King Abdullah University of Science and Technology KAUST

CS 247 – Scientific Visualization
Lecture 3: The Visualization Pipeline

Markus Hadwiger, KAUST

Reading Assignment #2 (until Feb 9)

Read (required):

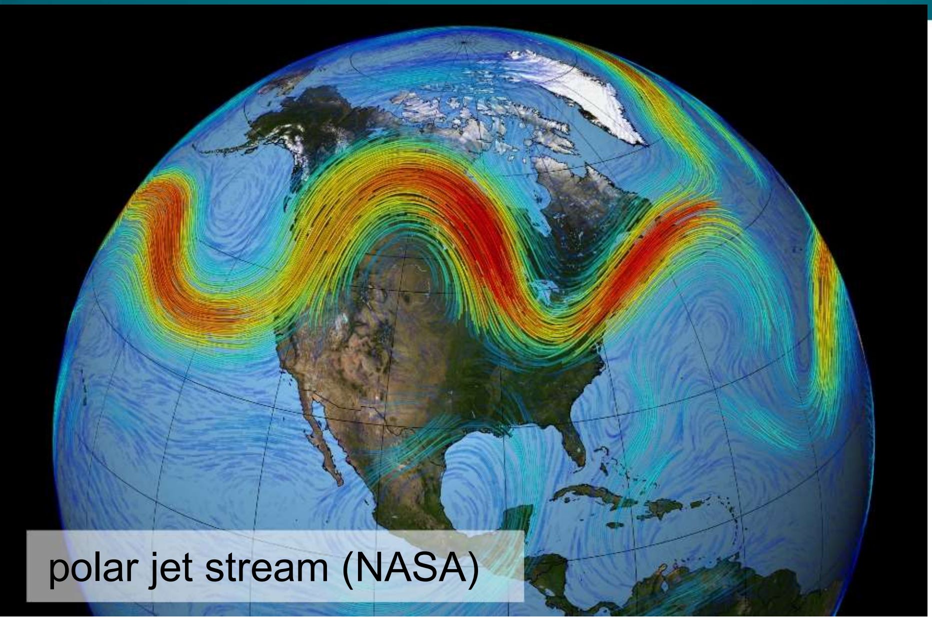
- Data Visualization book, finish Chapter 2
- Data Visualization book, Chapter 3 until 3.5 (inclusive)
- Data Visualization book, Chapter 4 until 4.1 (inclusive)

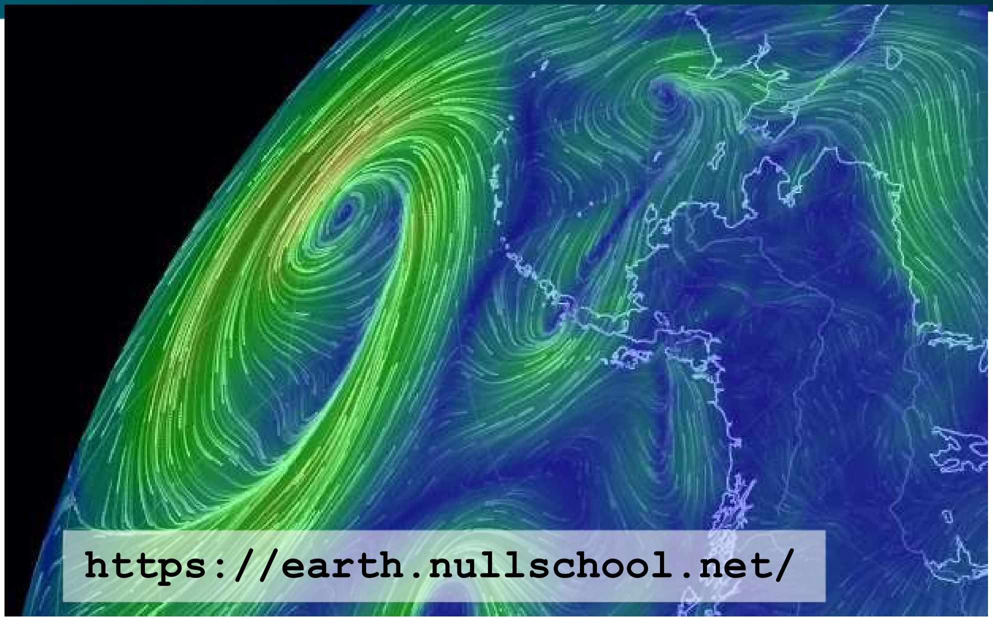
- Continue familiarizing yourself with OpenGL if you do not know it !

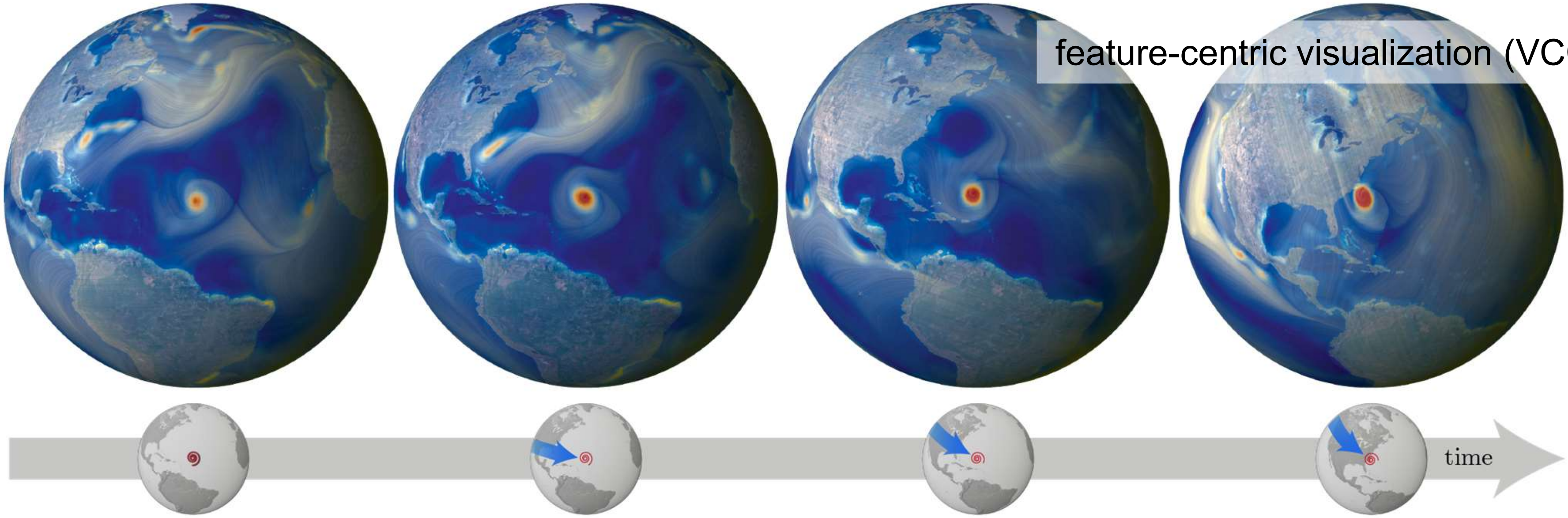
Programming Assignments Schedule (tentative)

