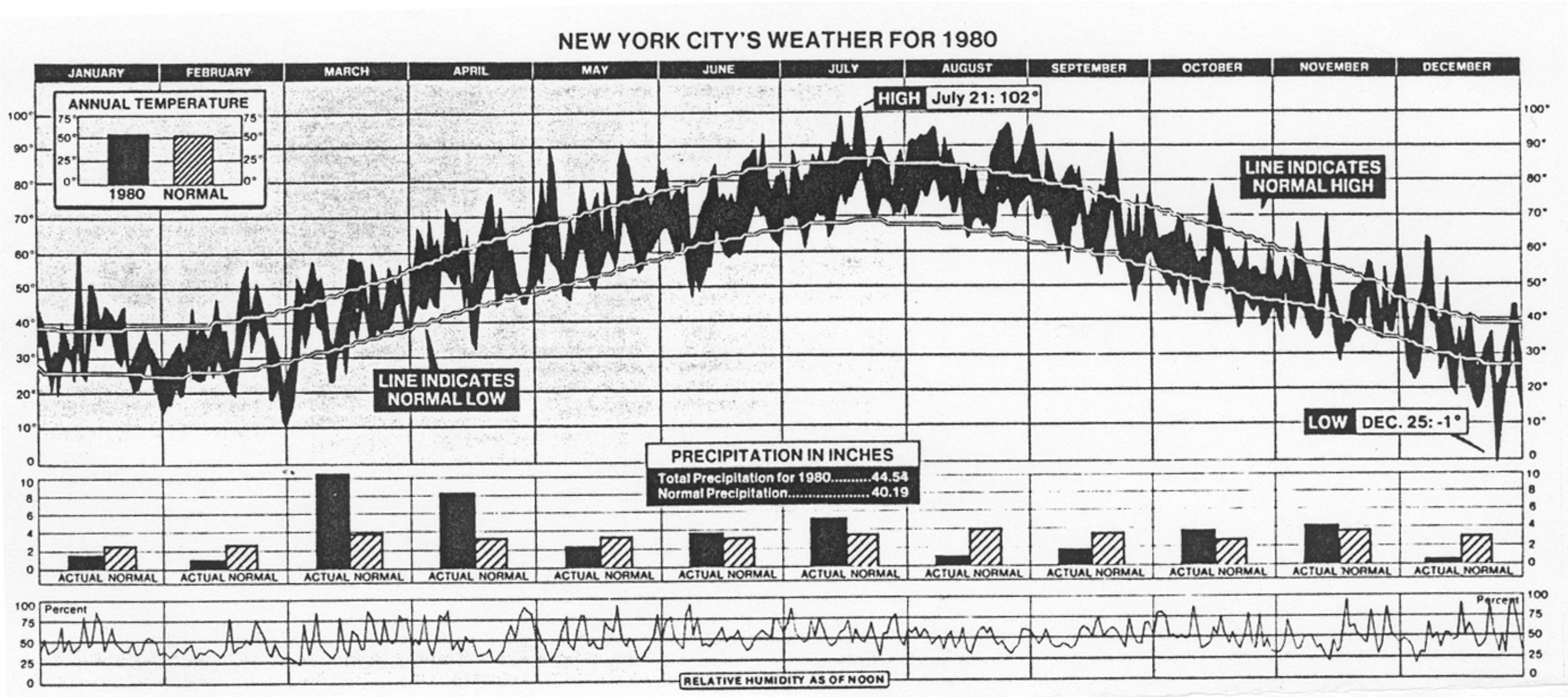
- www.worldmapper.org



# Population



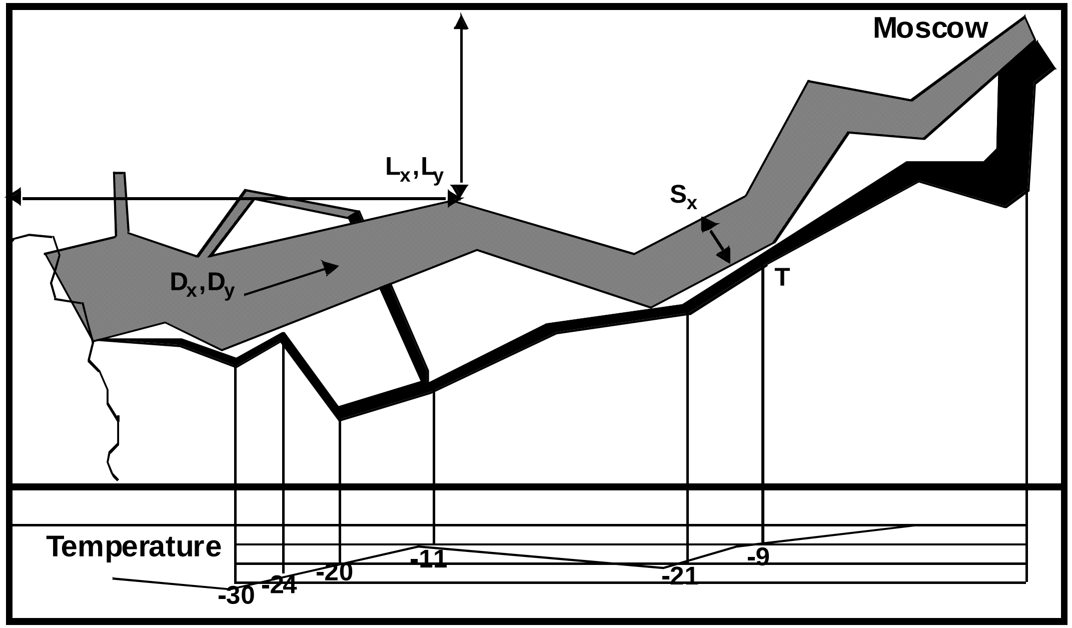
# Time Series



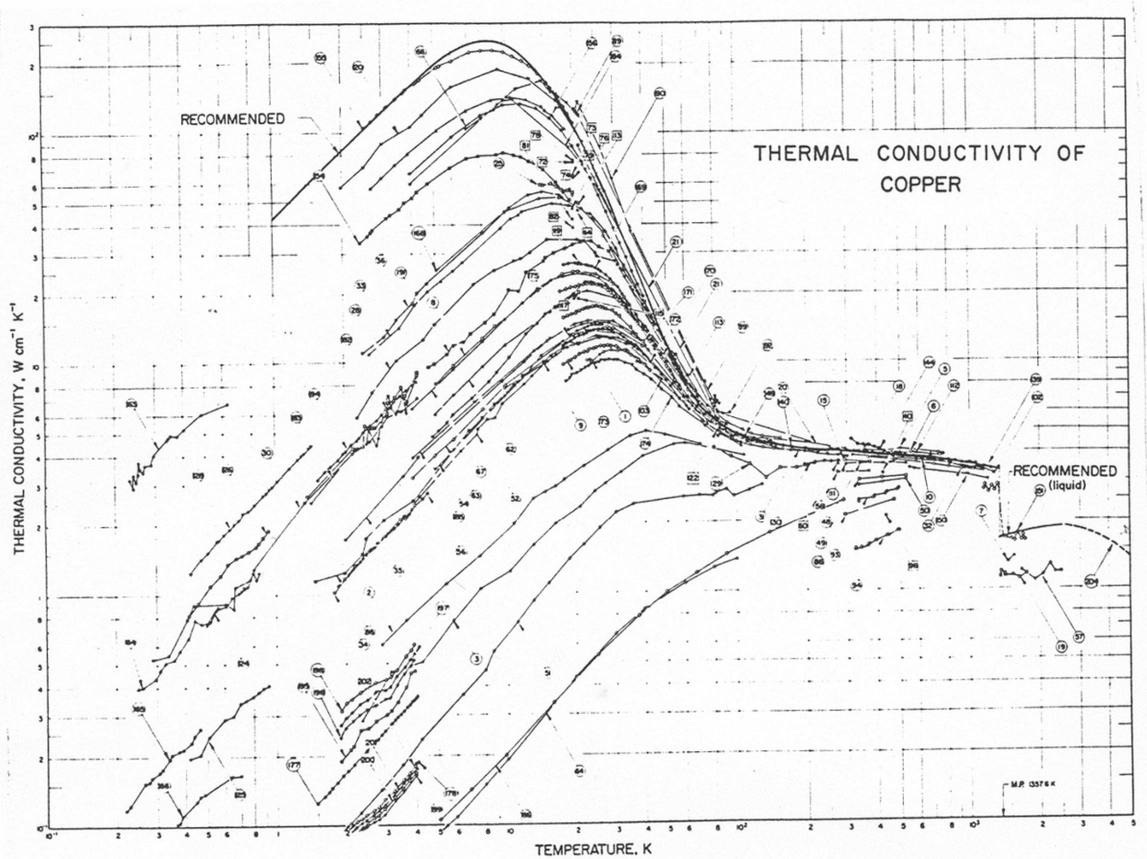

*New York Times*, January 11, 1981, p. 32.

# A Classic Narrative Example: Fate of Napolean's Army in Russia

- Charles Joseph Minard (1781-1870)
- Depicts the fate of Napoleon's army in Russia
- 6 variables are plotted:
  - size of the army (Sx)
  - its location on a 2D grid (Lx, Ly)
  - direction of the army's
  - Movements (Dx, Dy)
  - temperature on various dates (T)



# Relational Graphics




C. Y. Ho, R. W. Powell, and P. E. Liley, *Thermal Conductivity of the Elements: A Comprehensive Review*, supplement no. 1, *Journal of Physical and Chemical Reference Data*, 3 (1974), 1–244.

MANCHESTER 1824

The University of Manchester

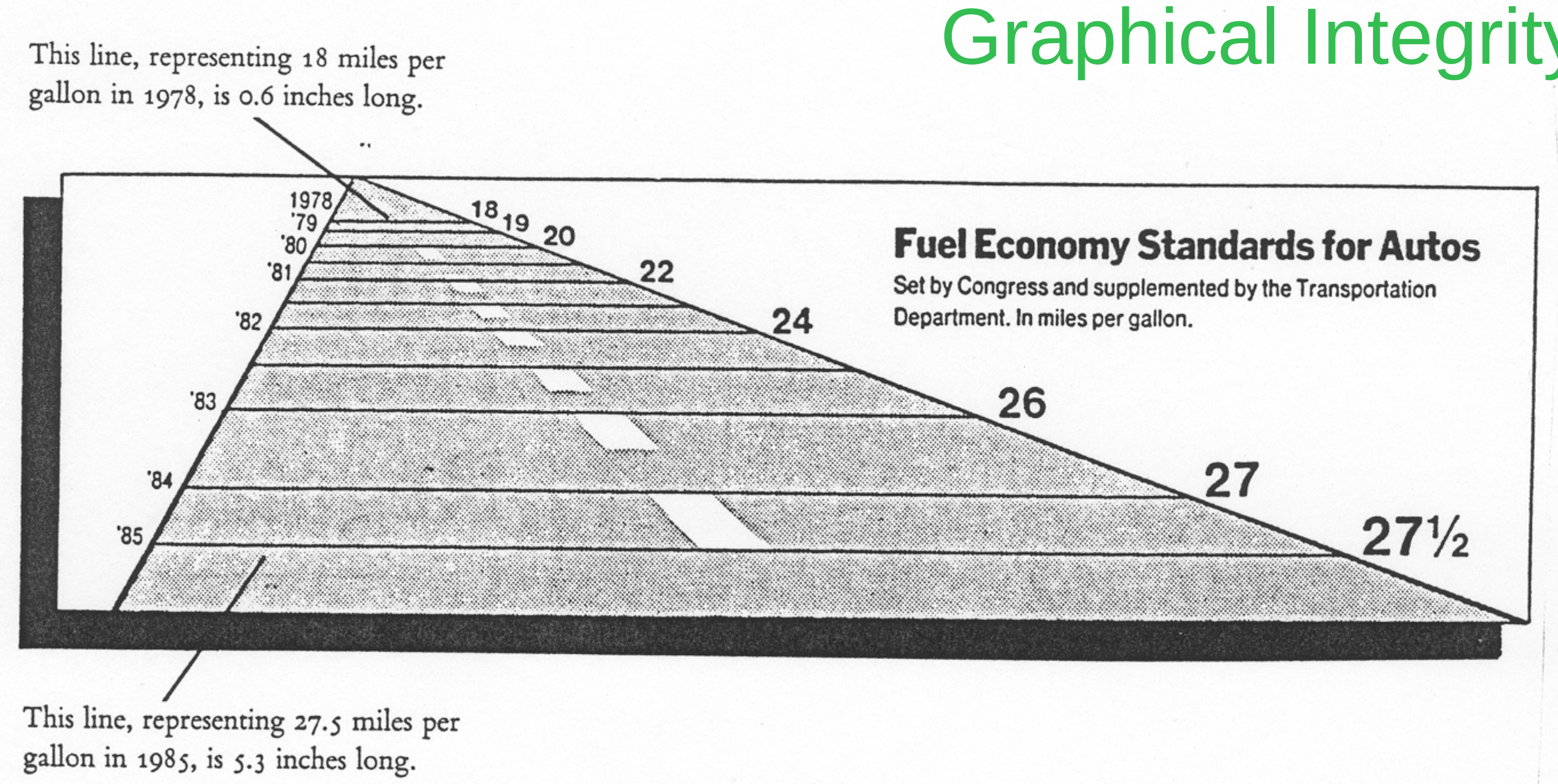
# Information Visualization

| Objective Measures | Subjective Measures |
|---|---|
| Lie Factor | 3D |
| | Context |
| Data Ink | Chart Junk |
| Data Density | How to present data? |

# Graphical Integrity

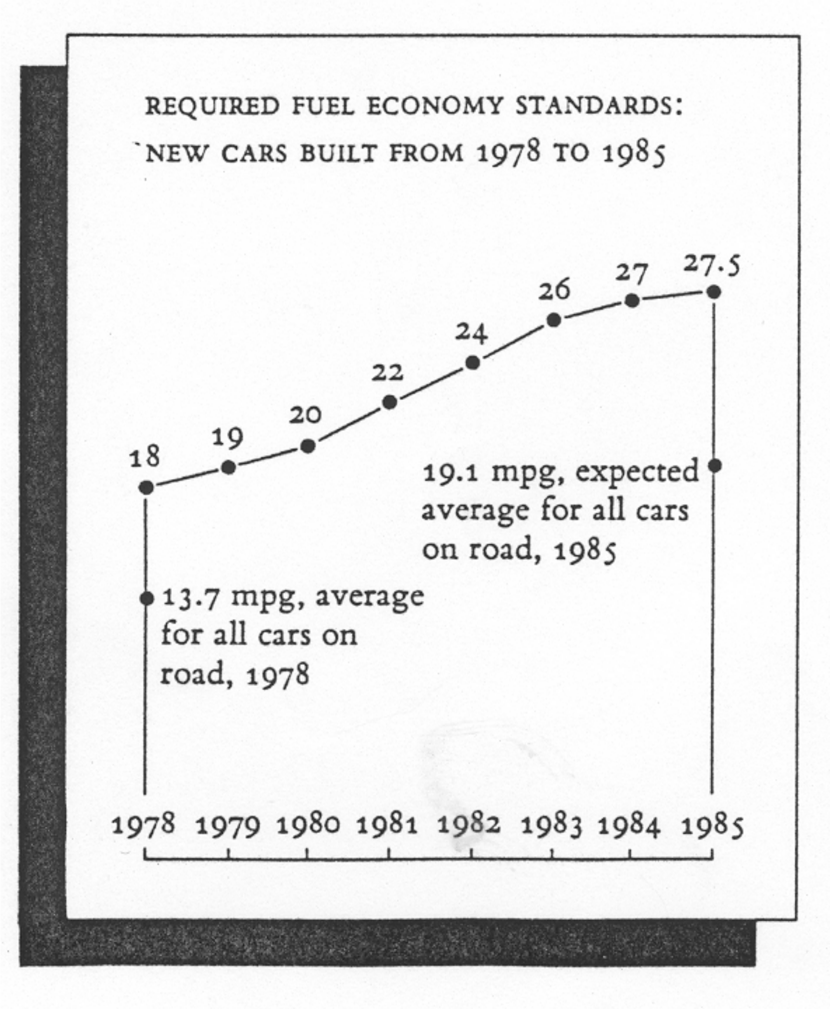
- Lie Factor = variation in visual effect / variation in data
- These should be the same!
- data variation should be truthfully represented