Assignment 0:	Lab sign-up: join discord, setup github account + get repo	until	Feb 5
	Basic OpenGL example [tutorial today at 16:00]		
Assignment 1:	Volume slice viewer	until	Feb 16
Assignment 2:	Iso-contours (marching squares)	until	**Mar 2**
Assignment 3:	Iso-surface rendering (marching cubes)	until	**Mar 23**
Assignment 4:	Volume ray-casting, part 1	until	**Apr 13**
	Volume ray-casting, part 2	until	**Apr 20**
Assignment 5:	Flow vis, part 1 (hedgehog plots, streamlines, pathlines)	until	**May 4**
Assignment 6:	Flow vis, part 2 (LIC with color coding)	until	**May 14**

Scientific Visualization – Examples





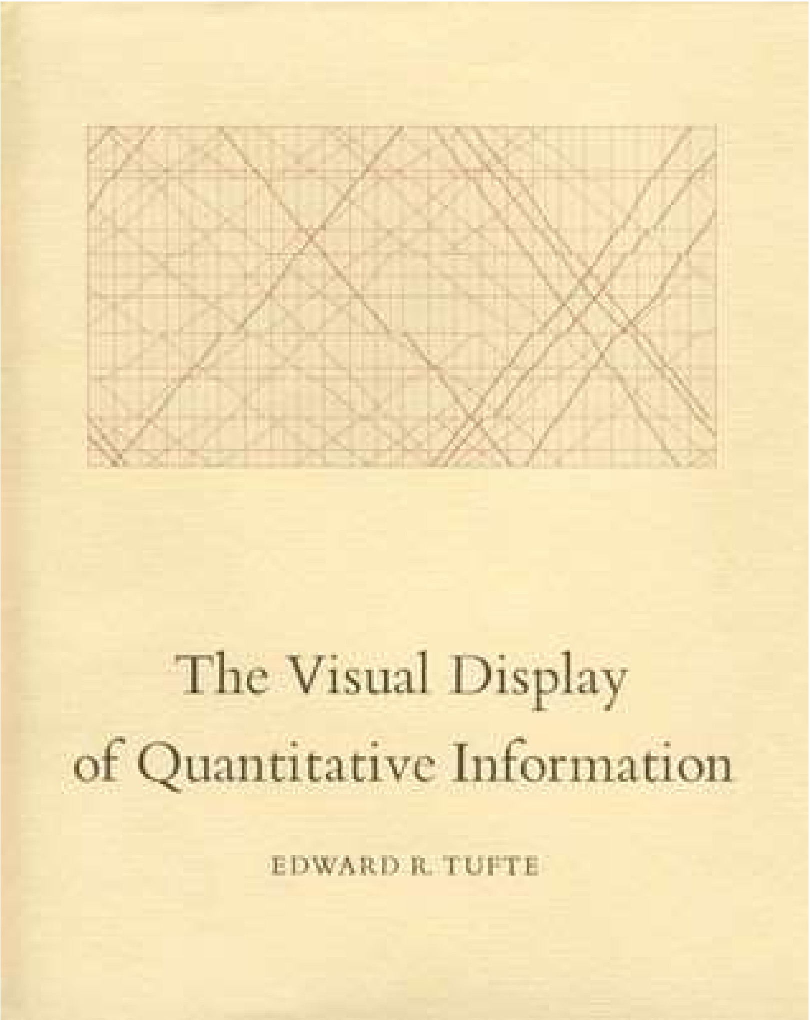


Data Graphics / Info Graphics / InfoVis

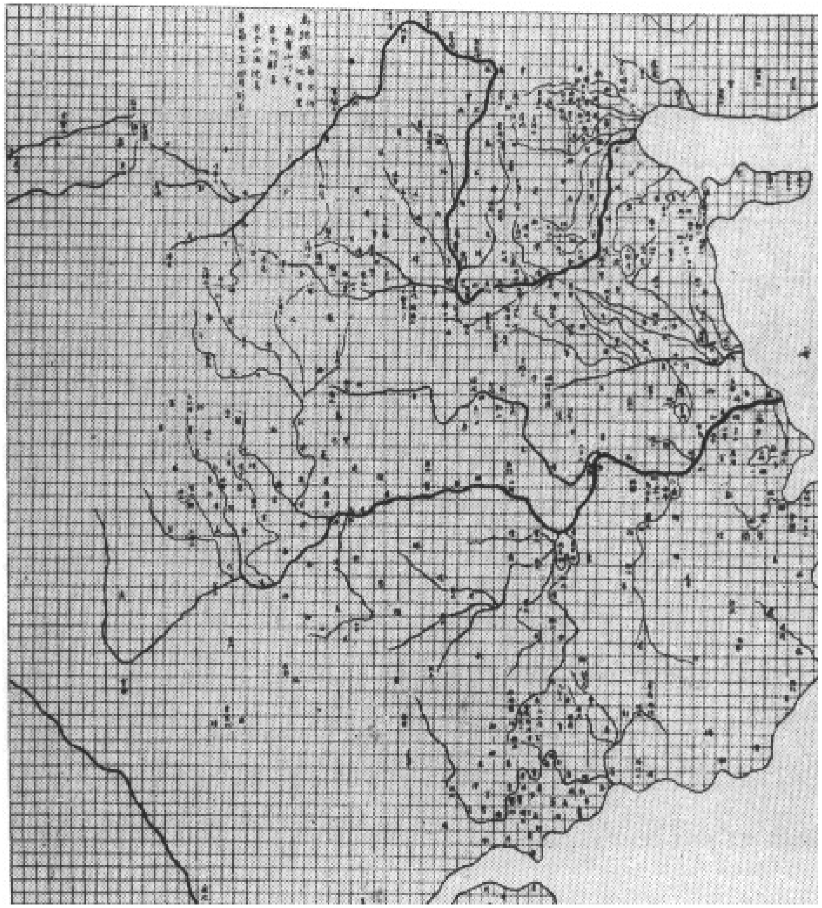
Famous book by Edward Tufte
(first edition 1983;
second edition 2001)

Selected great (and some bad) information visualizations

- William Playfair (1759-1823)
  - Bar chart, pie chart, …
- Charles Joseph Minard (1781-1870)
  - Napoleon’s Russia campaign, …
- …