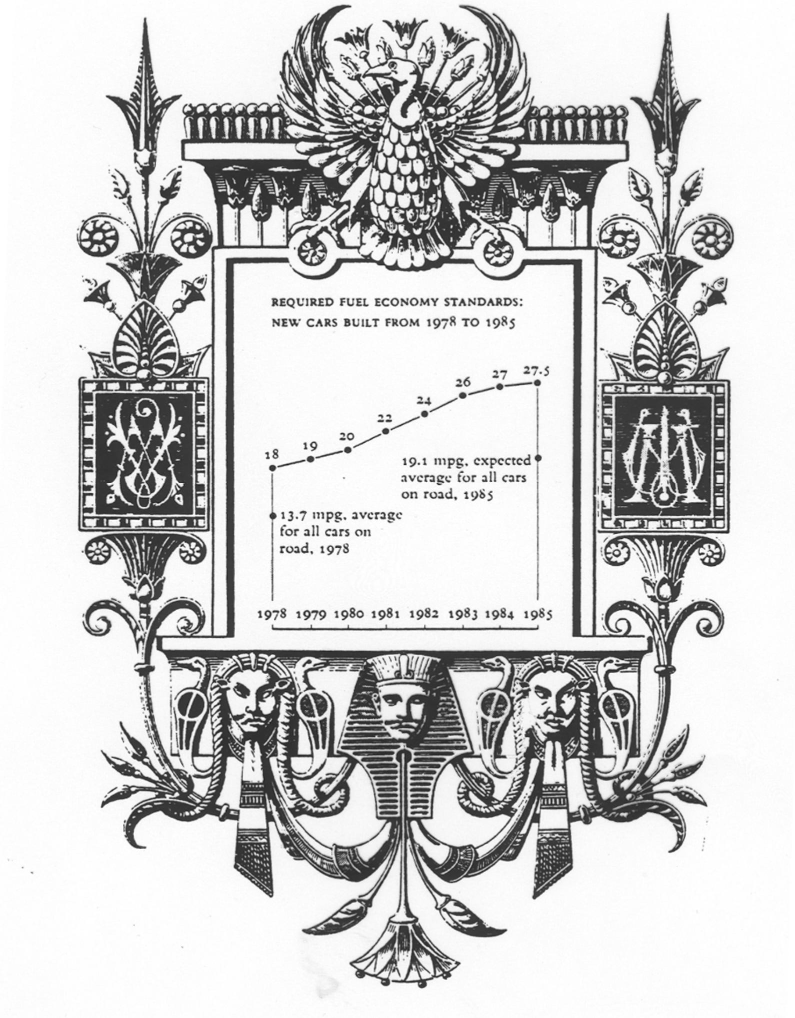
# Graphical Integrity

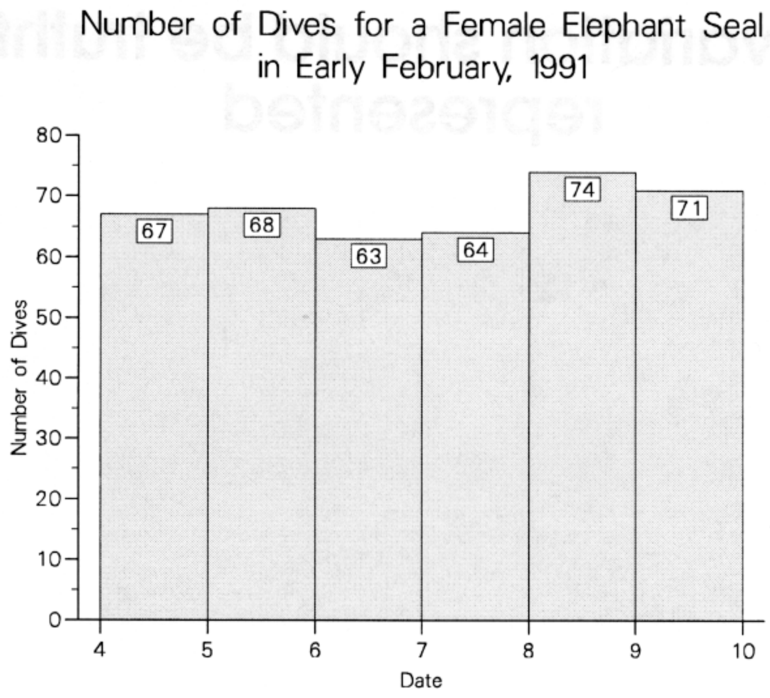


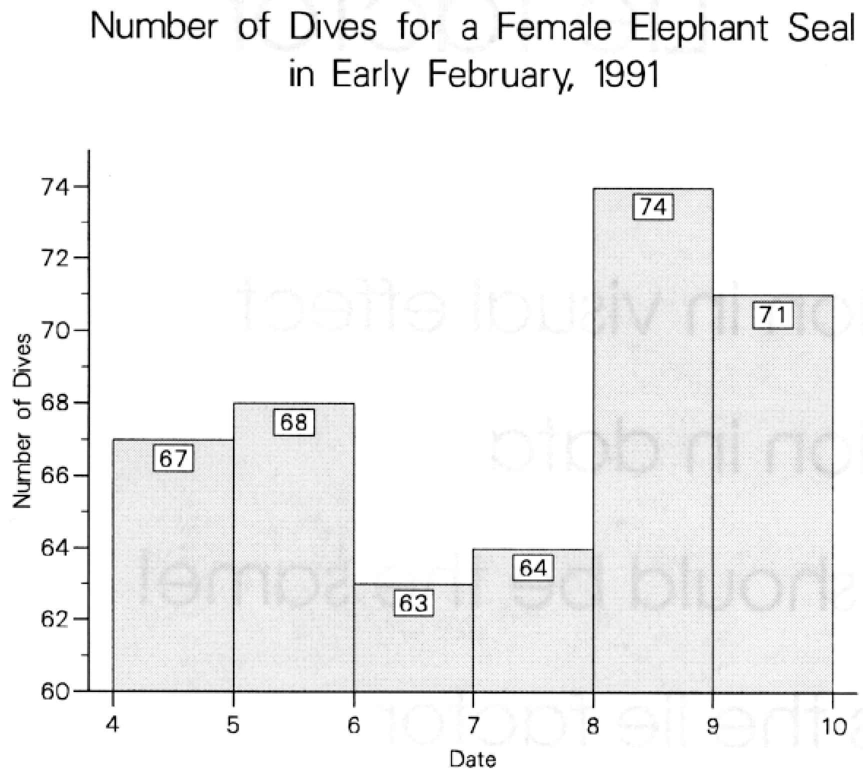

- Change in data = (27.5-18)/18 = 53%
- Change in graph = (5.3-0.6)/0.6 = 783%
- **Lie Factor = 783/53 = 14.8**

# Graphical Integrity




Number of Dives for a Female Elephant Seal
in Early February, 1991
Number of Dives
Date
80
70
60
50
40
30
20
10
0
4
5
6
7
8
9
10
67
68
63
64
74
71

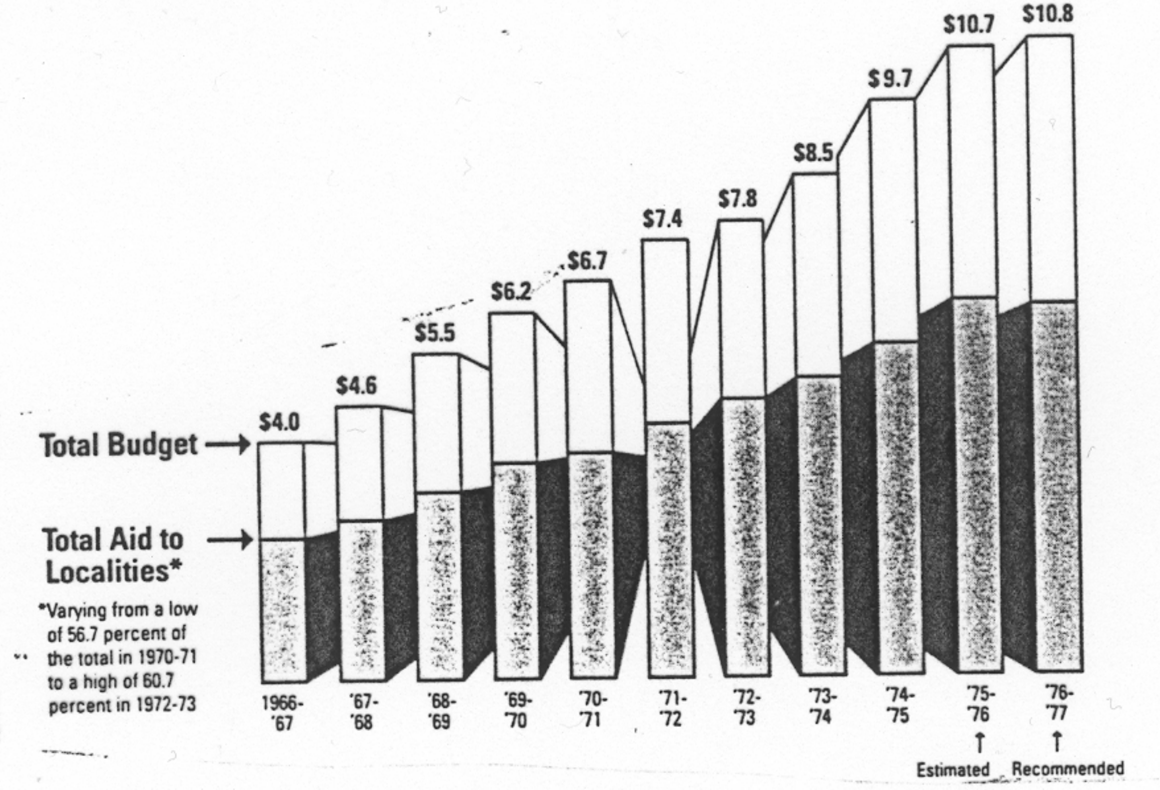

Number of Dives for a Female Elephant Seal
in Early February, 1991
Number of Dives
Date
74
72
70
68
66
64
62
60
4
5
6
7
8
9
10
67
68
63
64
74
71

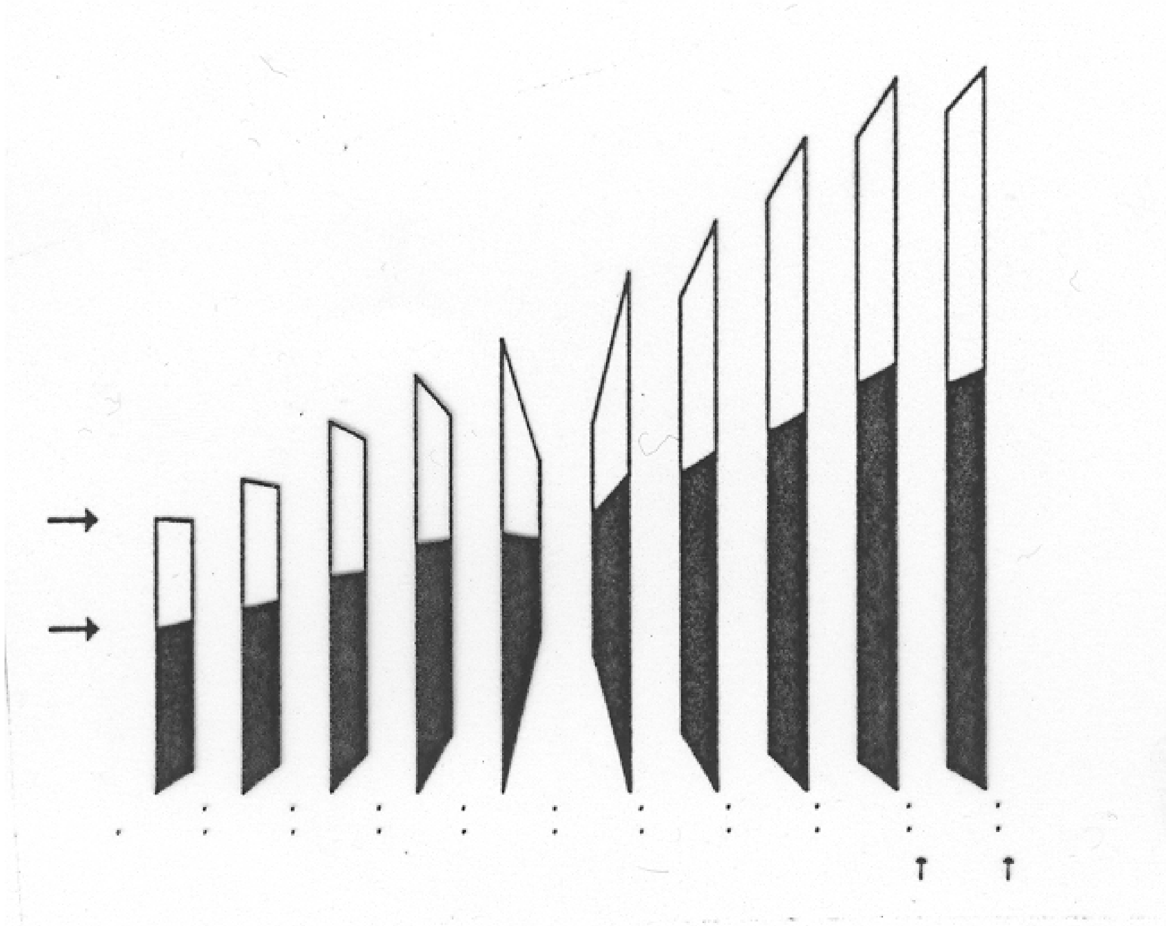
# Why use Graphics that Lie?

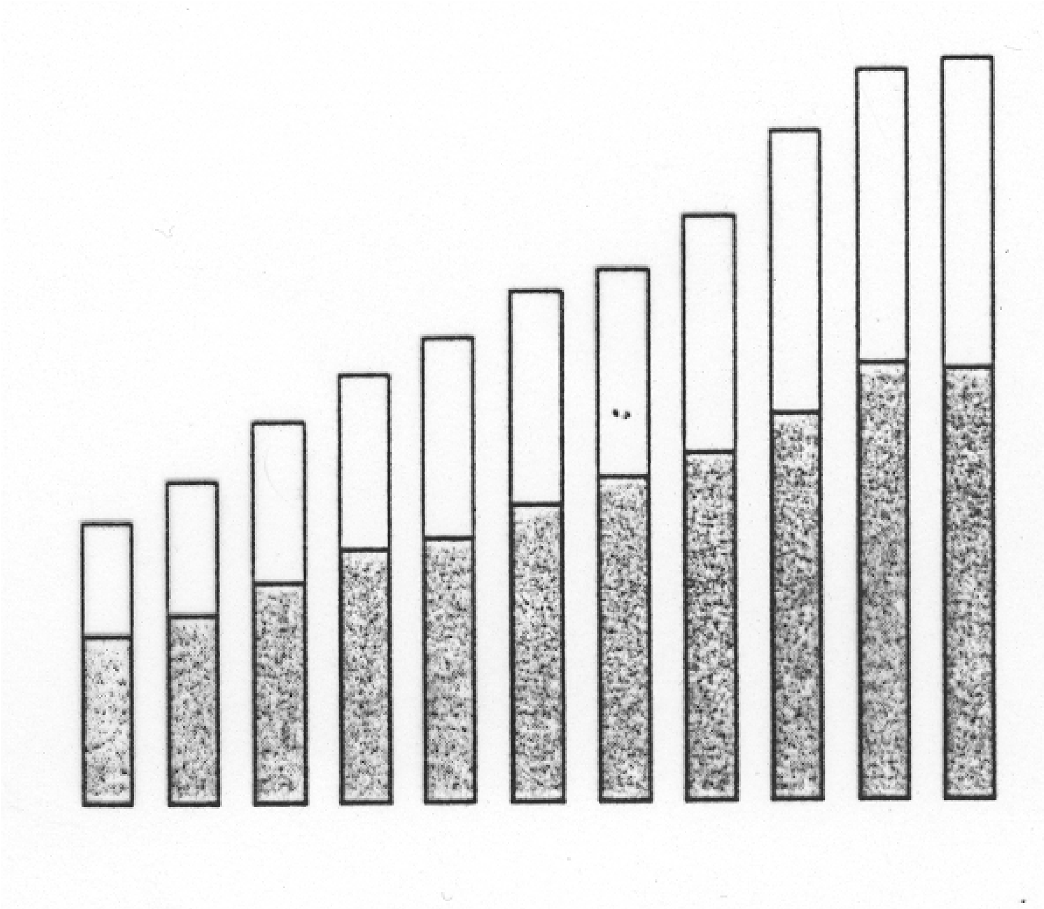
- Lack of skill
- Statistical data is boring
- They are for the unsophisticated
- Cheesy marketing

- The consequences … mediocrity

# Don't be Fooled by 3D

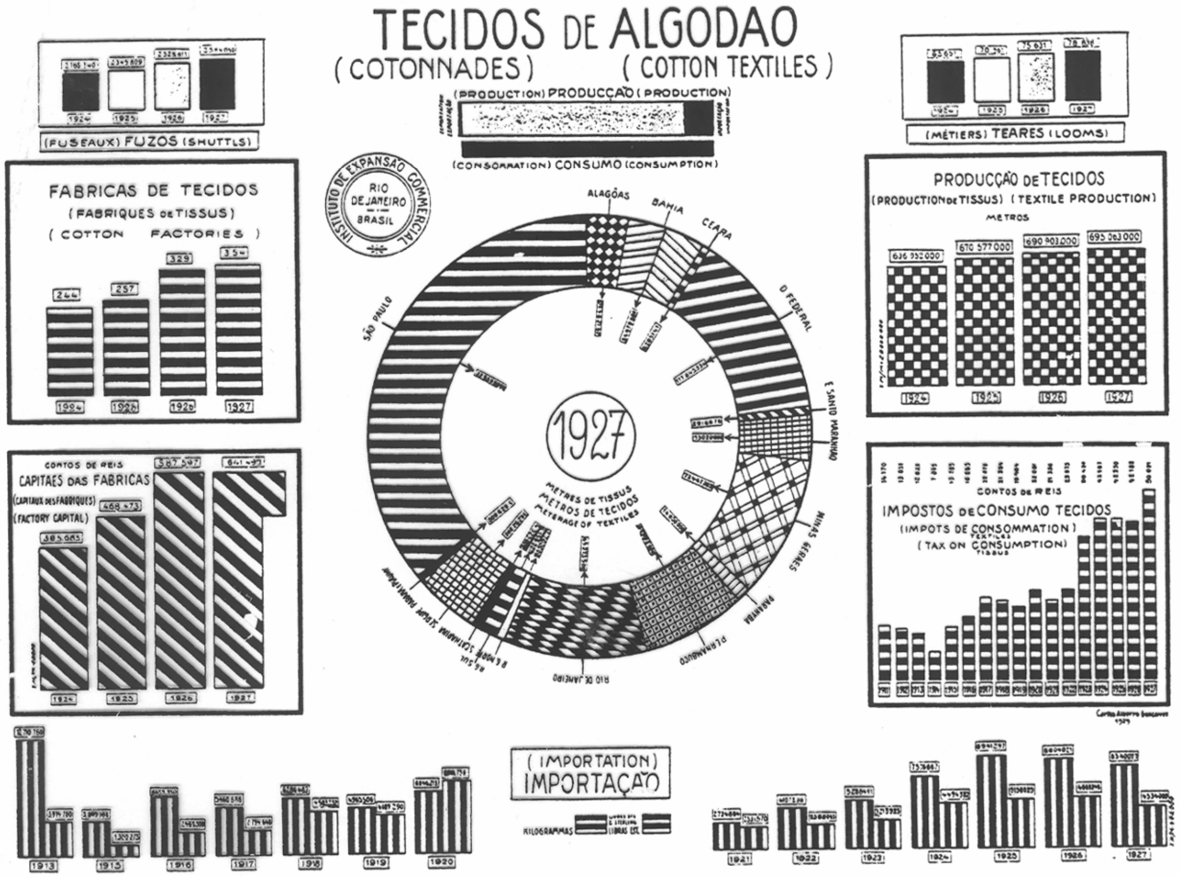






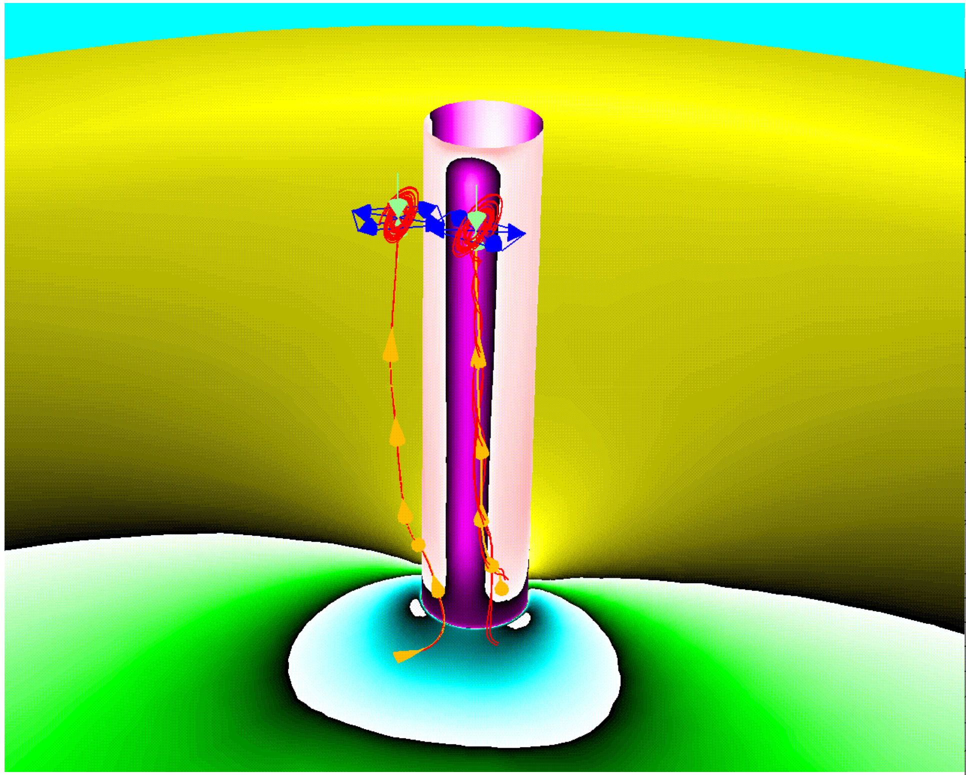
# Chart Junk

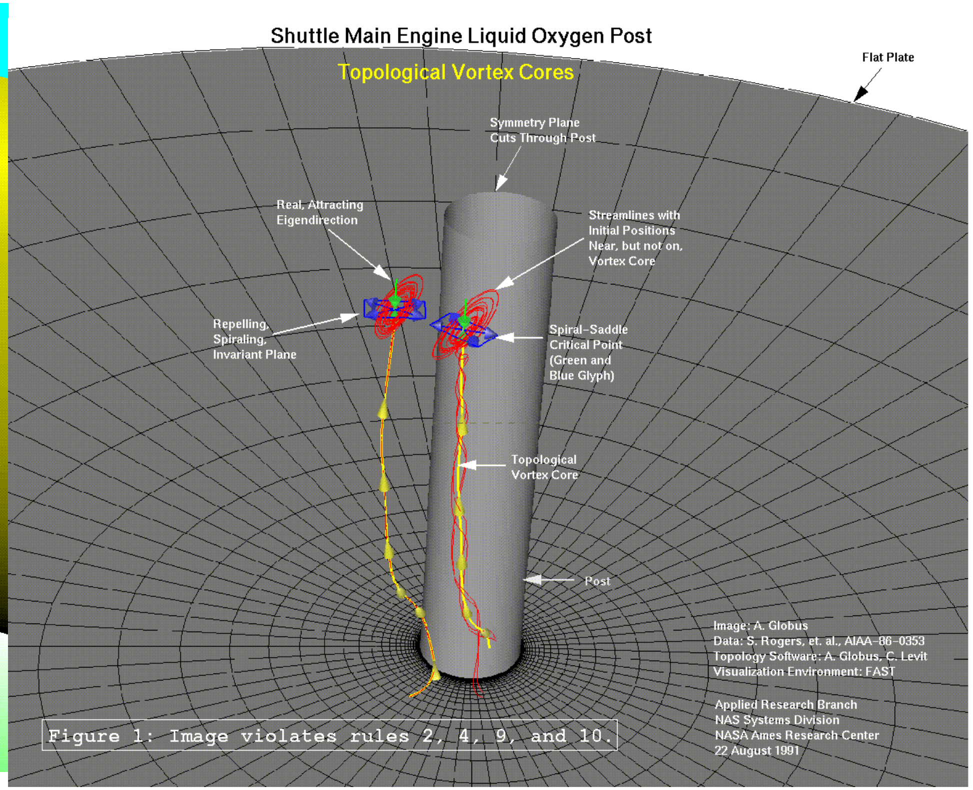
Instituto de Expansão Commercial, *Brasil: Graphicos Economicos–Estatisticas* (Rio de Janeiro, 1929), p. 15.



# 13 Ways to Say Nothing

# 13 Ways to say nothing





# 13 Ways to say nothing (2)

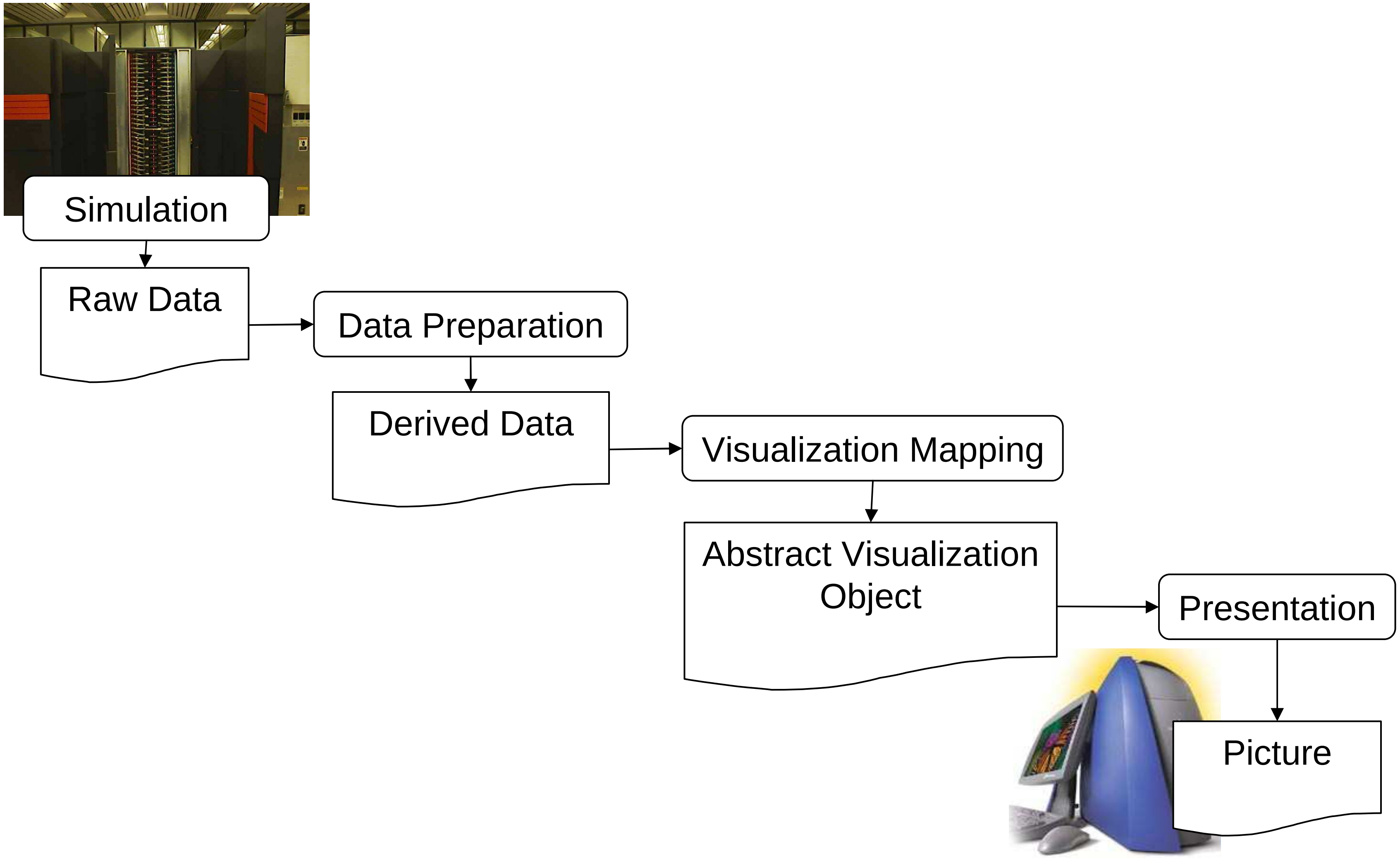
- Never include a colour legend
- Avoid annotation
- Never mention error characteristics
- When in doubt, smooth
- Avoid providing performance data
- Quietly use stop-frame video techniques

# 13 Ways to say nothing (3)

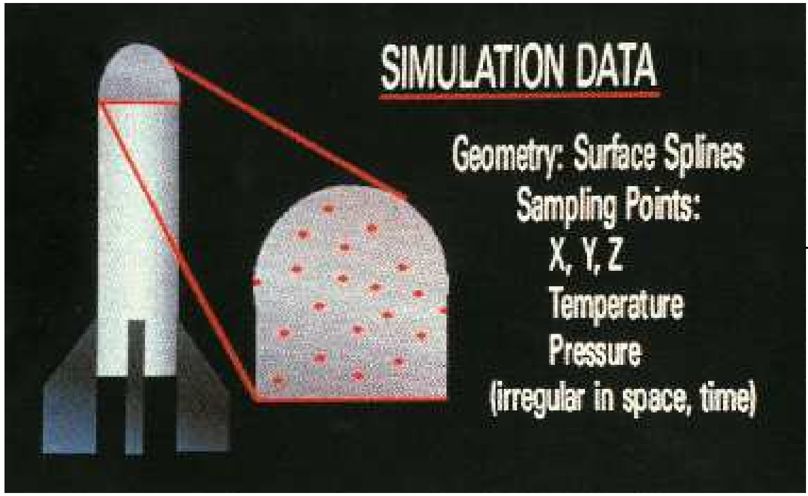
- Never learn anything about the science or data
- Never compare your results with other visualization techniques
- Avoid visualization systems
- Never cite references for your data
- Claim generality from one dataset
- Use viewing angle to hide blemishes
- “This is easily extended to 3D”

# Scientific Visualization

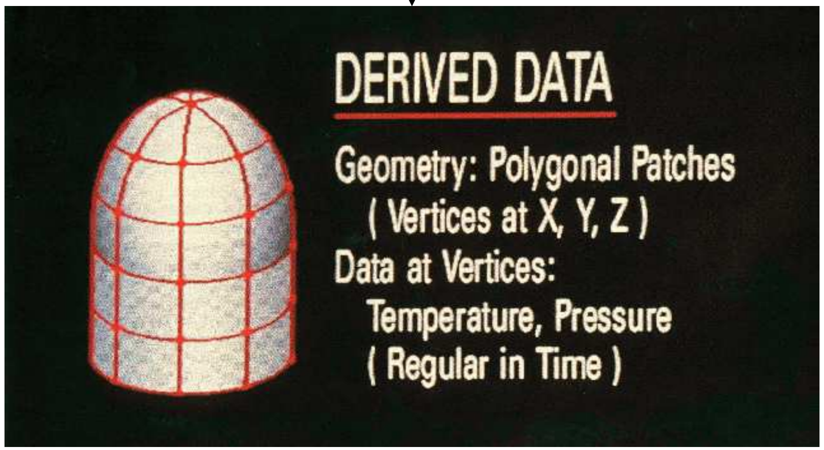
# The Visualization Pipeline (Haber & McNabb)



# Simulation & Derived Data




Data Preparation

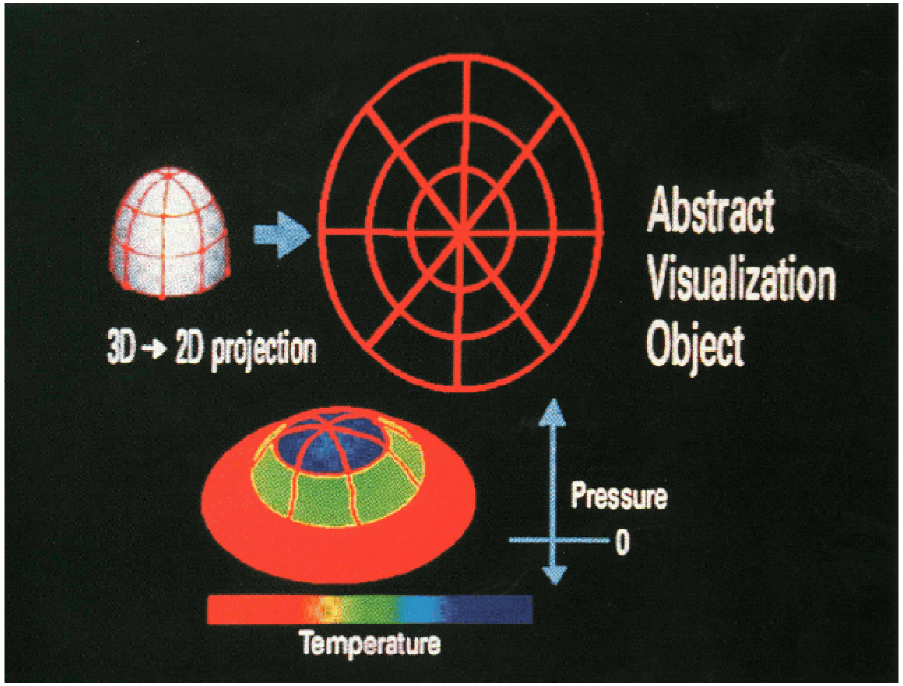


# Data Preparation

- Acts on the raw data (measured or simulated)
- Creates a model of the data
- Generates a new derived data set
- Typical processes:
  - calibration
  - smoothing
  - interpolation
  - calculation of derived quantities.
- Sometimes non-interactive

# Visualization Mapping

- Creates an Abstract Visualization Object (AVO)
- Maps variables to the attributes that describe the AVO
  - spatial dimensions
  - time
  - colour
  - transparency
- Generally interactive



# Abstract Visualization Object: Appearance

- Often the AVO is similar to a real object
  - e.g. temperature samples over an aircraft
- May be completely abstract
- Balance information richness with ease of interpretation
- Can have multiple AVOs

# Abstract Visualization Object: Select a Good Mapping

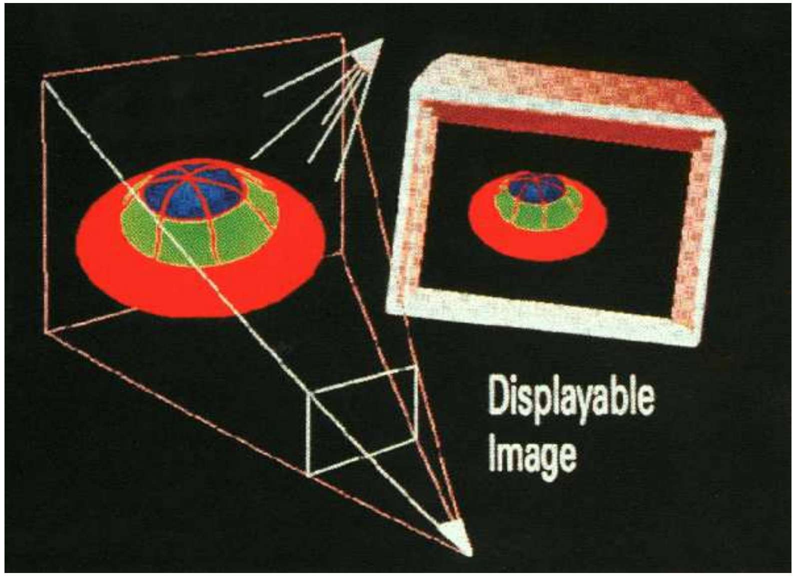
- Many ways to map the derived data onto an AVO
  - Marching Cubes
  - Contour Tracking etc
- Basically, these techniques allow you to create a surface
- Aim is to produce an AVO which is
  - readily understood
  - clearly shows interesting features
  - avoids distracting details
- Typical tasks the mapping can be used to achieve:
  - exploring the relationship between variables
  - increasing sensitivity to important variation
  - looking for structure

# Presentation Stage 1: Render AVO on an Output Device

- Render AVO, present as an image or pair of images
  - ultra realistic computer graphics not required
  - responsive, approximate methods adequate
  - often take advantage of graphics hardware
  - true 3D devices exist but are rare
  - stereo and VR systems provide a good alternative 3D environment
- Communicative (pretty) visualization has different requirements
- Collect input from user, pass to visualization system

# Presentation - Stage 2: AVO Manipulated and Measured

- A few tasks to be performed at this stage:
  - view transformations
  - hidden surface removal
  - lighting and shading
  - Compositing
  - Display
  - final-form output (print, video, etc)



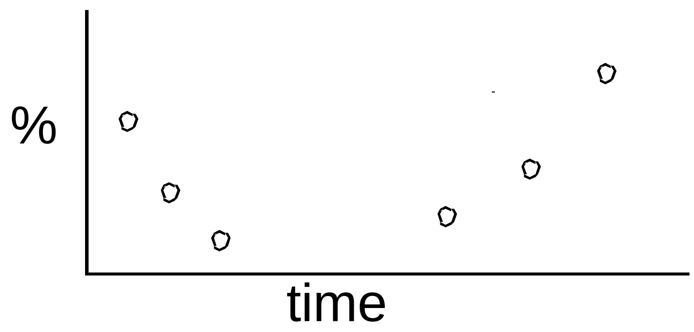

- Depending on the objects (i.e. geometric or voxelised) being visualized the above tasks will vary