Travelling Routes of Yu the Great

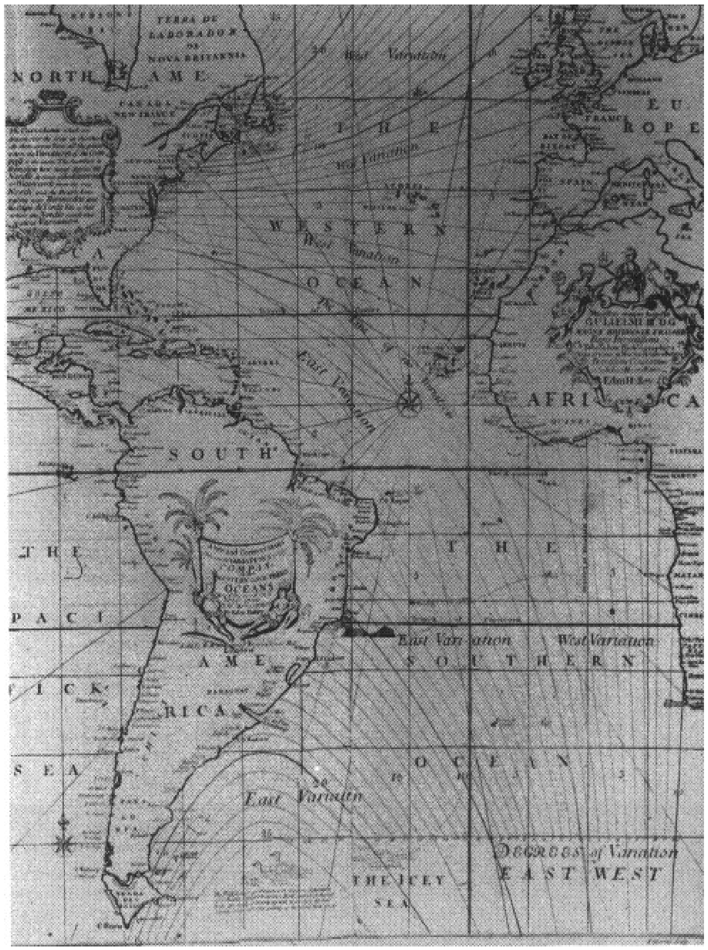


China, 1137

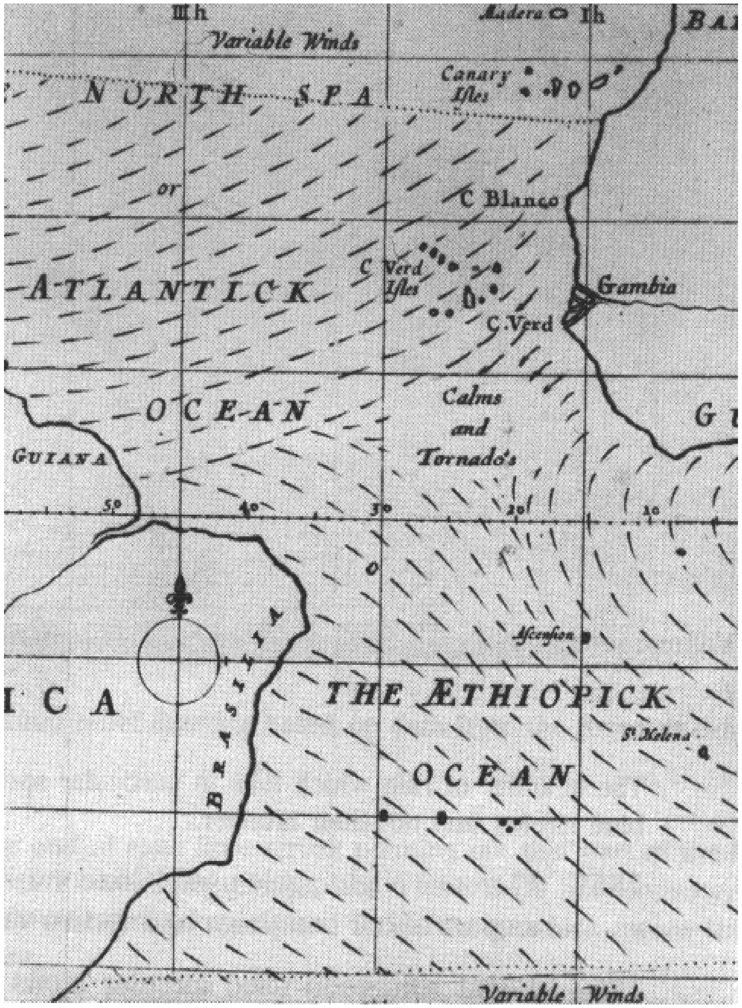
Geographical map using Cartesian coordinates