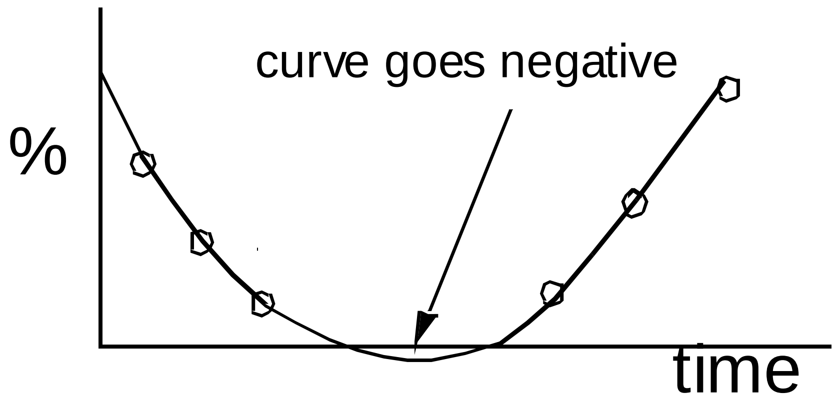
# Interpolation

- The underlying data model dictates what methods we should and, more importantly, should not use
- We will illustrate this by briefly looking at some examples of:
  - Restrictions from the model e.g., Positivity
  - Local v Global interpolation
  - Data v Colour interpolation

# The Real Data

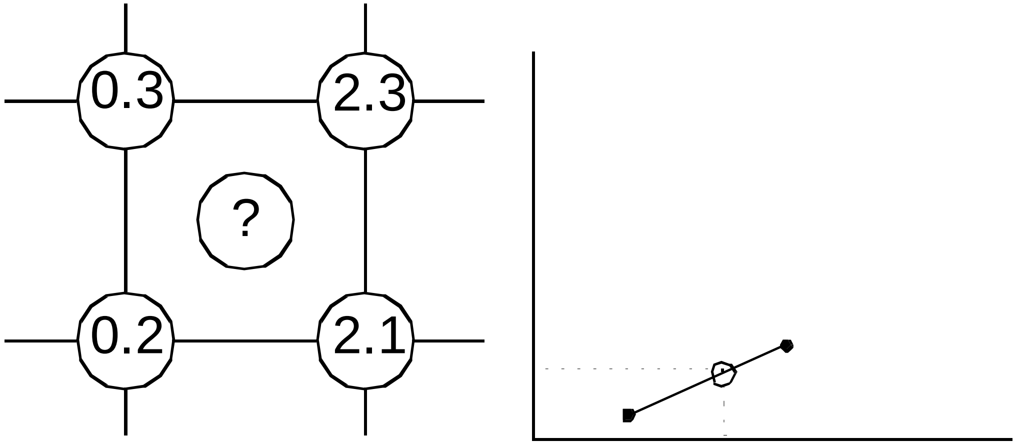
- The observed values for the process are:
  - 20.8 8.8 4.2 0.5 3.9 6.2 9.6
- This can be plotted as a simple scatter plot



# Local v Global Interpolation

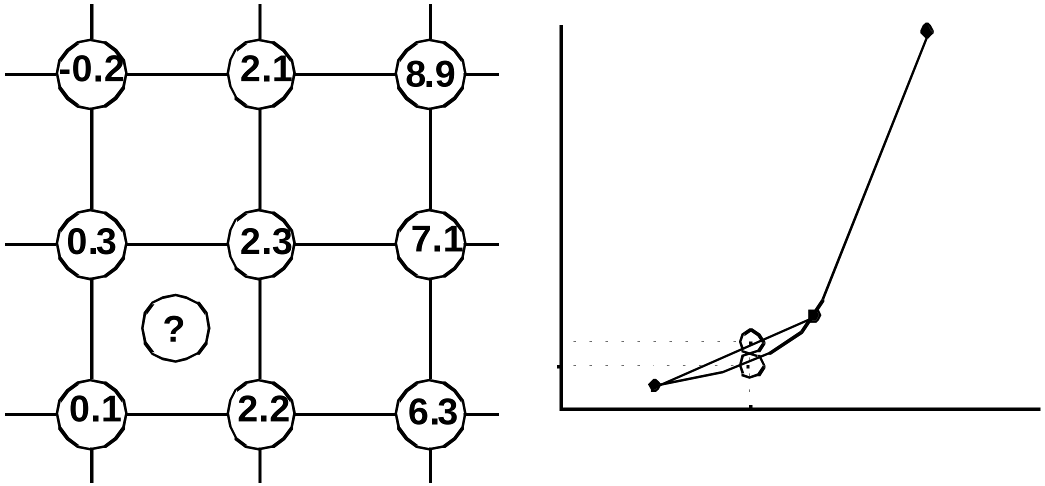
- Consider the grid of values




- You could imagine the value is probably 1.2?

# Local v Global Interpolation

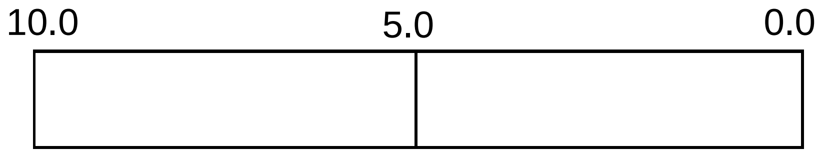
- If we look at a larger area of the grid though



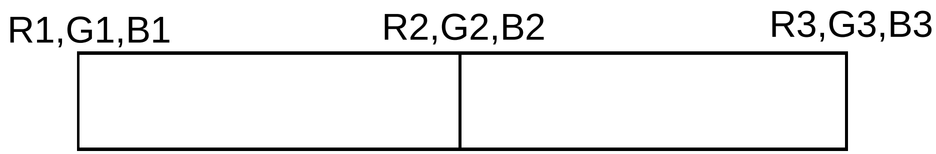

- Sometimes local fitting is chosen to ease the computational load (this is the wrong reason). The underlying model must be considered

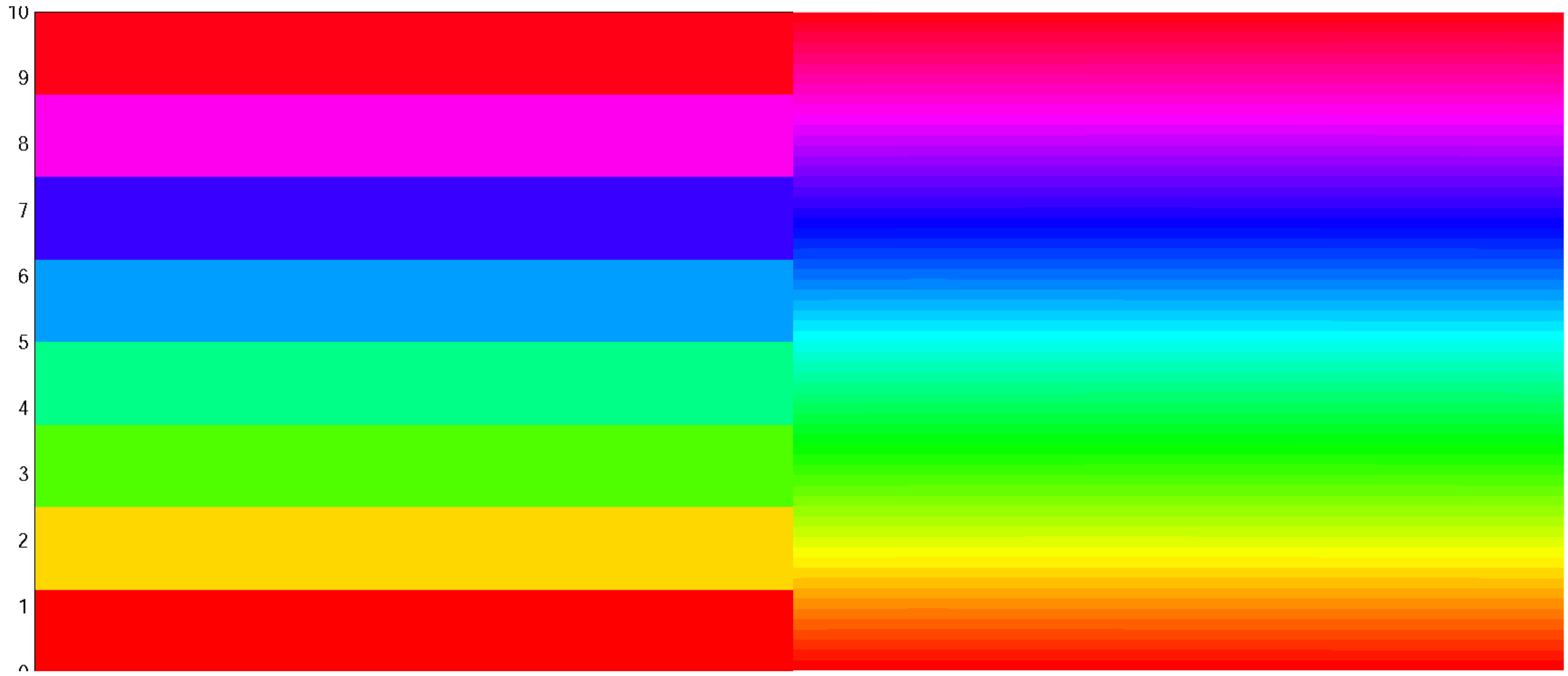
# Colour v Data Interpolation

- Consider the following grid/mesh with data values associated at each node




- Most visualization systems will index into the colourmap using the data values to assign a colour to each vertex

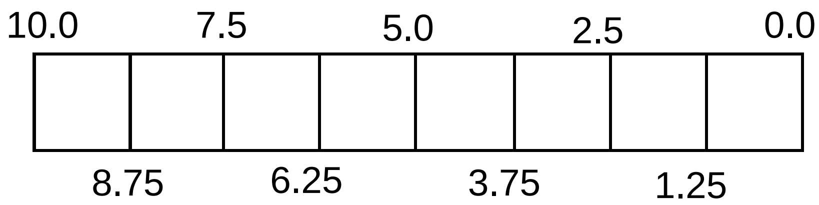




10
9
8
7
6
5
4
3
2
1
0

# The problem

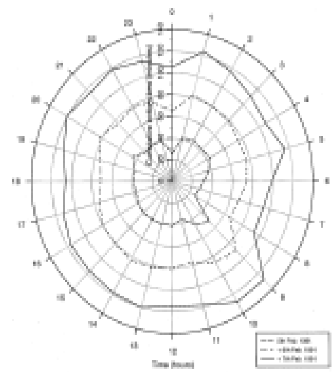
- The changes between the two nodes has been lost
- To counteract this a finer grid/mesh could be generated before passing to the visualization system



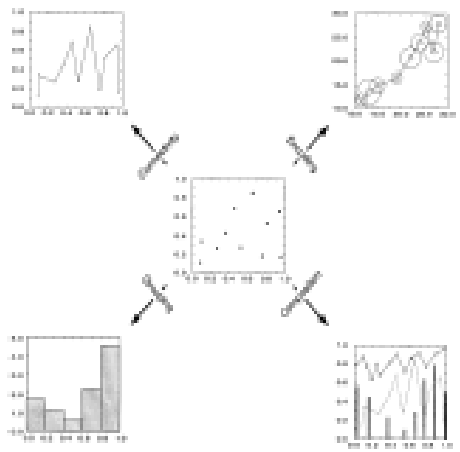

- Data interpolation would be the ideal solution but the visualization system would still need to provide control over this

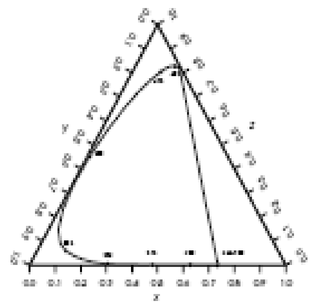
# Graphs & Charts

- Objective Measures of “Goodness”
  - Lie Factor
  - Data Density
  - Data Ink Ratio