Grid with longitudinal and latitudinal lines

Cartography

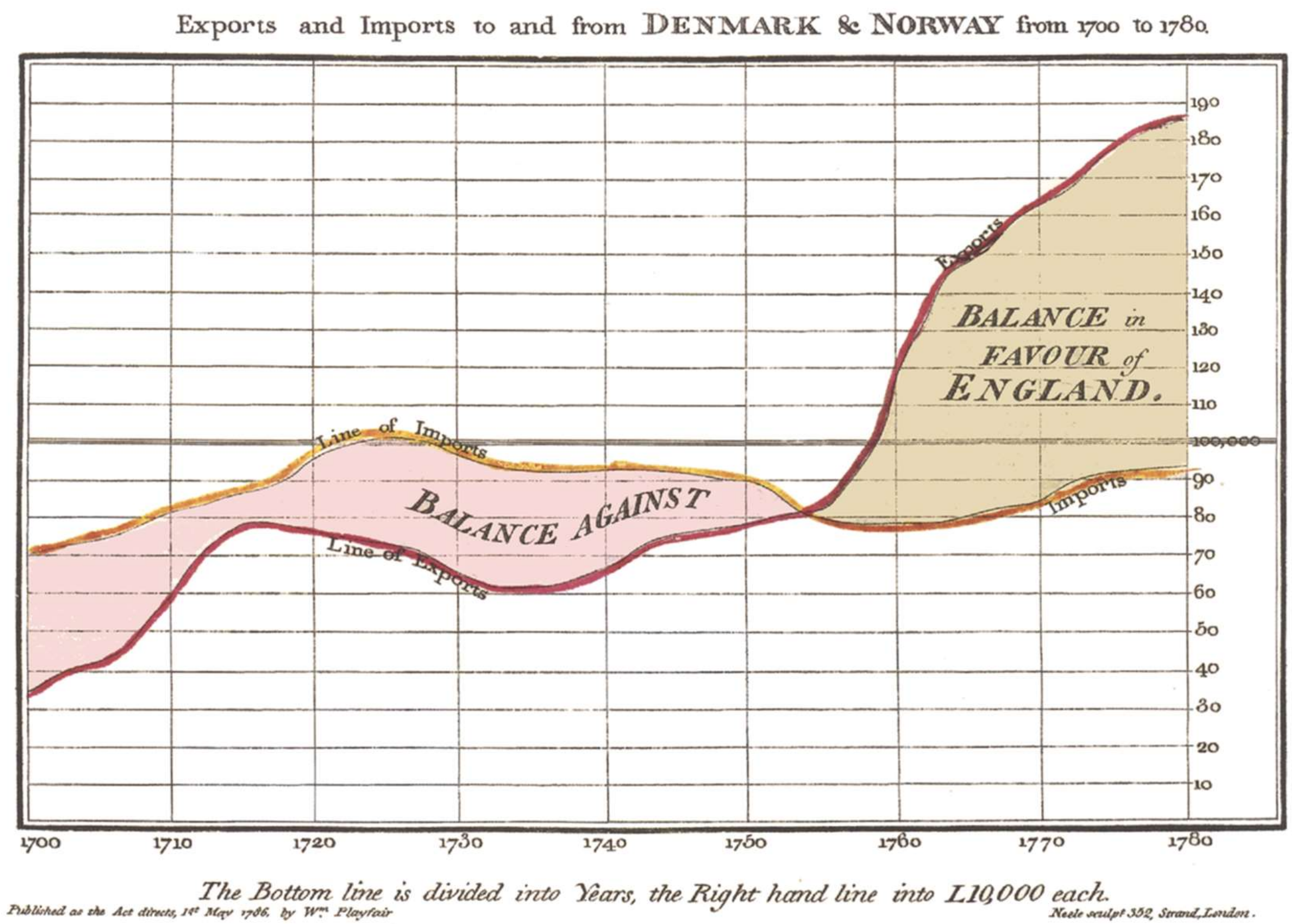


Isolines to visualize compass deviations



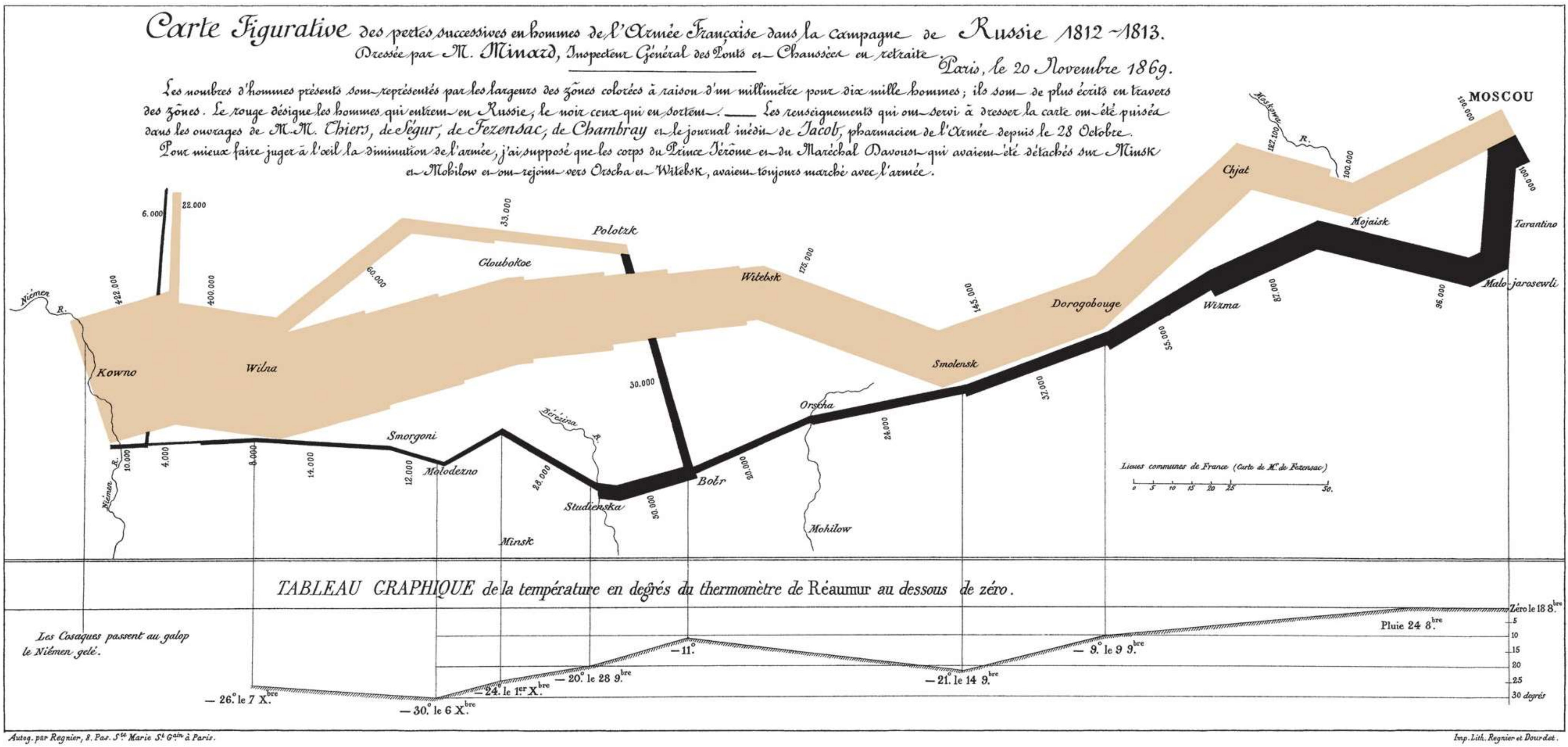
Wind flow visualization

Business Graphics



William Playfair, Scottish economist, Commercial and Political Atlas, 1785

Russia Military Campaign of Napoleon



Charles Joseph Minard, 1869

Cholera Epidemic in London

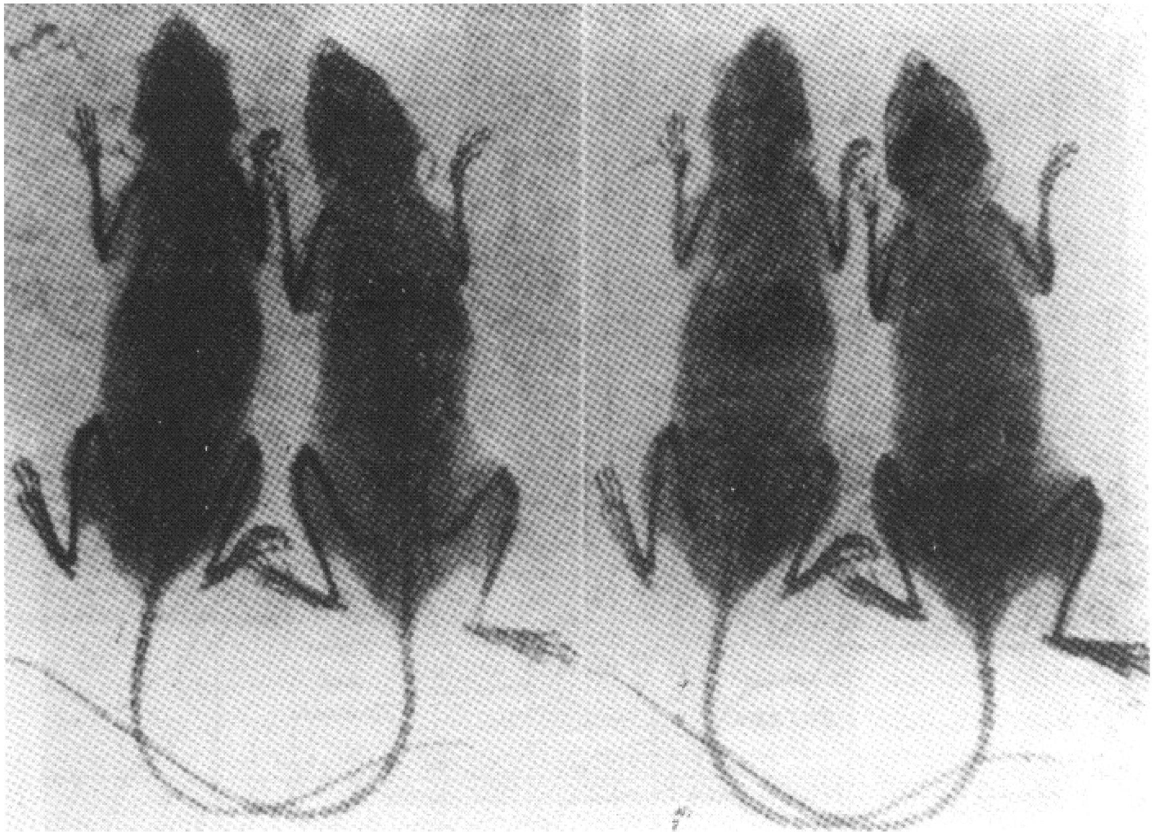
Dr. John Snow, 1854

Cartographic visualization

Correlation between water supply and disease incidents detected

Visualization in Medicine

- X-rays (Wilhelm Conrad Röntgen, 1895)
- Stereo X-ray images (1896)