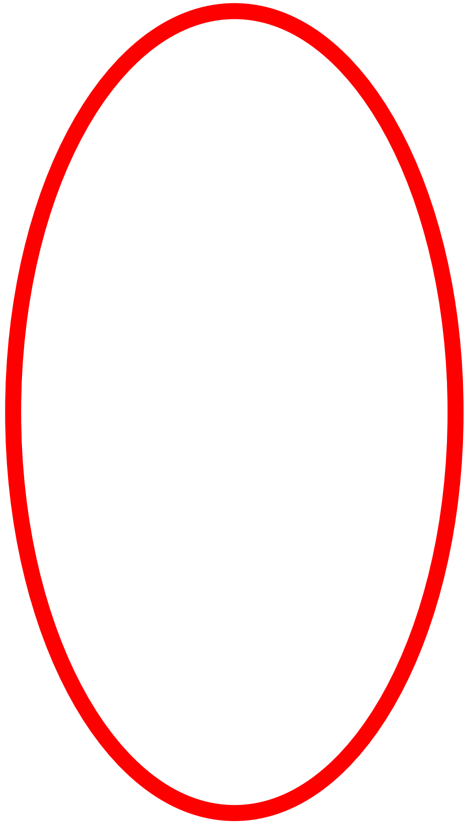


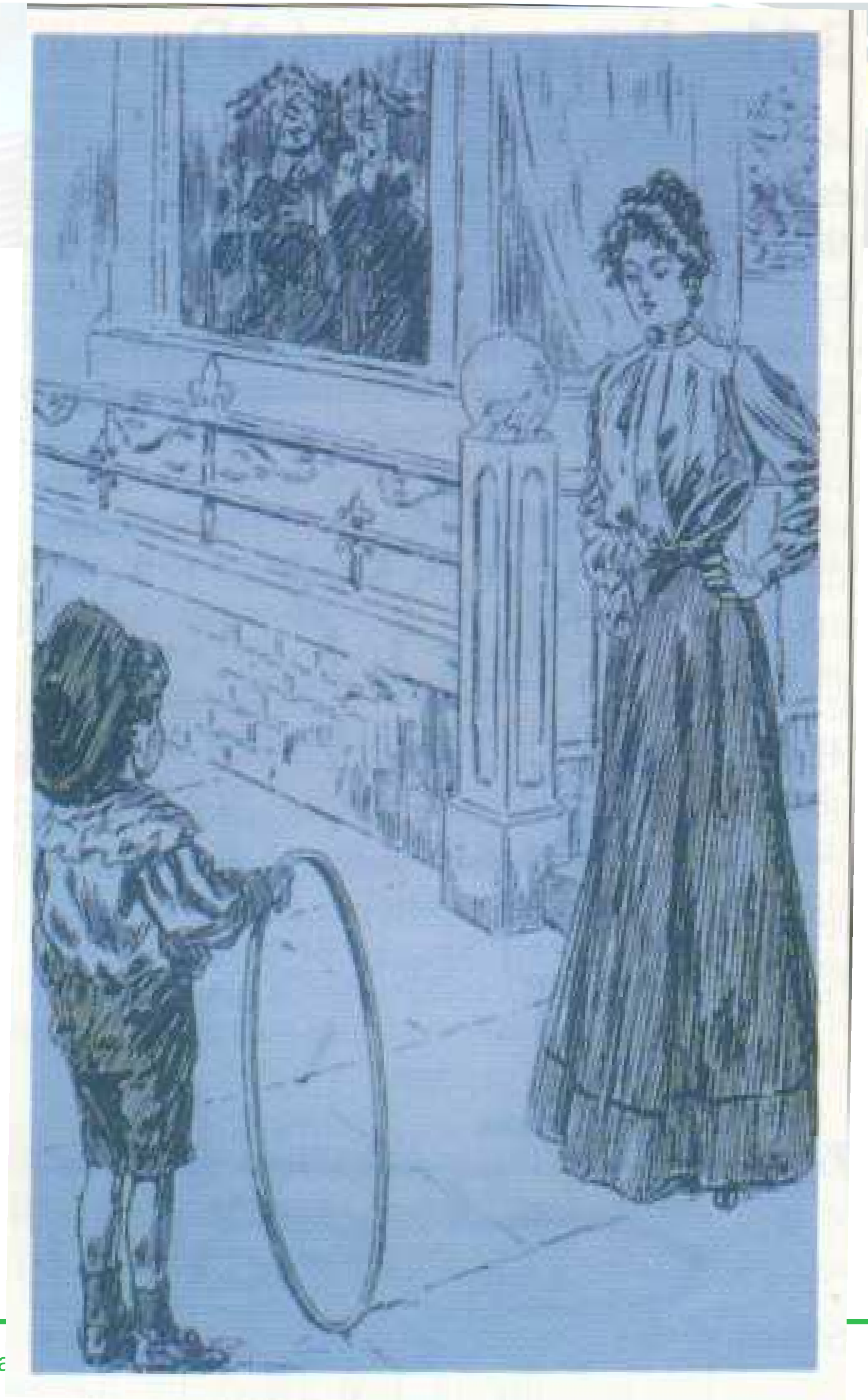
- 1D Charts, 2D Charts



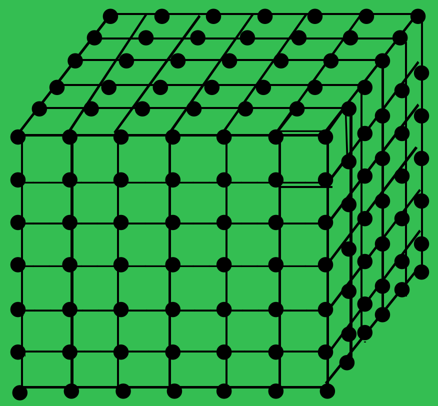


# Perception

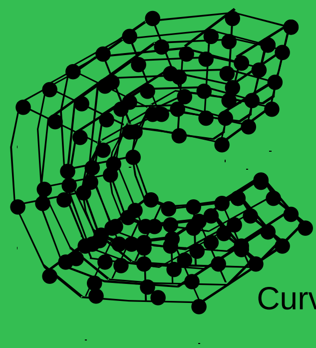




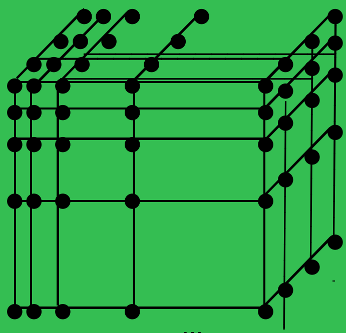
# Data Classification



Regular

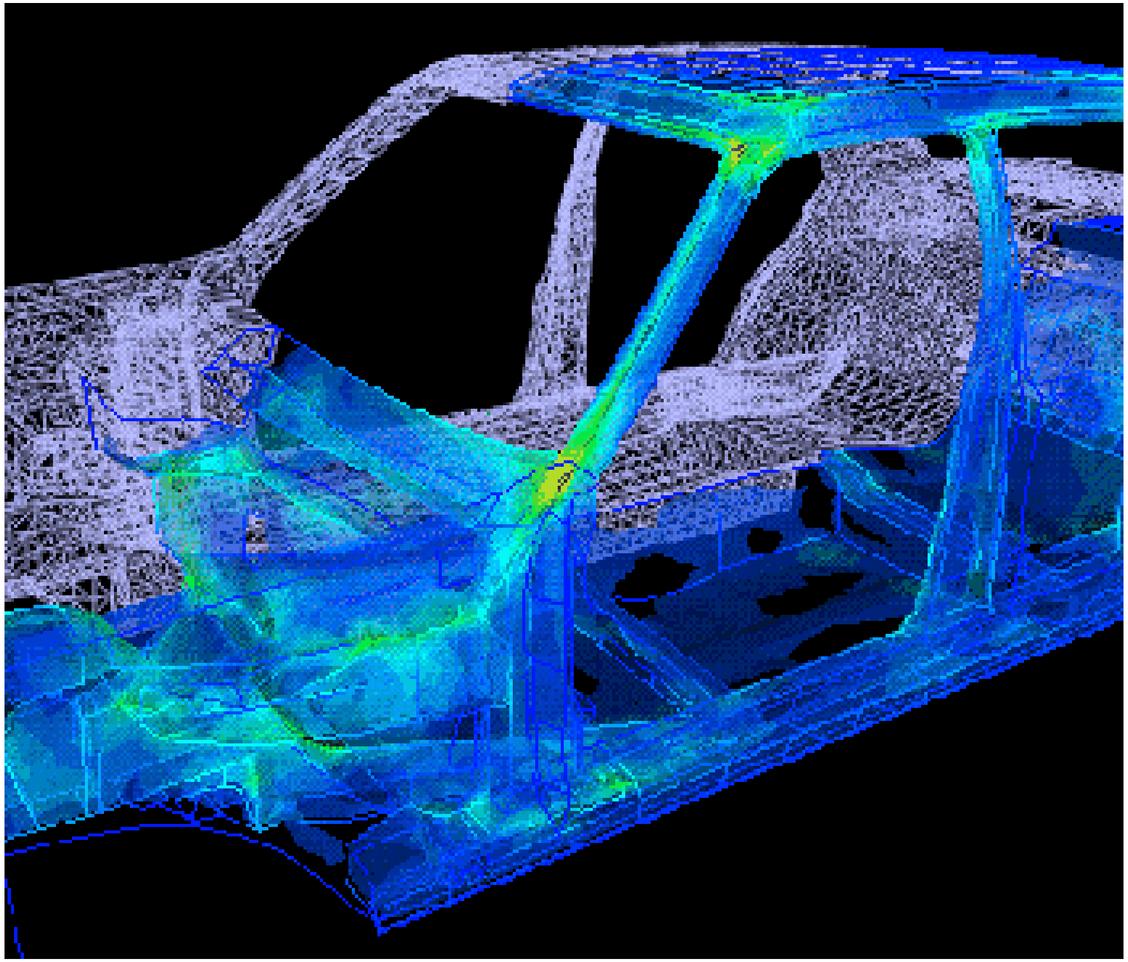


Curvilinear

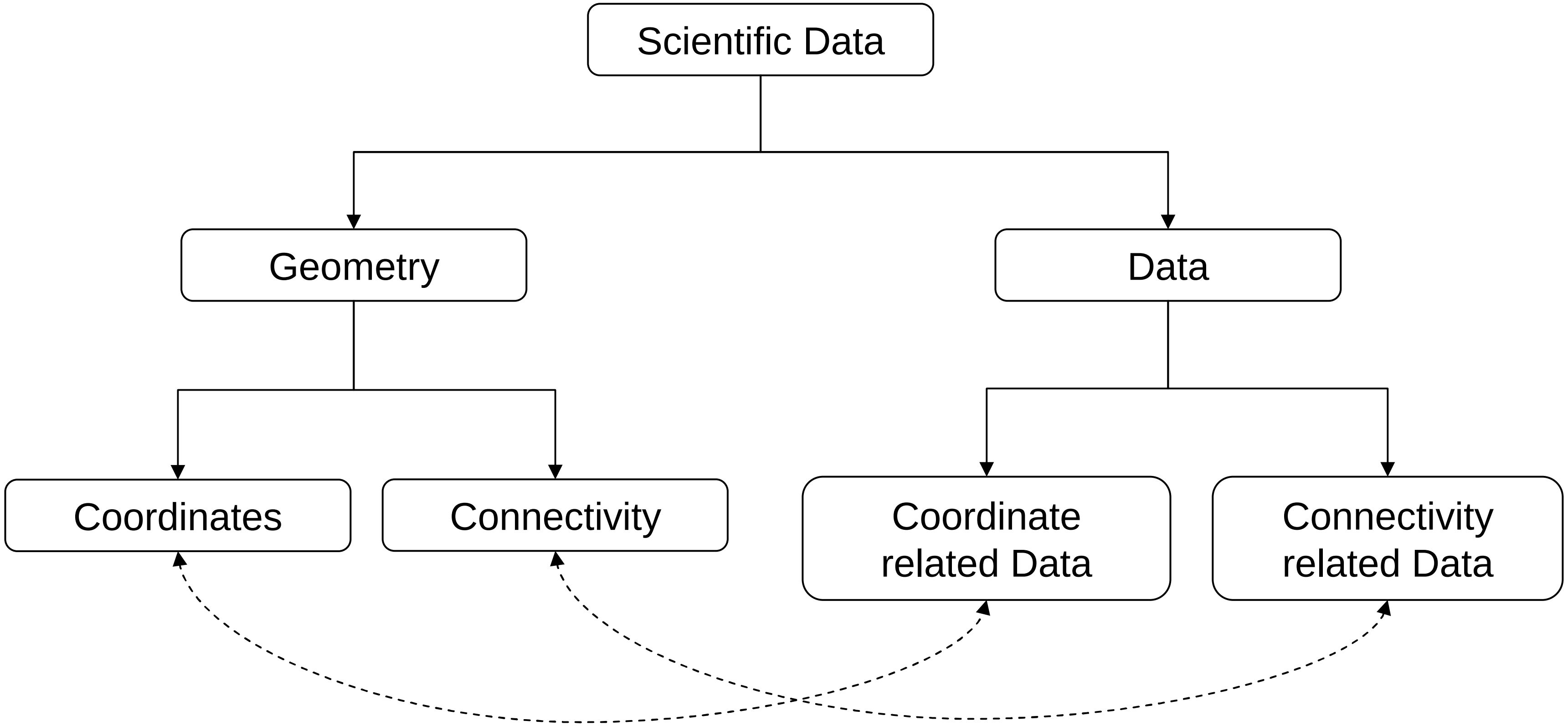


Rectilinear

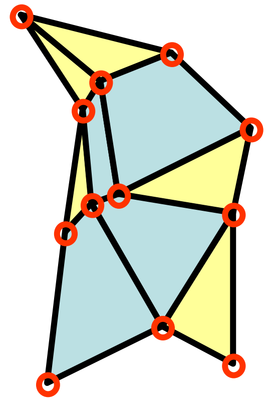
# Data Classification…



# Data Classification



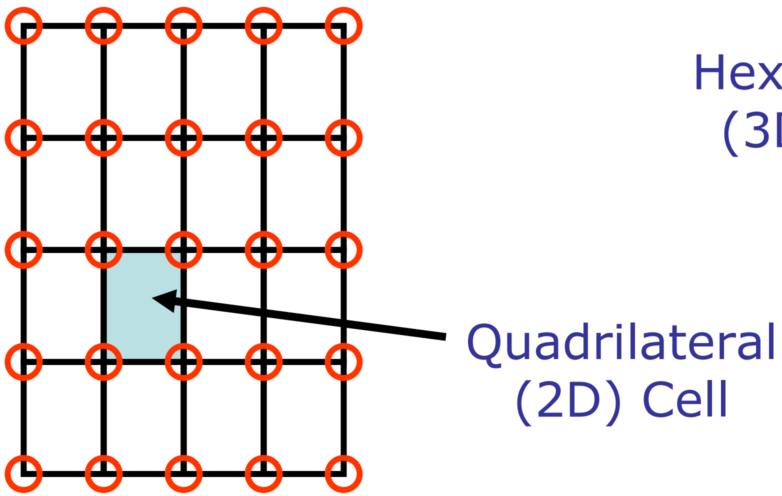
# Geometry Classification



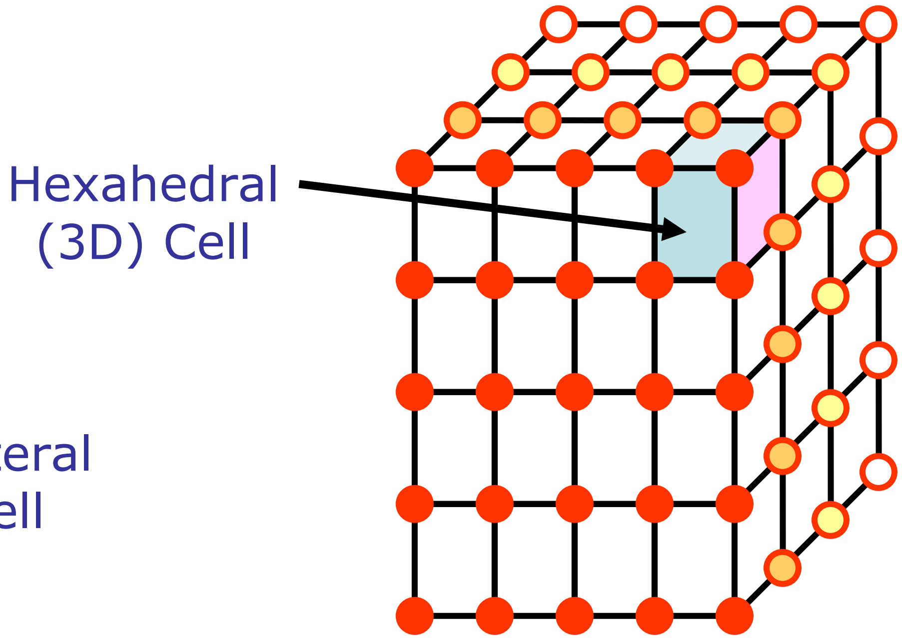
- Two types of Geometries
  - Unstructured
    - *Coordinates are specified for each point*
    - *Connectivity has to be given explicitly*
      - Connectivity elements (cells) can have different shapes
  - Structured
    - *Connectivity is given implicitly*
      - Connectivity elements have identical shapes
    - *Coordinates are specified by the Structure Constraints*
      - Uniform
      - Rectilinear
      - Irregular

# Uniform Geometries

- Coordinates are specified for two corners
- Equidistant spacing along the axes



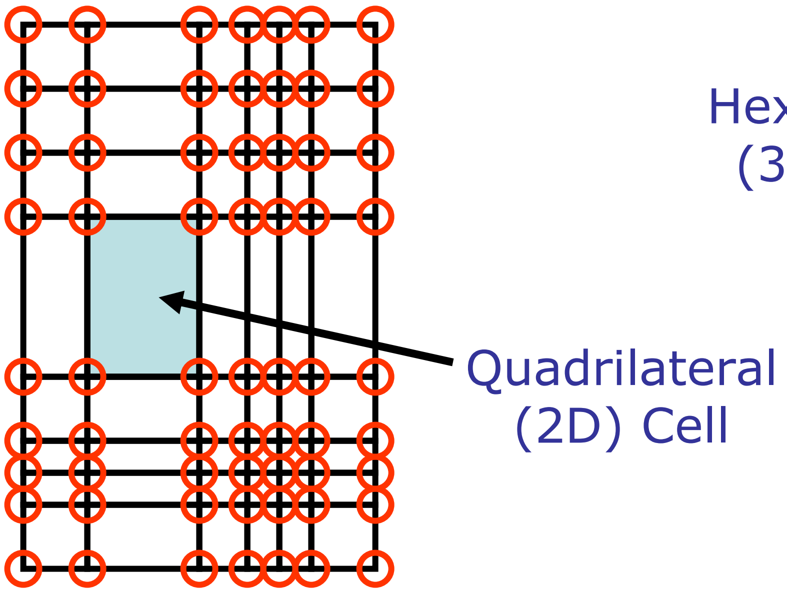

2D Uniform Grid



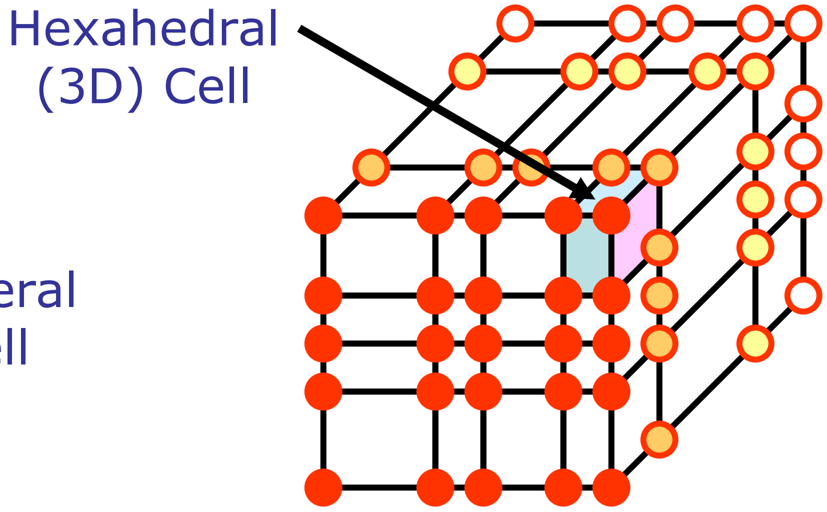

3D Uniform Grid

# Rectilinear Geometries

- Coordinates are specified as distances along each axis
- Uneven spacing but axis aligned




2D Rectilinear Grid

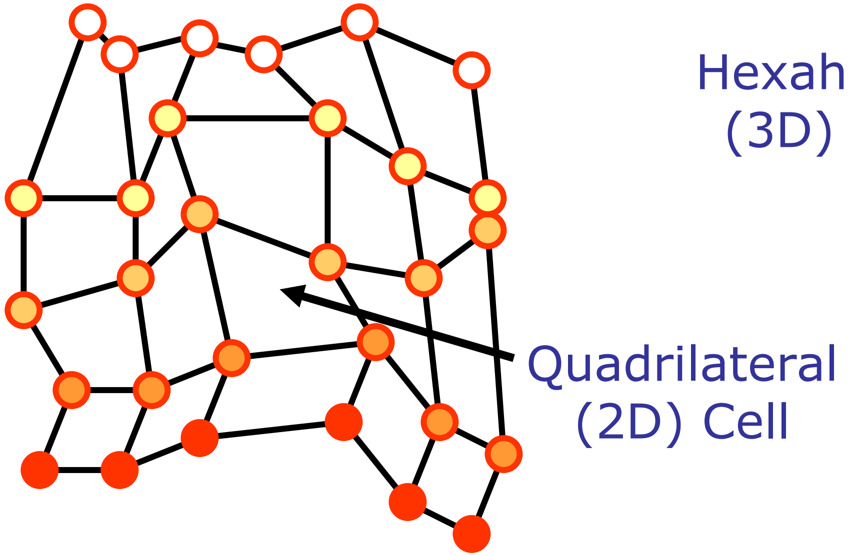



3D Rectilinear Grid

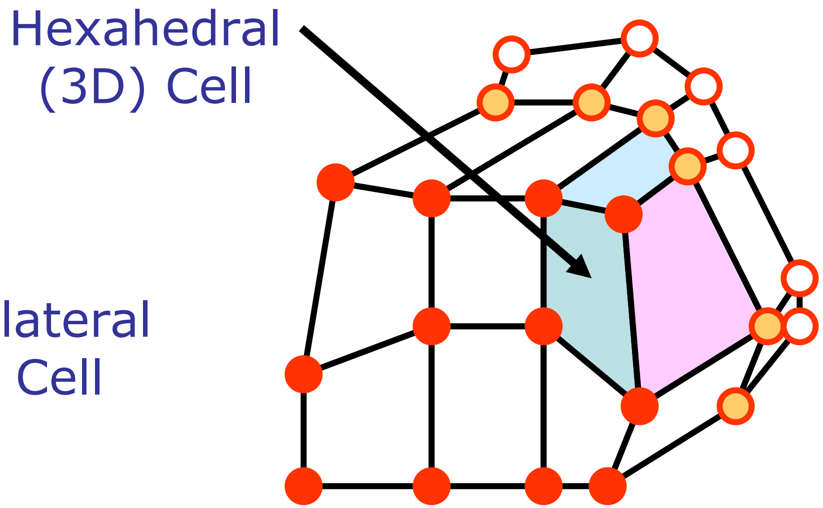
The University of Manchester

# Irregular Geometries

- Coordinates are specified for each point
- Dimensions for each axis are defined




2D Irregular Grid




3D Irregular Grid

# Data Classification

- Coordinate related / Node data
  - Data is specified for the coordinate of the point
    - *Physical Properties at a certain point*
    - *Scalar Data*
      - Temperature
      - Pressure
    - *Vector Data*
      - Wind Velocity