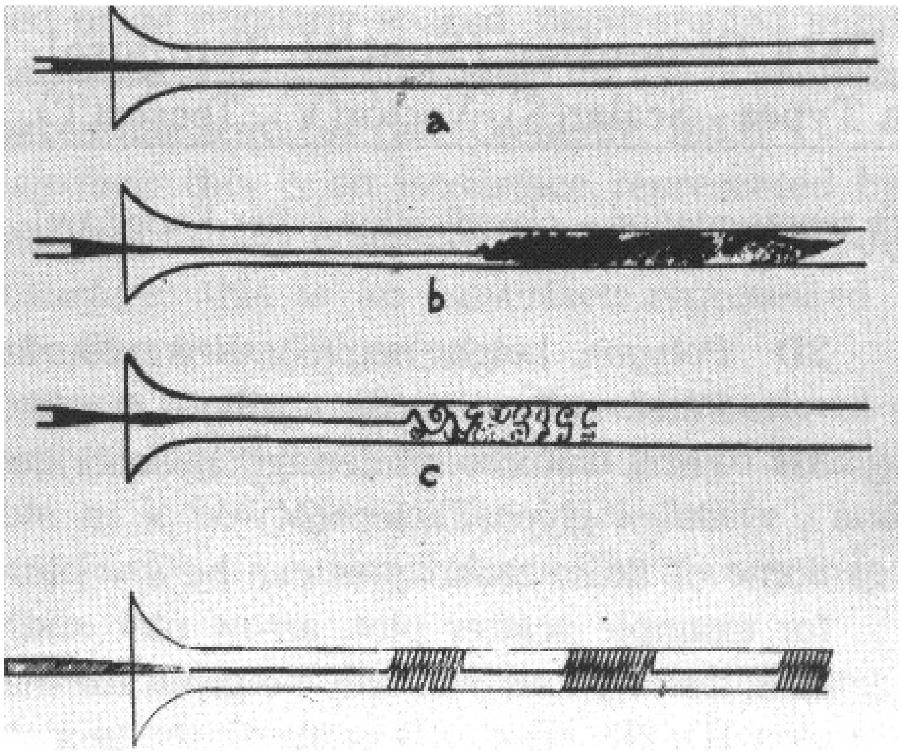


X-ray tomography

Experimental Flow Investigation

Fixation of tufts, ribbons on

- Aircraft in wind tunnels
- Ship hull in fluid tanks



- Introduction of smoke particles (in wind tunnel)
- Introduction of dye (in fluids)

Data Generation, Visualization, Interaction

Coupling between the three can vary considerably

- Data generation (data acquisition):
  - Measuring, simulation, modeling
  - Can take very long (measuring, simulation)
  - Can be very costly (simulation, modeling)
- Visualization (rest of visualization pipeline):
  - Data enhancement, visualization mapping, rendering
  - Depending on computer, implementation: fast or slow
- Interaction (user feedback):
  - How can the user intervene, vary parameters

Passive Visualization

All three steps separated:

- Off-line data generation
  - Measurements
  - Simulation
  - Modeling
- Off-line Visualization
  - Previously generated data are visualized
  - Result: video or images/animation
- Passive Visualization
  - Viewing of the visualization results

Interactive Visualization

Only data generation is separated:

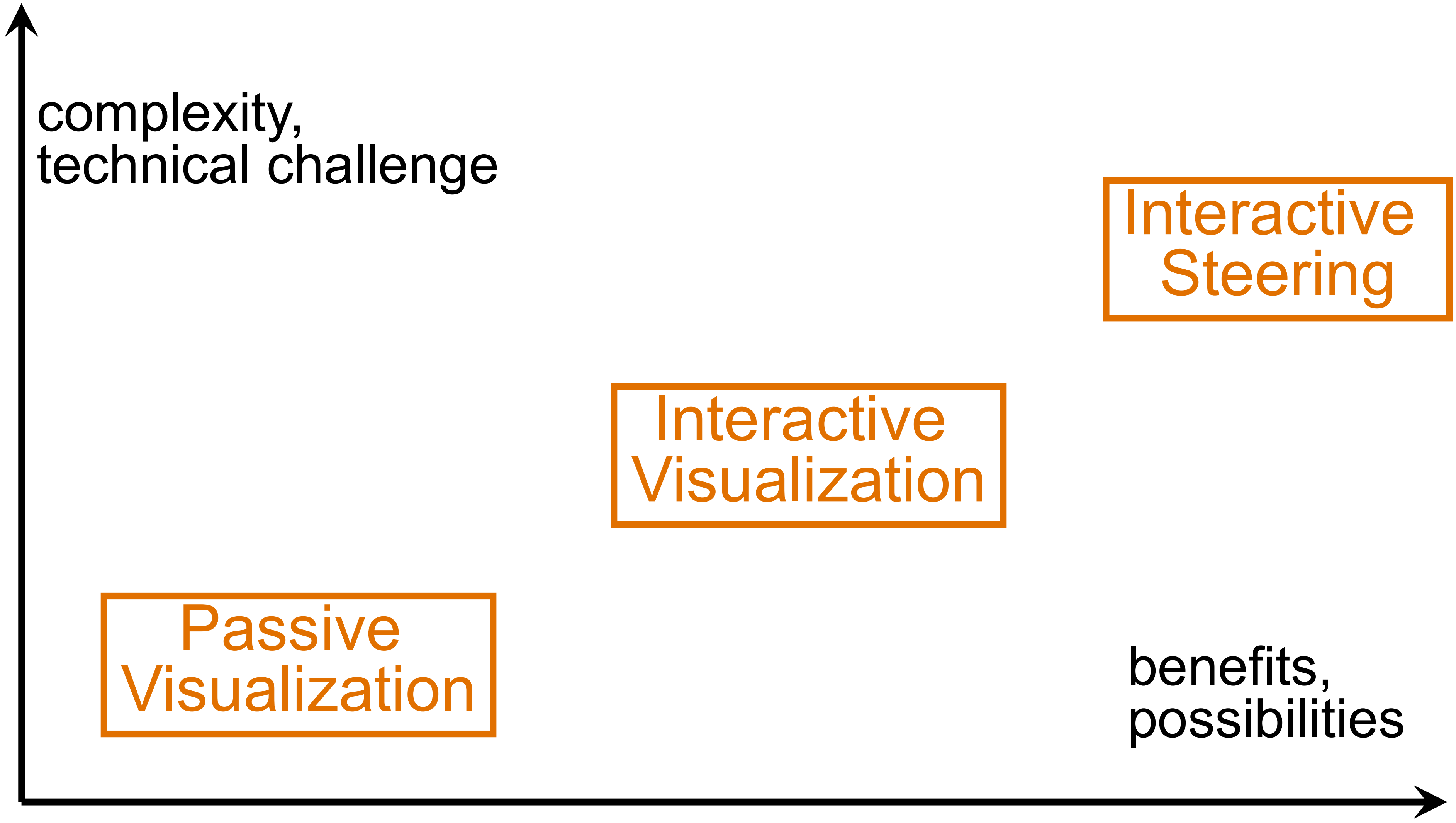
- Off-line data generation
  - Measurements, Simulation, Modeling
- Interactive visualization
  - Previously generated data are available
  - Visualization program allows interactive visualization of the data
  - Possibilities:
    choice, variation, parameterization of the visualization technique
  - Nowadays widespread
  - Focus of this course!

Interactive Steering

All three steps coupled:

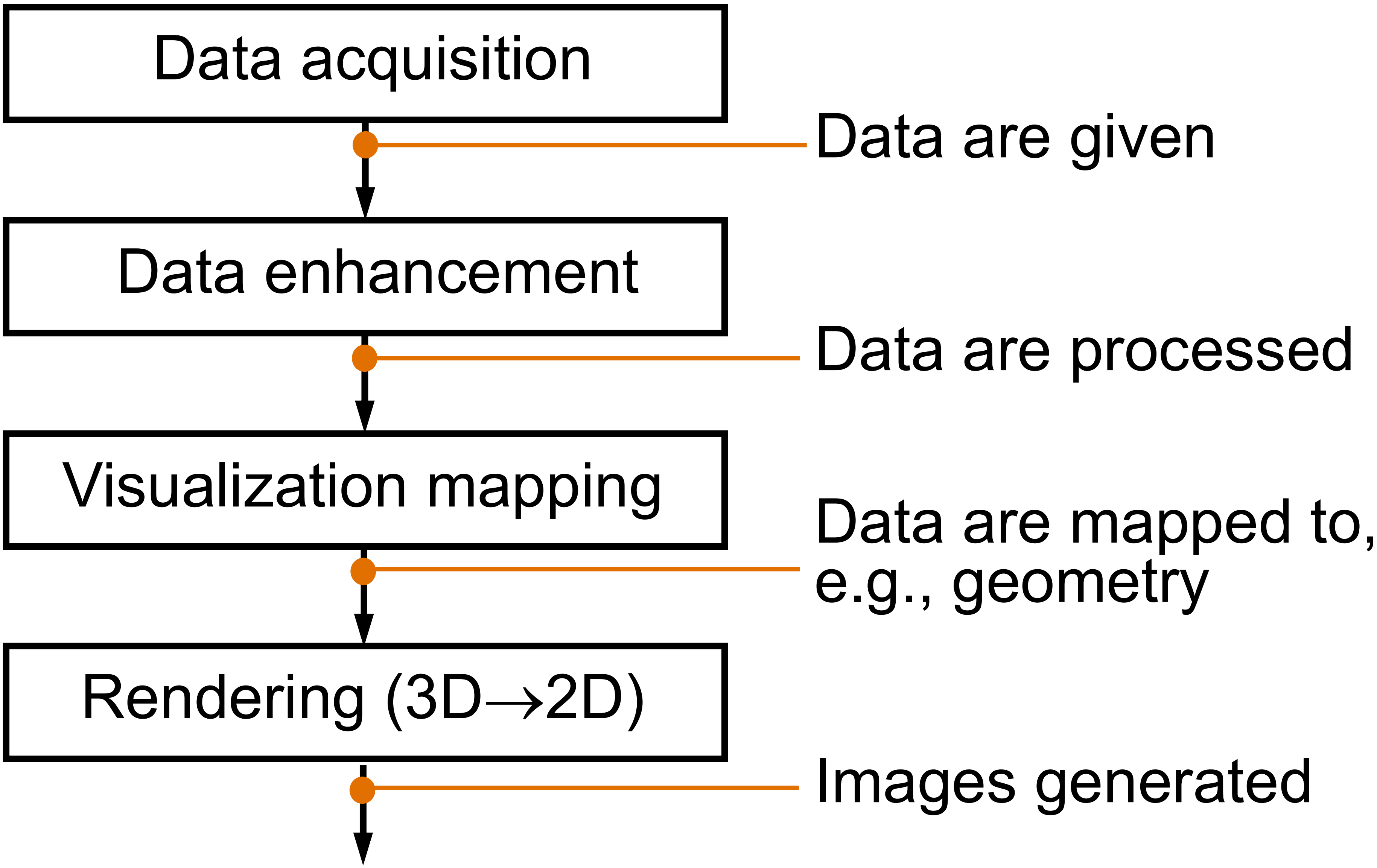
- Interactive steering
  - Simulation and/or modelling (measuring) generate data “on the fly”
  - Interactive visualization allows “real-time” insight into the data
  - Extended possibilities:
    user can interfere with the simulation and/or the modeling, change the design, ...
  - Often requires lots of effort, very costly

Visualization Scenarios



The Visualization Pipeline

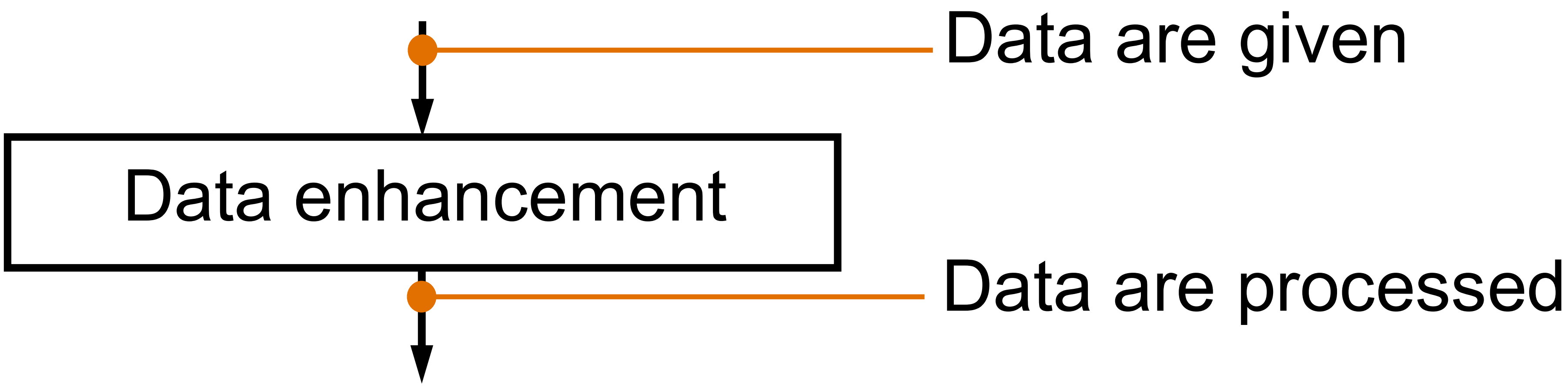
The Visualization Pipeline – Overview



The Visualization Pipeline – Stage 1

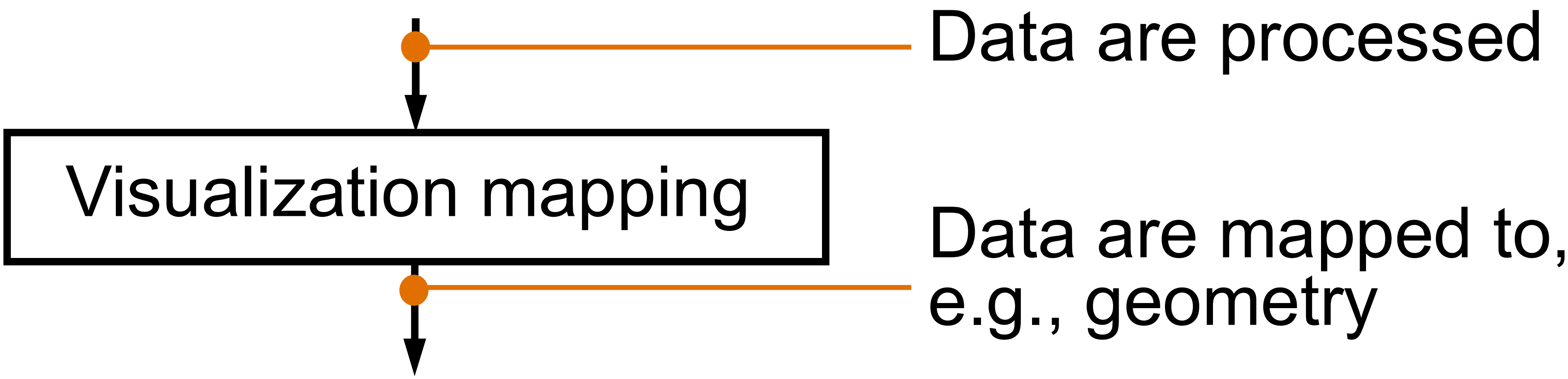
- Measurements, e.g., CT/MRI
- Simulation, e.g., flow simulation
- Modeling, e.g., game theory