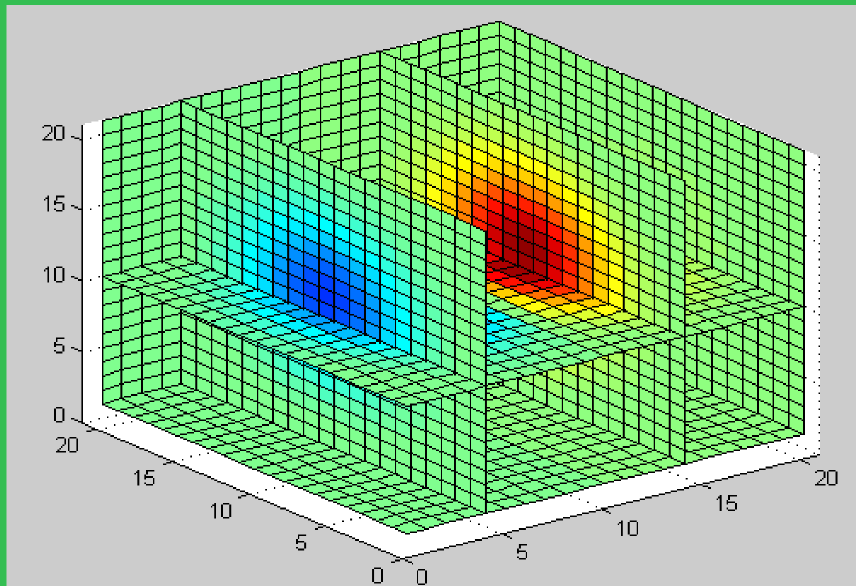
# Data Classification (2)

- Connectivity related / Cell Data
  - Data is specified for each Cell of the structure
    - *Classification data for cells*
      - Finite Element Simulation data
    - *Scalar Data*
    - *Vector Data*
      - displacements

The University of Manchester

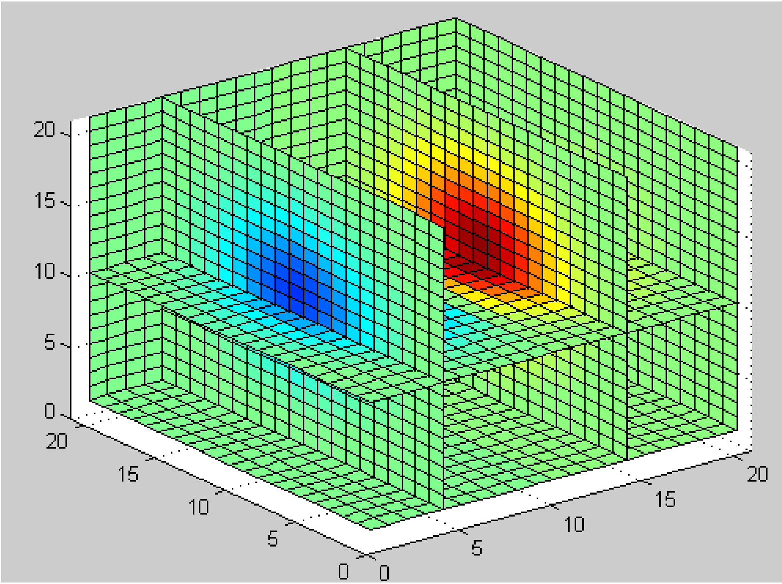
MANCHESTER 1824

# Volume Visualization



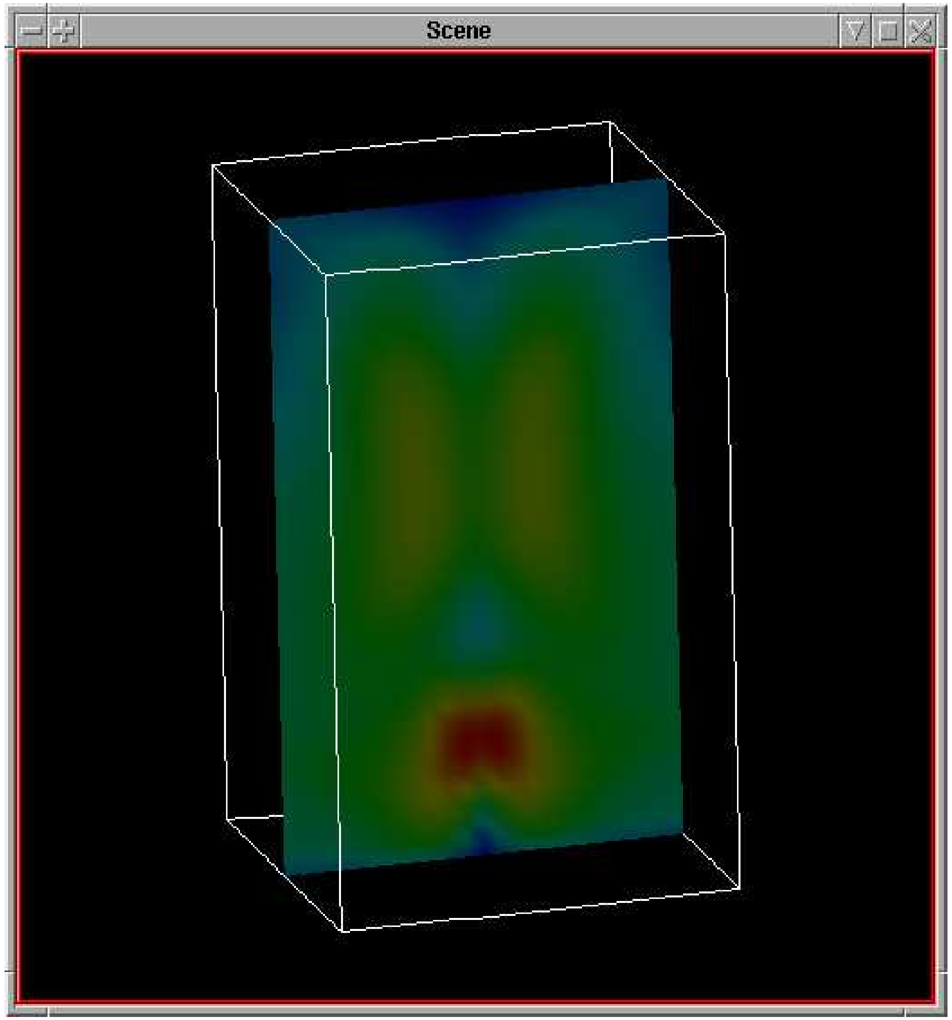
# Visualization Techniques for Scalar Data

- Image Processing (2D)
- Volume Visualization (3D)
- Isolines / Isosurfaces
- Slicing
- Thresholding
- Clamping



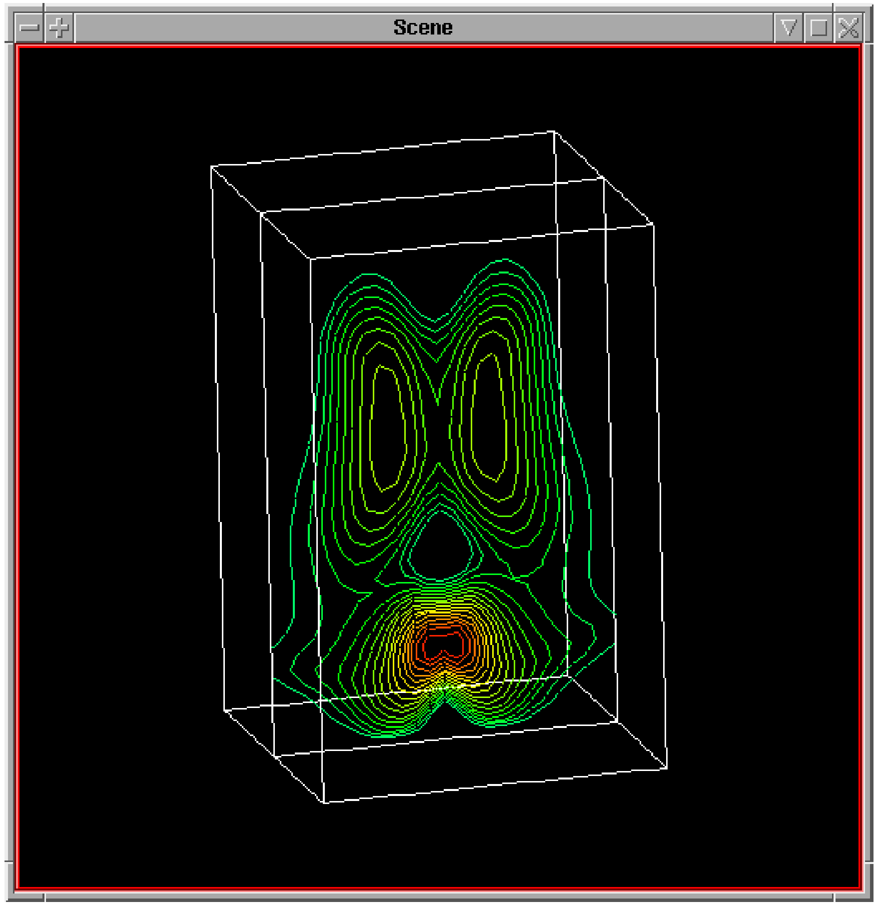
# Slice through Vortex Data

- Slicing is a simple method to get a cross-section image of a data volume
- Reduces the complexity from 3D to a 2D image
- Useful as method to check if the data was read properly
  - Wrong data-files (or descriptions) usually lead to extreme discontinuities in the resulting
    data ("scrambled eggs" effect)
- The datamap can hide more information than it shows

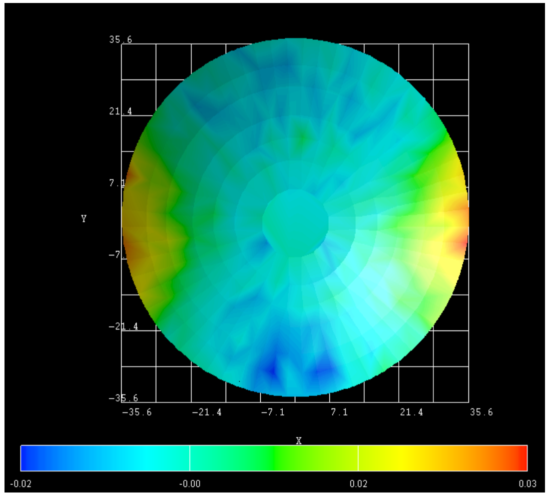


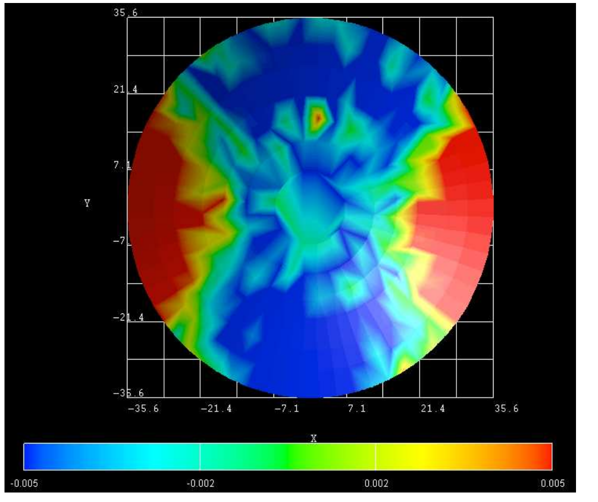
# Isolines on Slice through Vortex Data

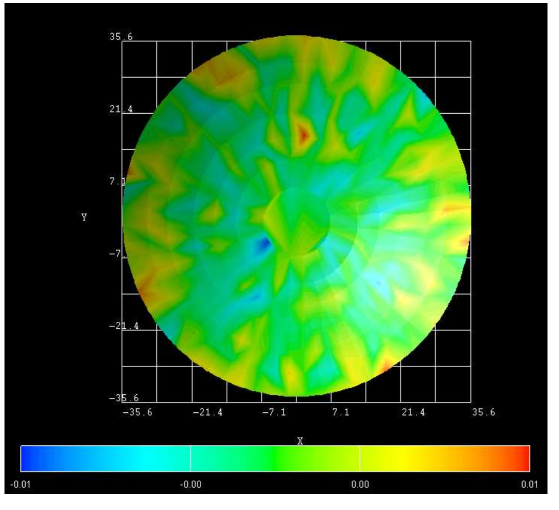
- Isolines can help with the datamap problem, as they only show discrete values.
- They are interpolated lines of equal values on the input slice.
- Well known and used
  - weather maps (isobars)
  - hiking maps (height lines)