The Visualization Pipeline – Stage 2



- Filtering, e.g, smoothing (de-noising, …)
- Resampling, e.g., on a different-resolution grid
- Data derivation, e.g., gradients, curvature
- Data interpolation, e.g., linear, cubic, …

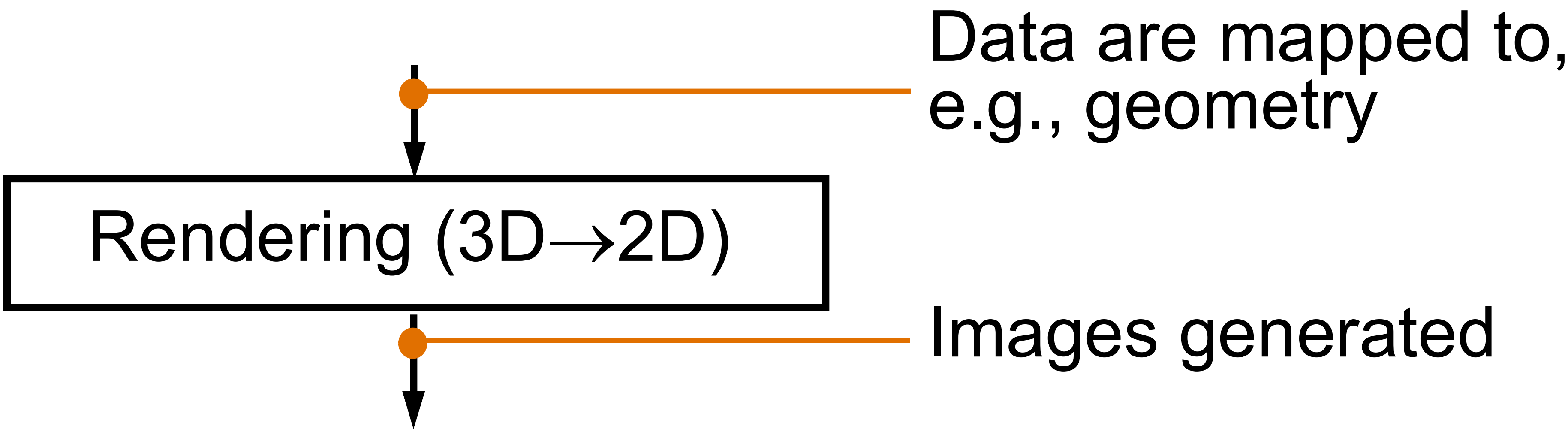
The Visualization Pipeline – Stage 3



Make data “renderable”

- Iso-surface calculation
- Glyphs, icons determination
- Graph-layout calculation
- Voxel attributes: color, transparency, …

The Visualization Pipeline – Stage 4



Rendering = image generation with computer graphics

- Visibility calculation
- Illumination
- Compositing (combine transparent objects, …)
- Animation

Data Representation

Our Input: Data

Focus of visualization, everything is centered around data

- Driving factor (besides user) in choice and attribution of the visualization technique
- Important questions
  - **Data space**: where do the data “live”? (domain)
  - **Type** of the data
  - Which **representation** makes sense (secondary aspect)

Data Space: Domain

Where do the data “live”? (domain)

- Inherent spatial domain (**SciVis**):
  - 2D/3D data space given
  - examples: medical data, flow simulation data, GIS data, etc.
- No inherent spatial reference (**InfoVis**):
  - abstract data,
    spatial embedding through visualization
  - example: data bases, deep neural nets
- **Aspects**: dimensionality, domain, coordinates,
  region of influence of samples (local, global)

Data Type: Codomain

What type of data?

- **Data types**:
  - Scalar = numerical value
    (natural, integer, rational, real, complex numbers)
  - Non-numerical (categorical) values (e.g., blood type)
  - Multi-dimensional values, i.e., codomain (n-dim. vectors, second-order ($n \times n$) tensors, higher-order tensors, ...)
  - Multi-modal values (vectors of data with varying type [e.g., row in a table])
- **Aspects**: dimensionality, codomain (superset of range/image)

Data Space (Domain) vs. Data Type (Codomain)

	1D	2D	3D
1D	y=f(x)		spatial curve **x**(t)
2D		2D flow **v**(**x**)	
3D	CT data s(**x**)		3D flow **v**(**x**)

examples

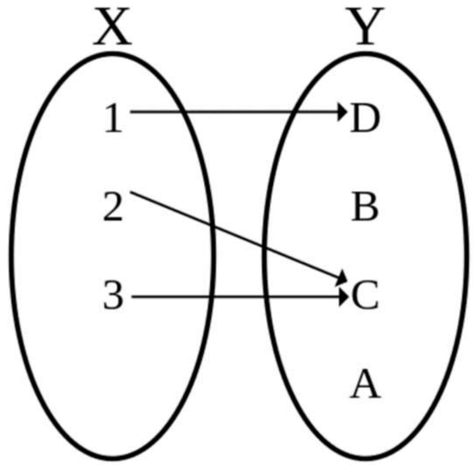
Data == Functions

Mathematical Functions

Associates every element of a set (e.g., X) with *exactly one* element of another set (e.g., Y)

Maps from *domain* (X) to *codomain* (Y)

$$f : X \to Y$$
$$x \mapsto f(x)$$



Also important: *range/image*; *preimage*; continuity, differentiability, dimensionality, ...

Graph of a function (mathematical definition):

$$G(f) := \{(x, f(x)) | x \in X\} \subset X \times Y$$

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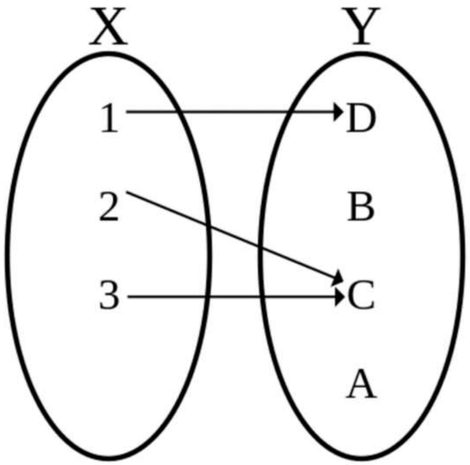