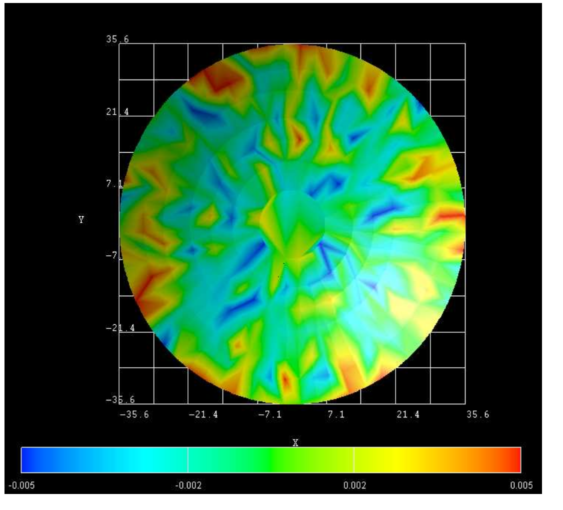


# Clamping


35.6
21.4
7.1
Y
-7.1
-21.4
-35.6
-35.6 -21.4 -7.1 7.1 21.4 35.6
X
-0.02 -0.00 0.02 0.03

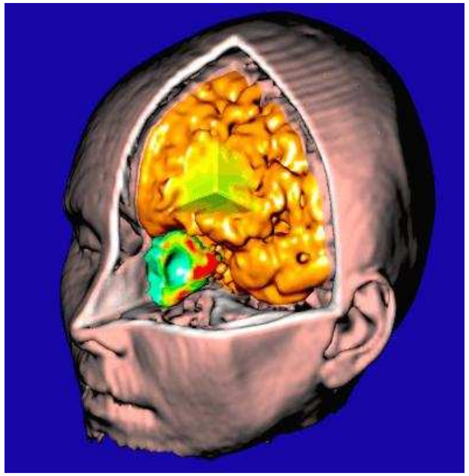

35.6
21.4
7.1
Y
-7.1
-21.4
-35.6
-35.6 -21.4 -7.1 7.1 21.4 35.6
X
-0.005 -0.002 0.002 0.005


35.6
21.4
7.1
Y
-7.1
-21.4
-35.6
-35.6 -21.4 -7.1 7.1 21.4 35.6
X
-0.01 -0.00 0.00 0.01

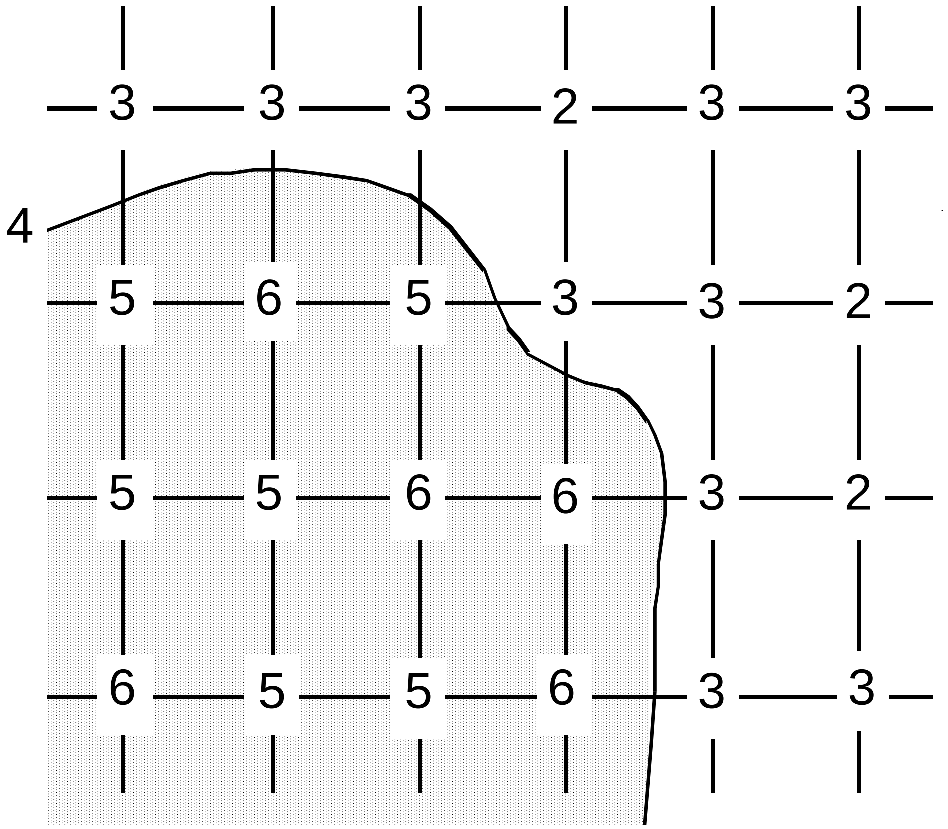

35.6
21.4
7.1
Y
-7.1
-21.4
-35.6
-35.6 -21.4 -7.1 7.1 21.4 35.6
X
-0.005 -0.002 0.002 0.005

# Why Volume Visualization?

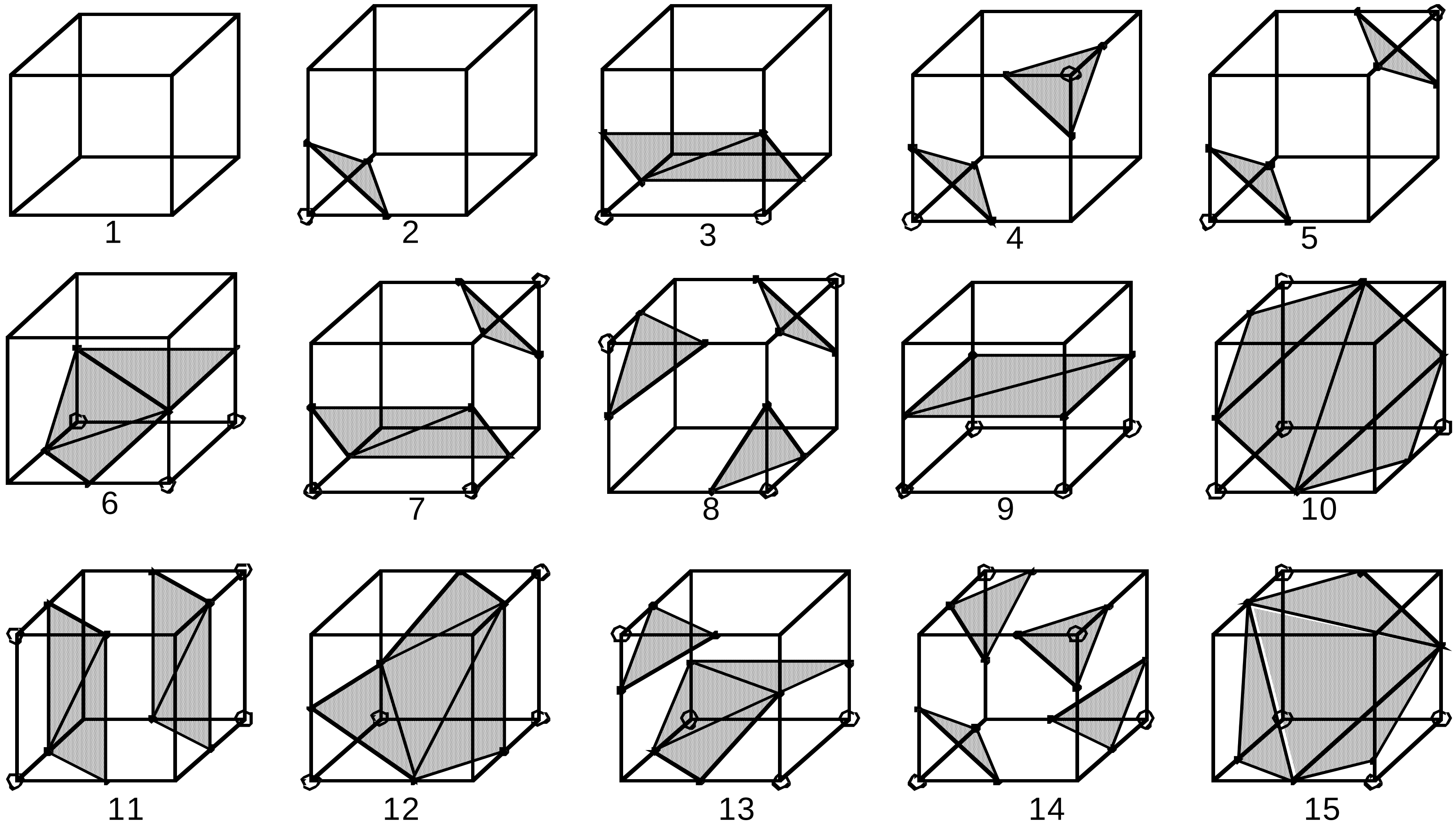
- Concerned with the representation & analysis of volume data
- To see internal structure/topology for minimal cost
- Used for
  - Medical applications
    - *Craniofacial, clinical diagnosis, radiation treatment planning, non-invasive surgery, medical education, neurology*
  - Molecular modelling
  - Non-destructive Evaluation
  - Astrophysics, Meteorology
  - Confocal Microscopy
  - Seismic Geophysics Interpretation



# Surface Extraction Methods
# Marching Cubes

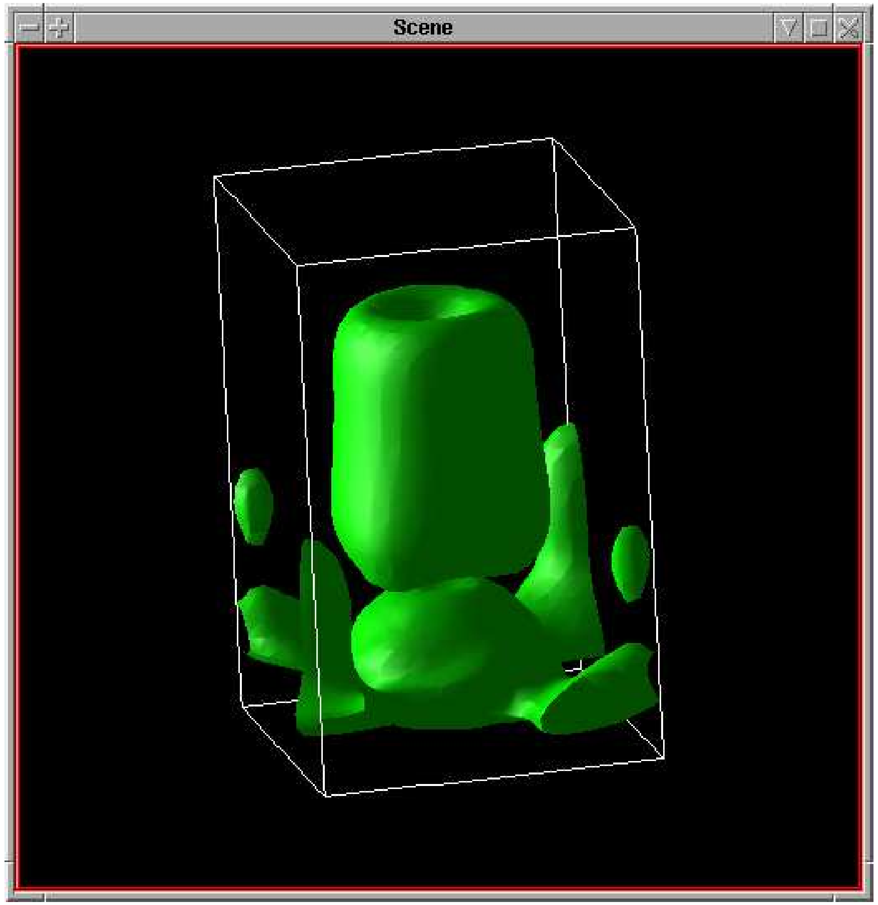


# Surface Extraction Methods
# Marching Cube



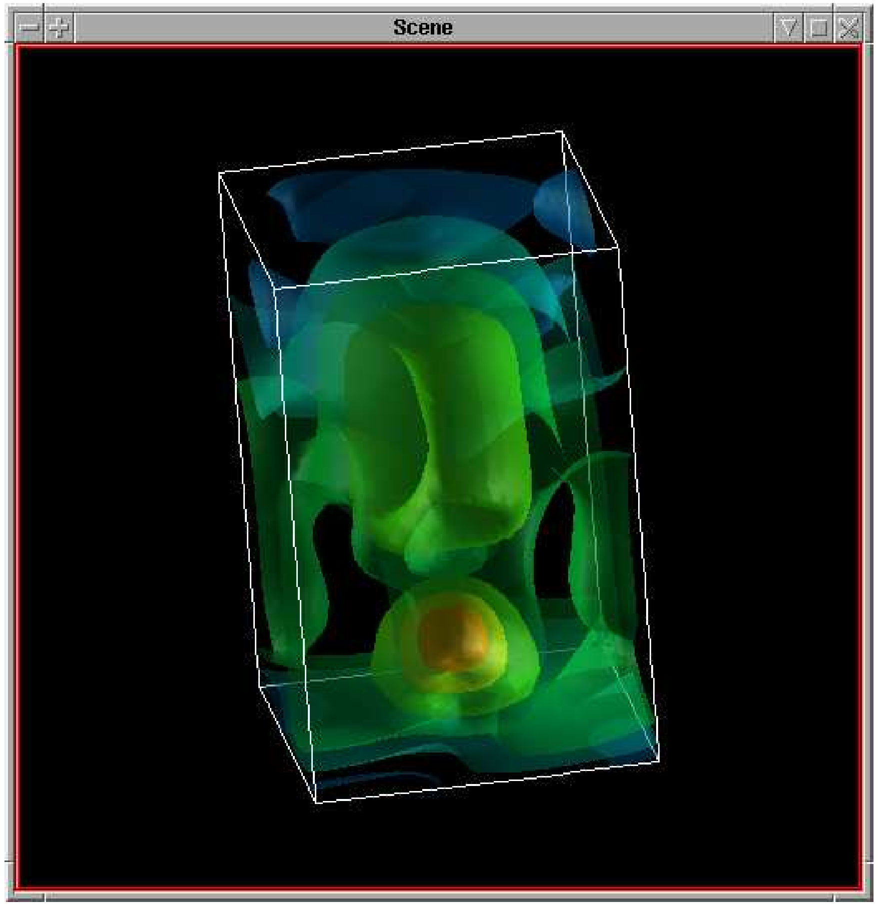
# Isosurface of Magnitude

- Surface of equal Values
  - Isolines in 3D
- Generated using marching cubes
- Interpolation (mapping) of a surface
- Useful to find special features
  - such as symmetries in the data



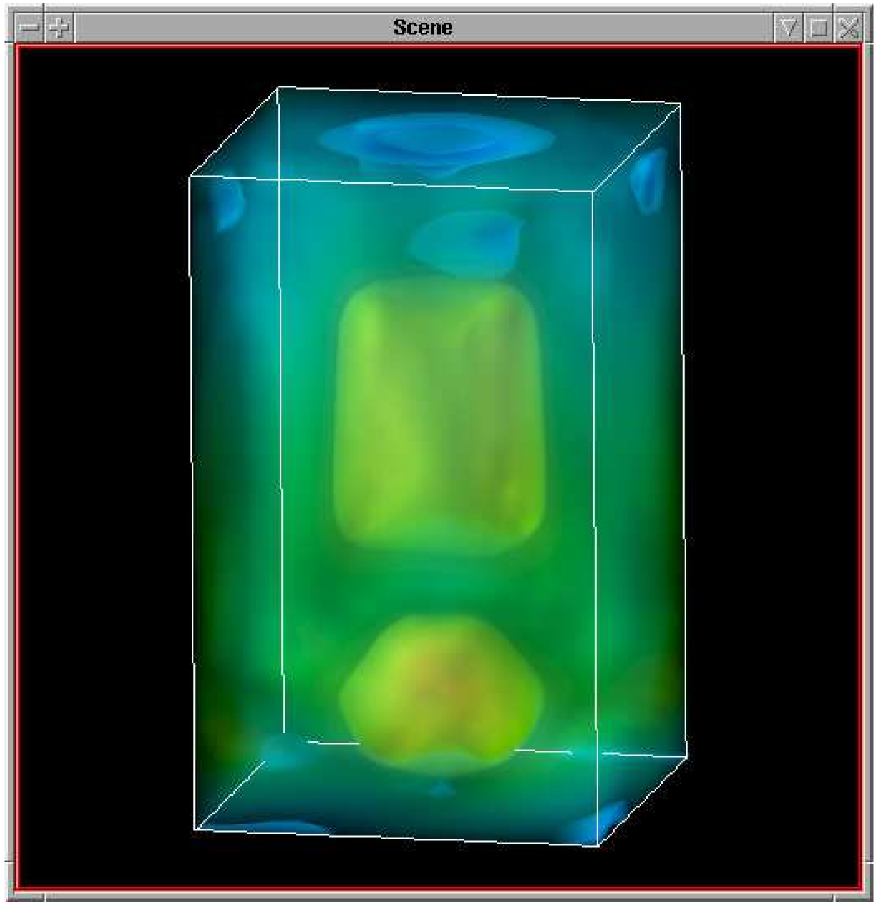
# Nested isosurfaces of Magnitude

- Nested Isosurface uses a number of surfaces to show different values
- Produces discrete steps of surfaces
- Uses transparency to show otherwise hidden objects
  - Colour coding can be hard to use
    as the transparency changes the appearance of objects
- Can be used as intermediate step between isosurfacing and volume rendering

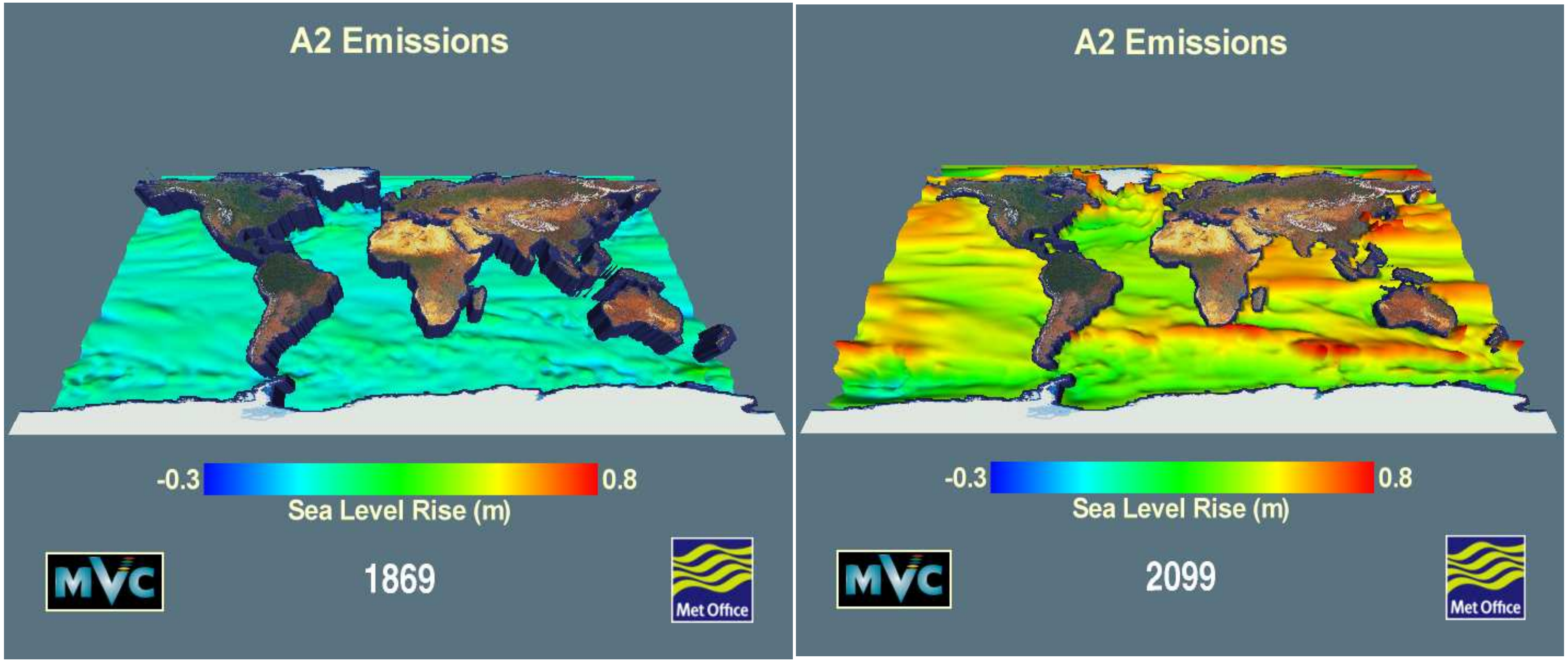


# Volume Rendering of Magnitude

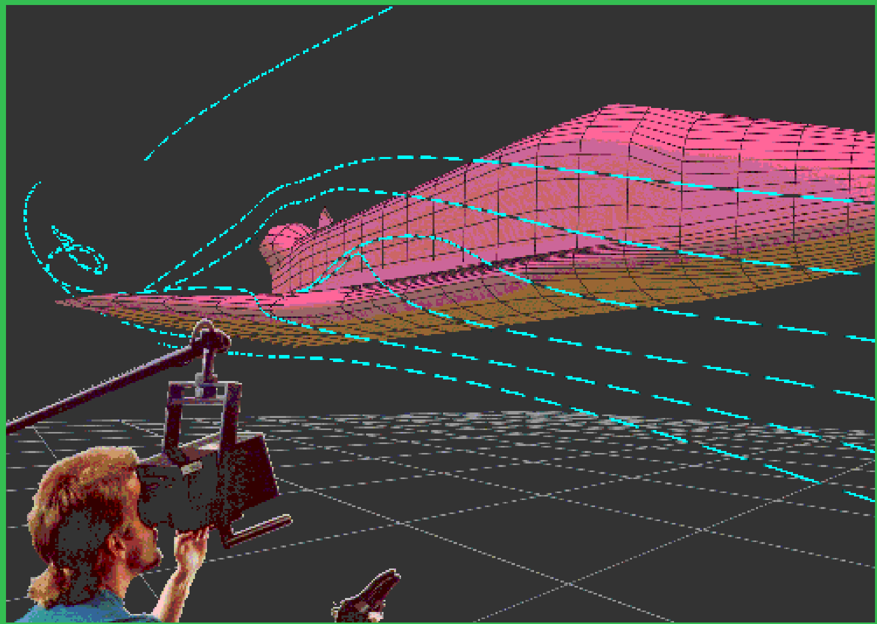
- Rendering of the volume through direct ray casting / ray tracing
- Uses transparency to give insight into the data volume (block of data)
- Colours "inside" can be hard to tell as the transparency takes effect

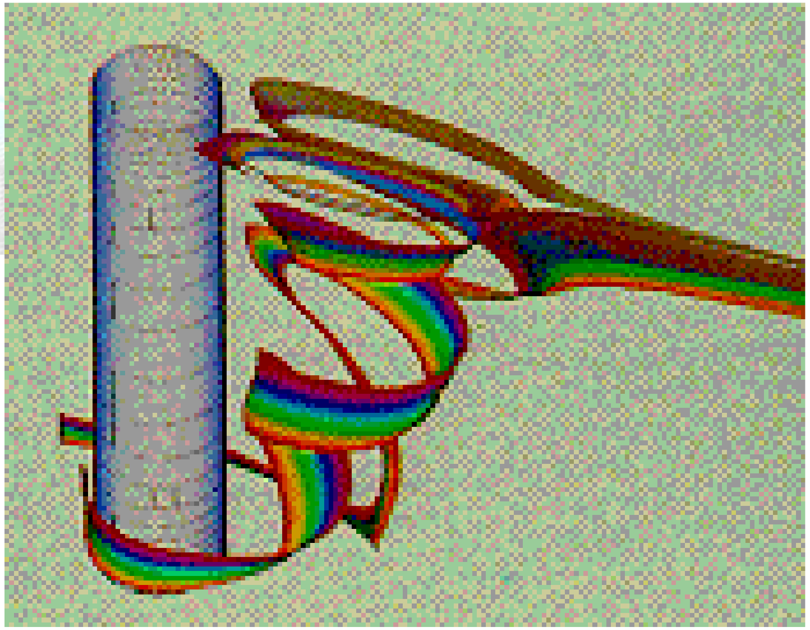


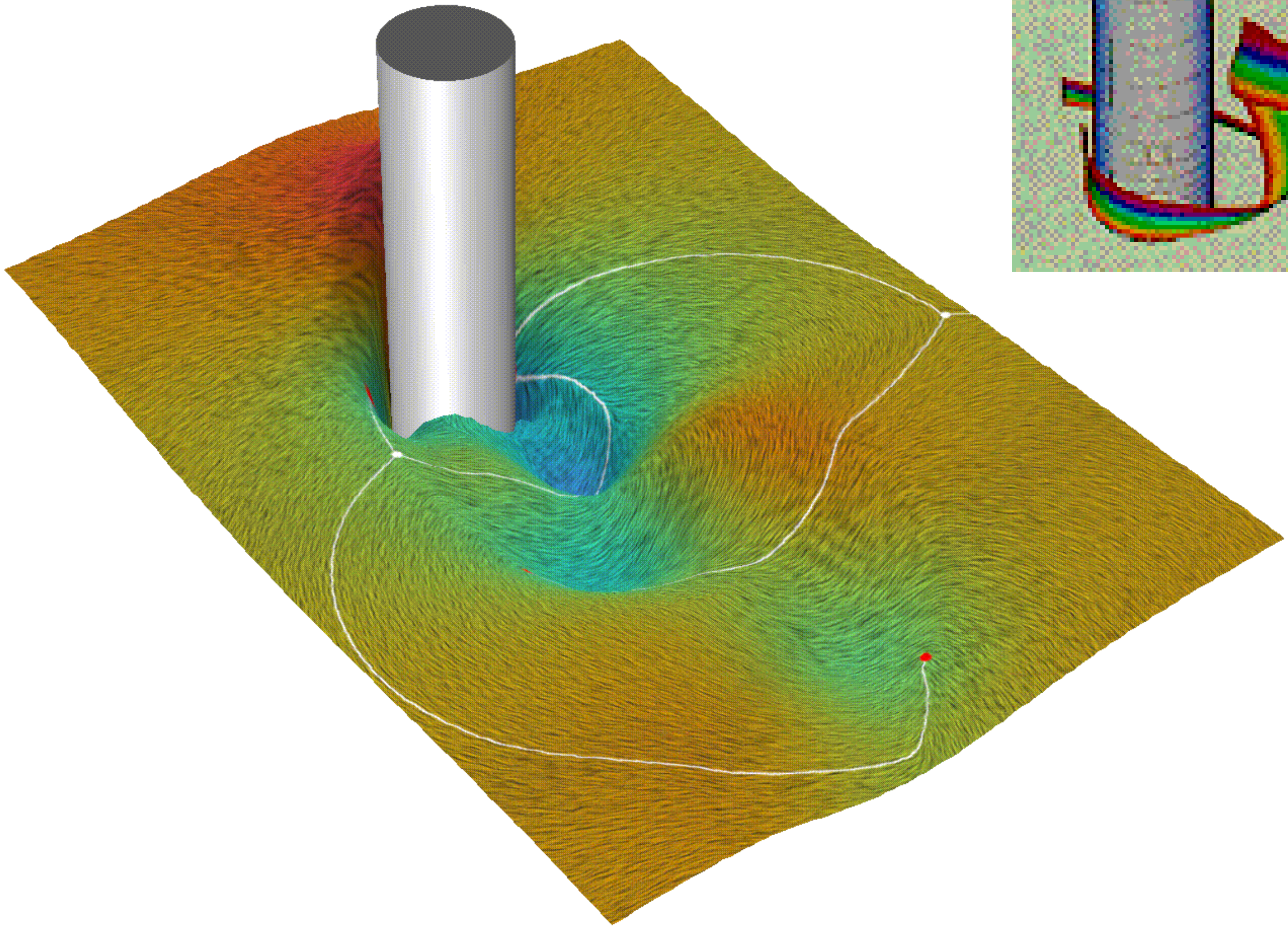
# Climate Modelling



# Flow Visualization





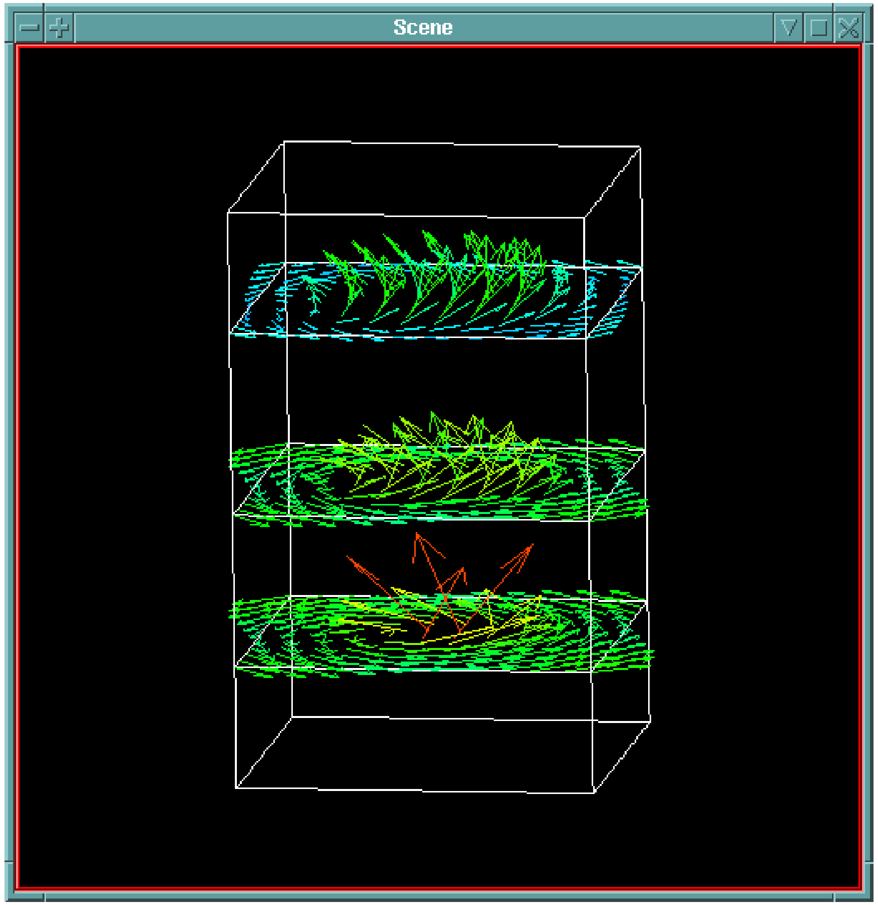


# Visualization Techniques for Vector Data

- Concerned with the representation and analysis of flow data
- Used to analyse the flow patterns and gain an insight into basically what is happening!
- Some examples:
  - Design of the components: turbines, combustion engines
  - Flow inside blood vessels
  - River and ocean flow
  - Wind effects between buildings
  - Etc …

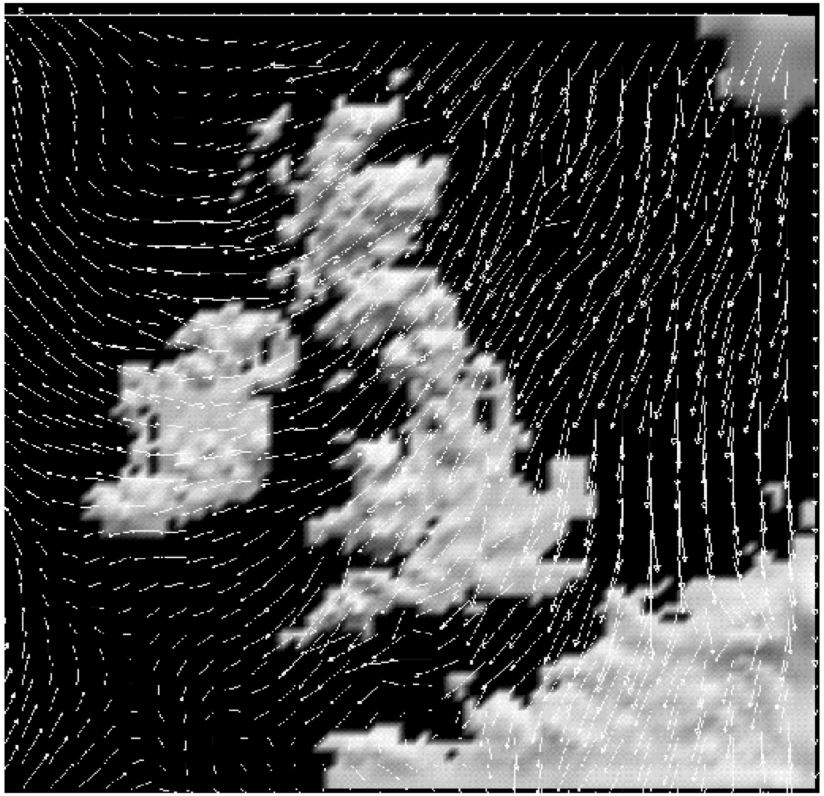
# Glyphing

- Addition of small objects representing the direction and magnitude of the flow



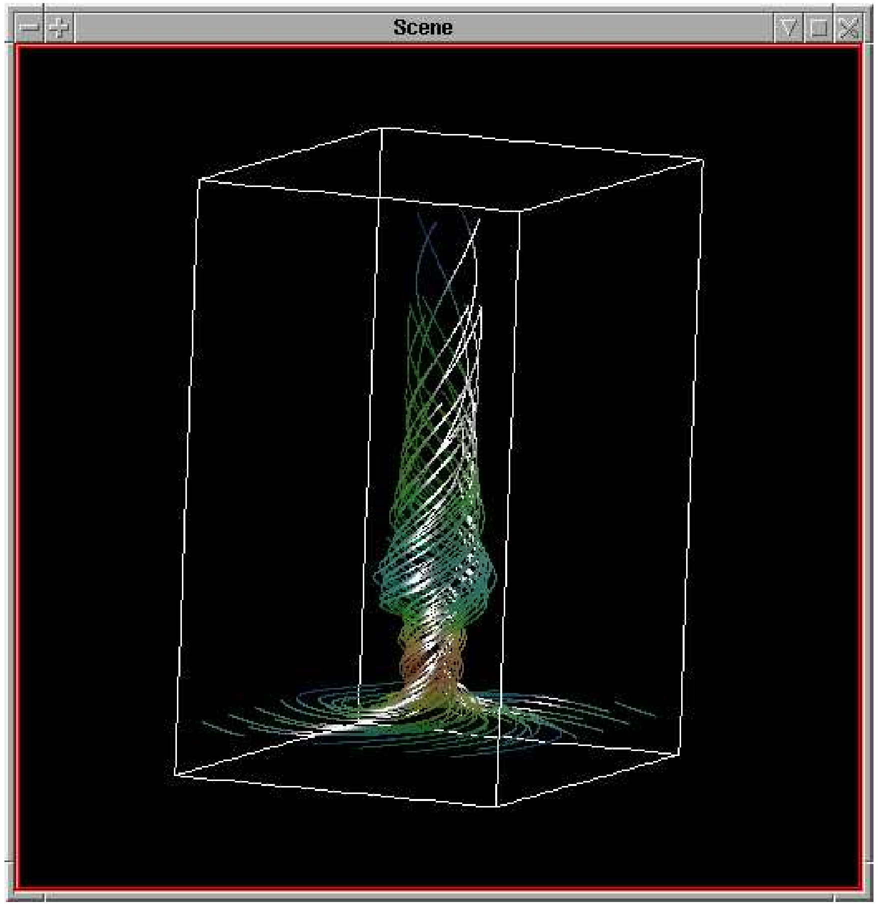
# Meteorological Visualization

- Data Courtesy of UK MET Office
- Visualization by MVC



# Streamlines

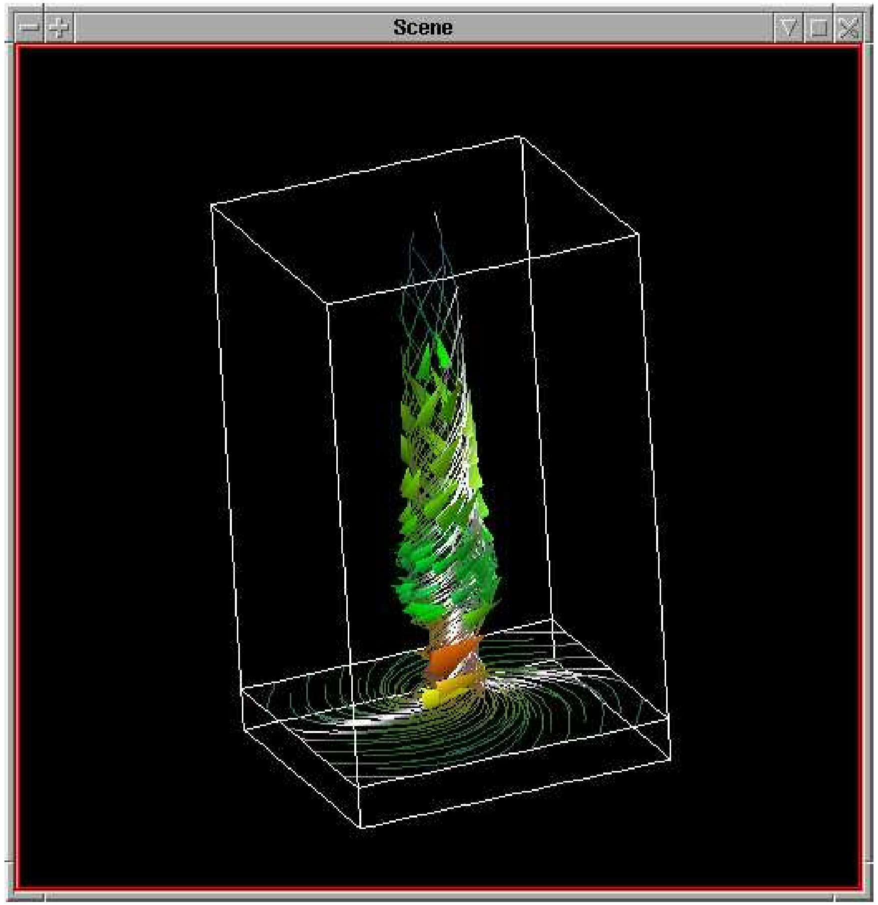
- Adding lines along the direction of the flow



# Design of cars, aircraft, ships, submarines and spacecraft

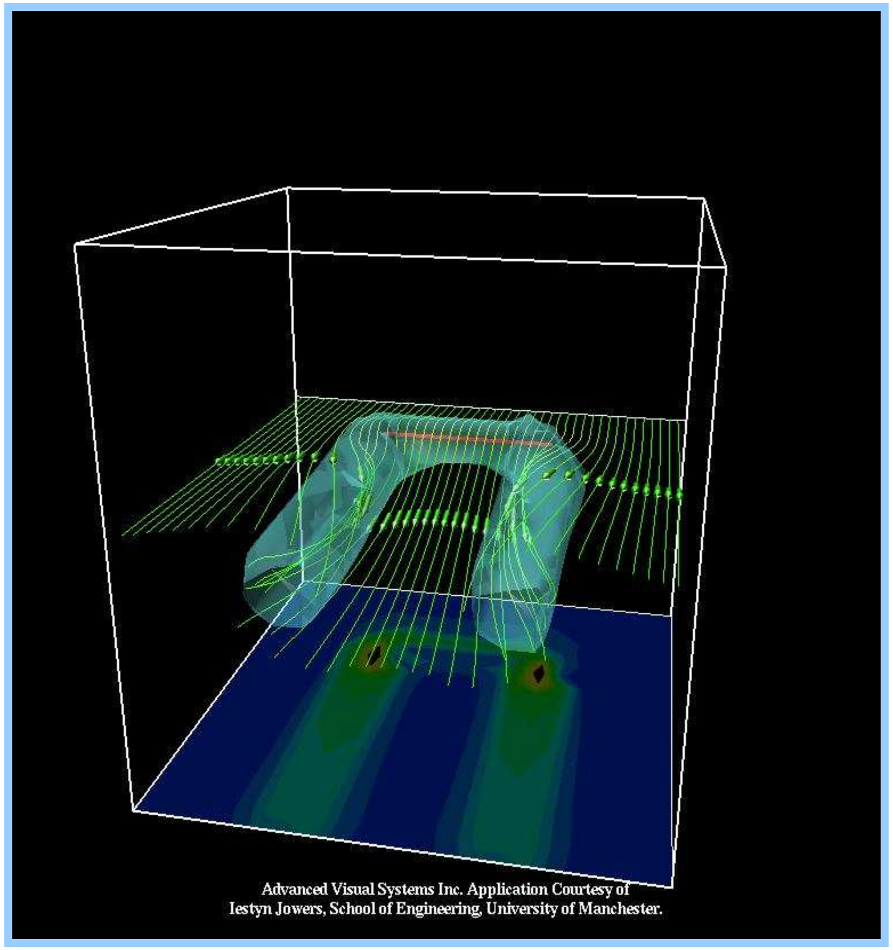
# Particle Advection

- Combination of glyphs and streamlines
- Animation of objects moving inside the flow field



# Virtual Wind Tunnel

- Finite Element Analysis of air flow over an aerofoil
- Engineering Research Project
- Teaching Tool



# Research Computing Services
# University of Manchester

***Contact Details***

www.rcs.manchester.ac.uk
mary.mcderby@manchester.ac.uk
tobias.schiebeck@manchester.ac.uk