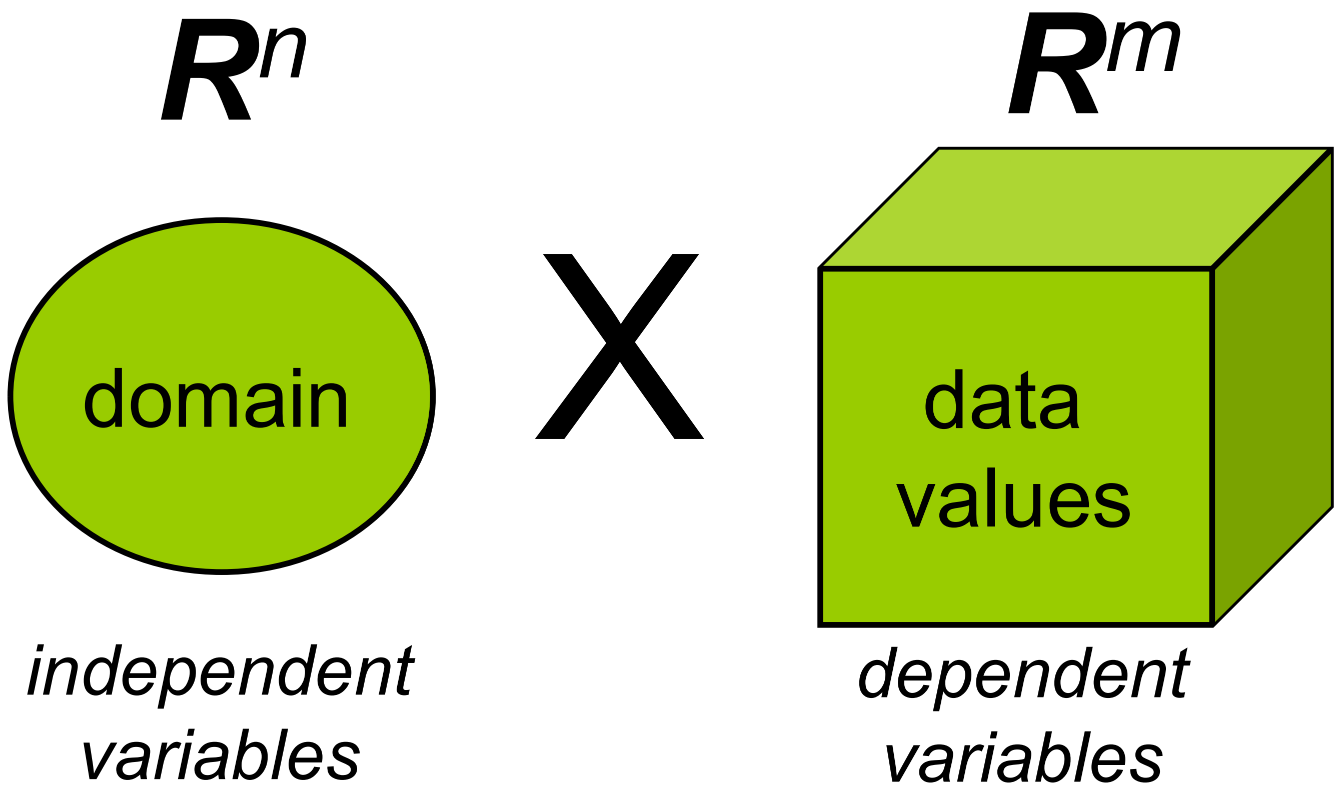
$$f : \mathbb{R}^n \to \mathbb{R}^m$$
$$x \mapsto f(x)$$

Also important: *range/image*; *preimage*; continuity, differentiability, dimensionality, ...

Graph of a function (mathematical definition):

$$G(f) := \{(x, f(x)) | x \in \mathbb{R}^n\} \subset \mathbb{R}^n \times \mathbb{R}^m \simeq \mathbb{R}^{n+m}$$

Data Representation



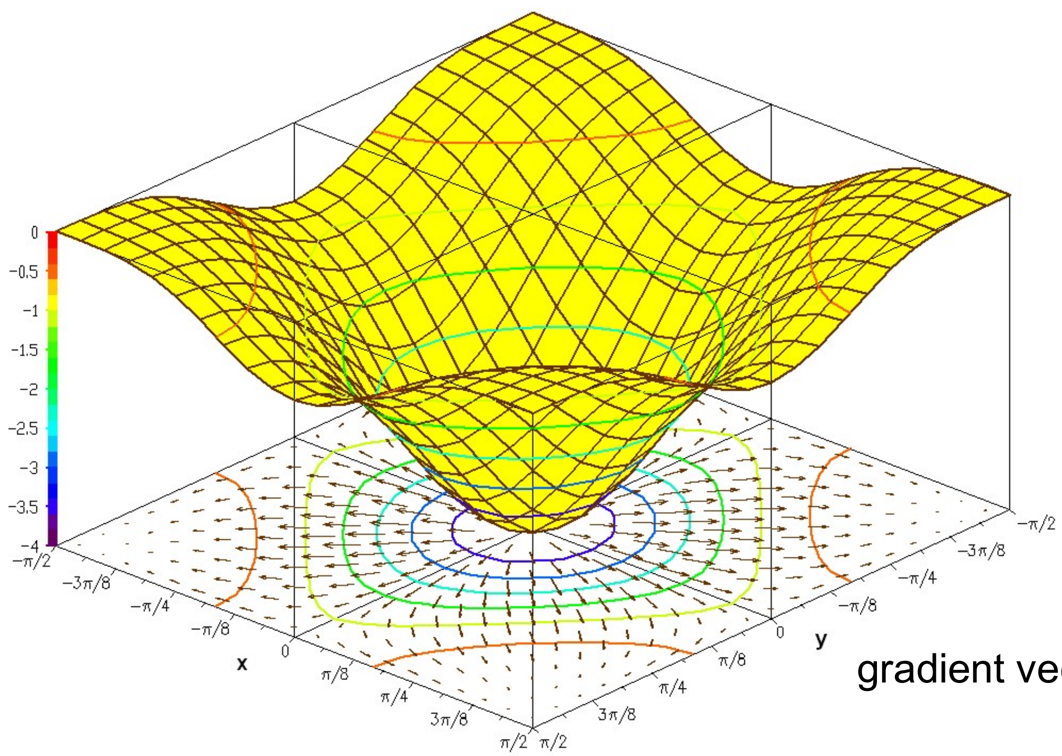
scientific data $\subseteq \mathbf{R}^{n+m}$

Example: Scalar Fields

2D scalar field

$$f : \mathbb{R}^2 \to \mathbb{R}$$
$$x \mapsto f(x)$$

Graph: $G(f) := \{(x, f(x)) | x \in \mathbb{R}^2\} \subset \mathbb{R}^2 \times \mathbb{R} \simeq \mathbb{R}^3$



gradient vector field ∇f

pre-image

$$S(c) := f^{-1}(c)$$

iso-contour

$$(\nabla f \neq 0)$$

Example: Scalar Fields

3D scalar field

$$f : \mathbb{R}^3 \to \mathbb{R}$$
$$x \mapsto f(x)$$

Graph: $G(f) := \{(x, f(x)) | x \in \mathbb{R}^3\} \subset \mathbb{R}^3 \times \mathbb{R} \simeq \mathbb{R}^4$

pre-image

$$S(c) := f^{-1}(c)$$

iso-surface

$$(\nabla f \neq 0)$$

?

Visualization Examples

data	description	visualization example
$N^1 \to R^1$	value series	bar chart, pie chart, etc.
$R^1 \to R^1$	scalar function over R	(line) graph
$R^2 \to R^1$	scalar function over R^2	2D-height map in 3D, contour lines in 2D, false color map
$R^2 \to R^2$	2D vector field	hedgehog plot, LIC, streamlets, etc.
$R^3 \to R^1$	scalar function over R^3 (3D densities)	iso-surfaces in 3D, volume rendering
$R^3 \to R^3$	3D vector field	streamlines/pathlines in 3D

Thank you.

Thanks for material

- Helwig Hauser
- Eduard Gröller
- Daniel Weiskopf
- Torsten Möller
- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama