King Abdullah University of Science and Technology

KAUST

CS 247 – Scientific Visualization
Lecture 3: The Visualization Pipeline; Data Representation, Pt. 1

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Reading Assignment #2 (until Feb 8)

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 1**
	Basic OpenGL example		
Assignment 1:	Volume slice viewer	until	**Feb 15**
Assignment 2:	Iso-contours (marching squares)	until	**Mar 1**
Assignment 3:	Iso-surface rendering (marching cubes)	until	**Mar 15**
Assignment 4:	Volume ray-casting, part 1	until	**Apr 12**
	Volume ray-casting, part 2	until	**Apr 19**
Assignment 5:	Flow vis, part 1 (hedgehog plots, streamlines, pathlines)	until	**May 3**
Assignment 6:	Flow vis, part 2 (LIC with color coding)	until	**May 13**

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

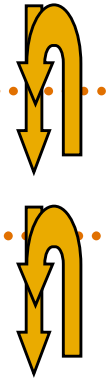
- Interactive visualization
  - Previously generated data are available
  - Visualization program allows interactive visualization of the data

  - Possibilities:
    choice, variation, parameterization of the visualization technique
  - Nowadays widespread
  - Focus of this course!

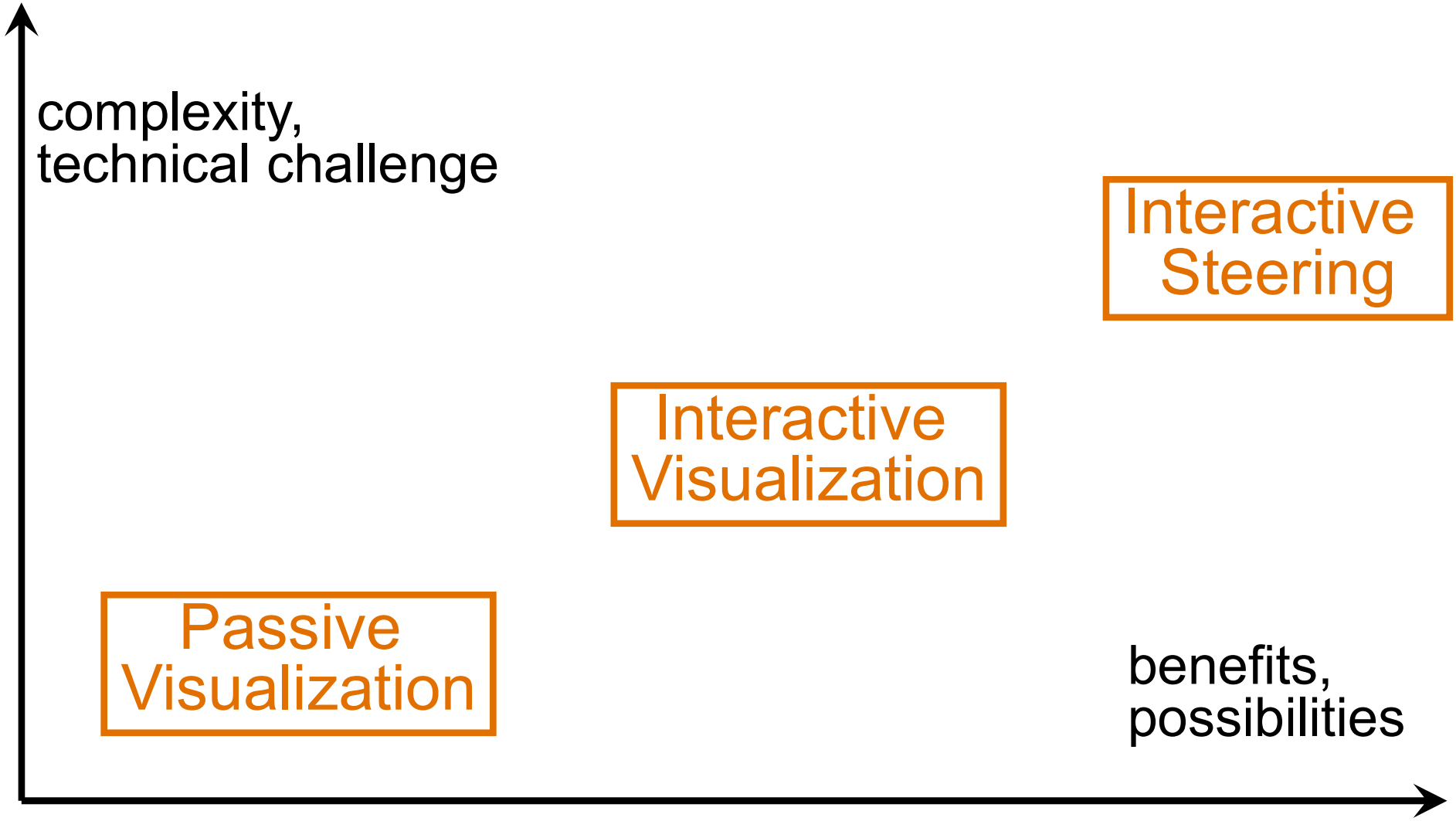
Interactive Steering

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

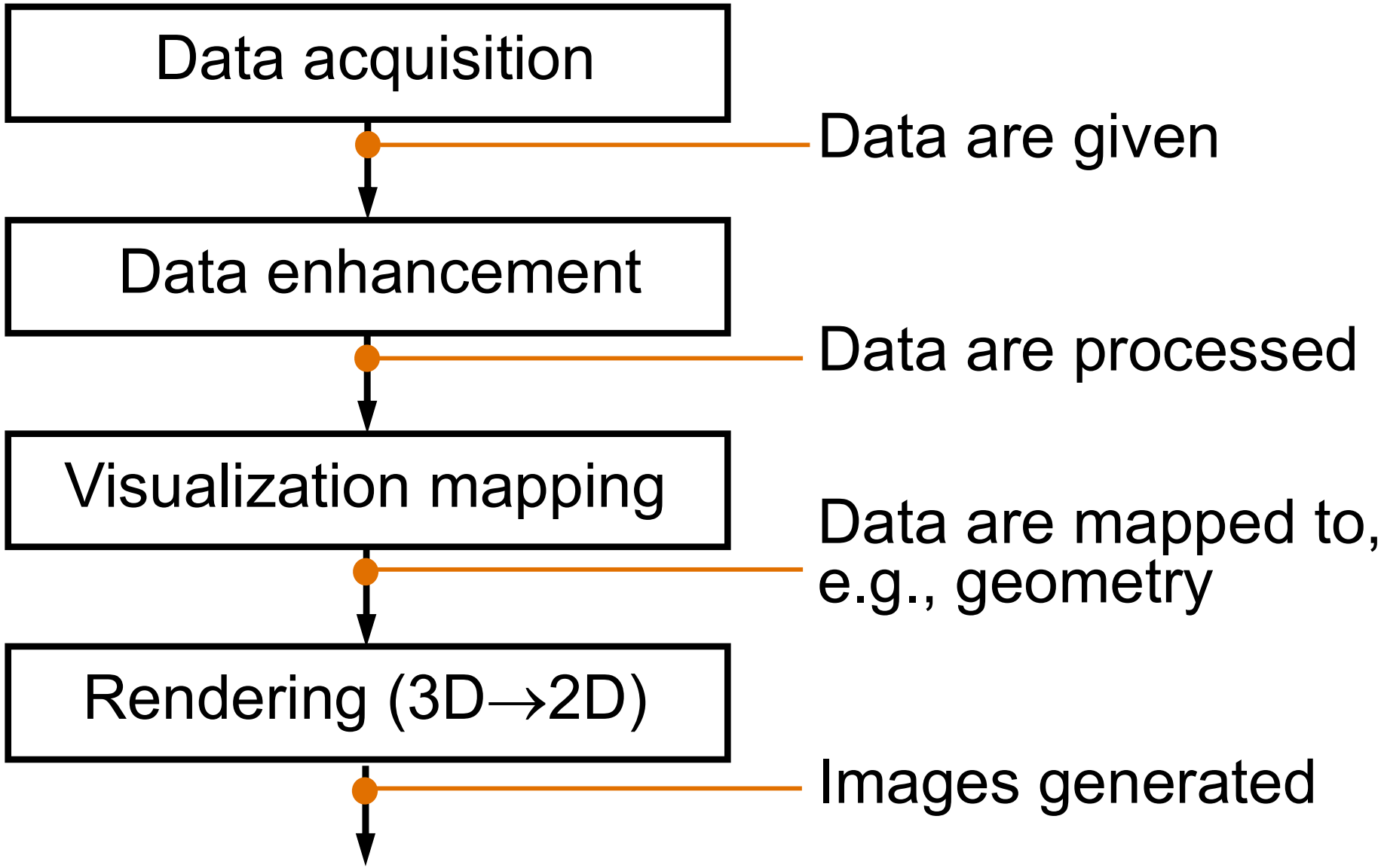


Visualization Scenarios



The Visualization Pipeline

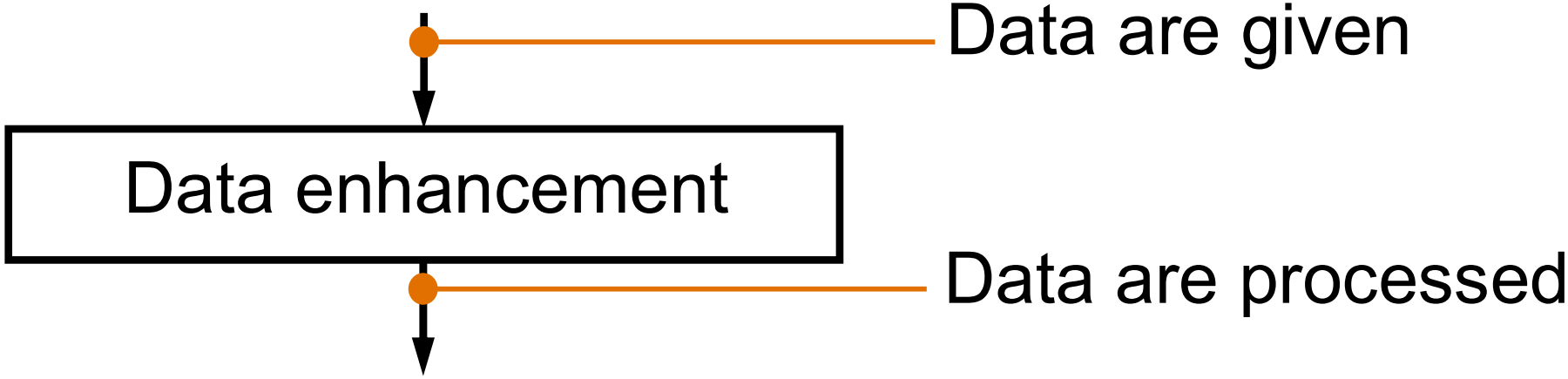
The Visualization Pipeline – Overview



The Visualization Pipeline – Stage 1

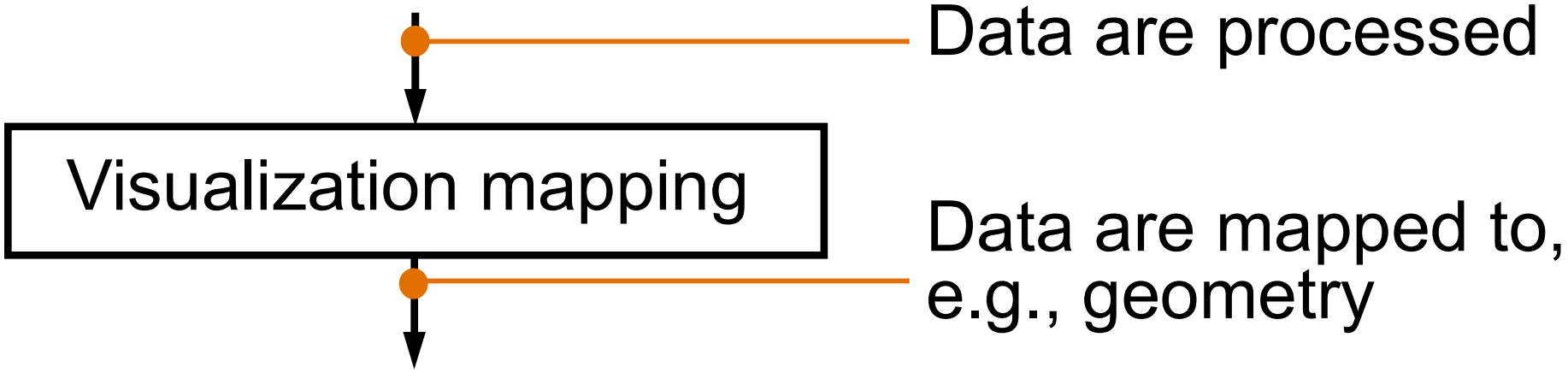
- Measurements, e.g., CT/MRI
- Simulation, e.g., flow simulation
- Modeling, e.g., game theory

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, …

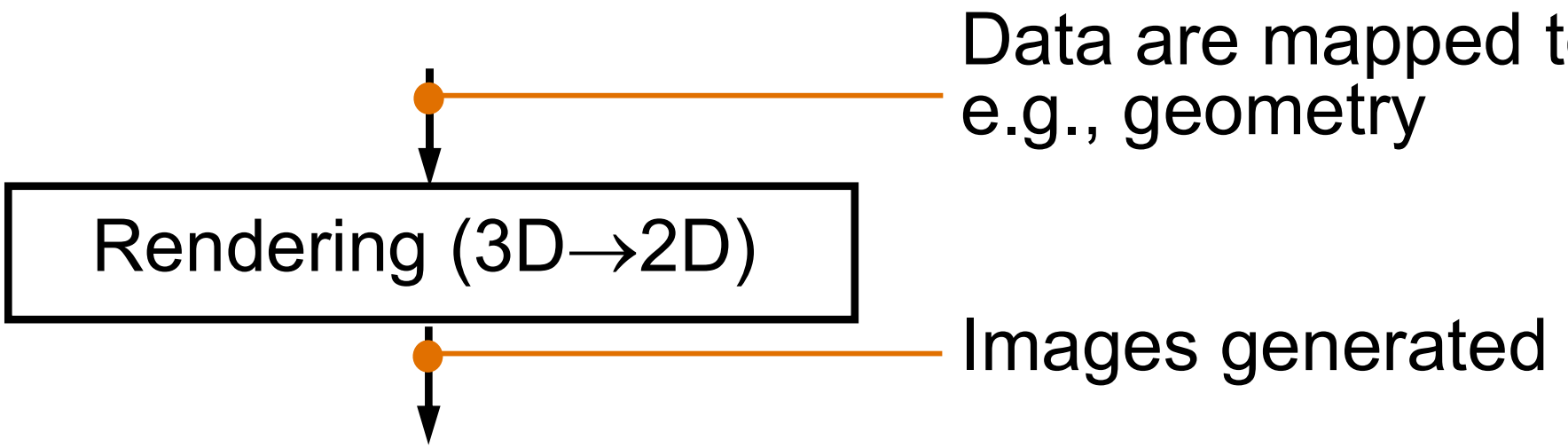
The Visualization Pipeline – Stage 3



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)

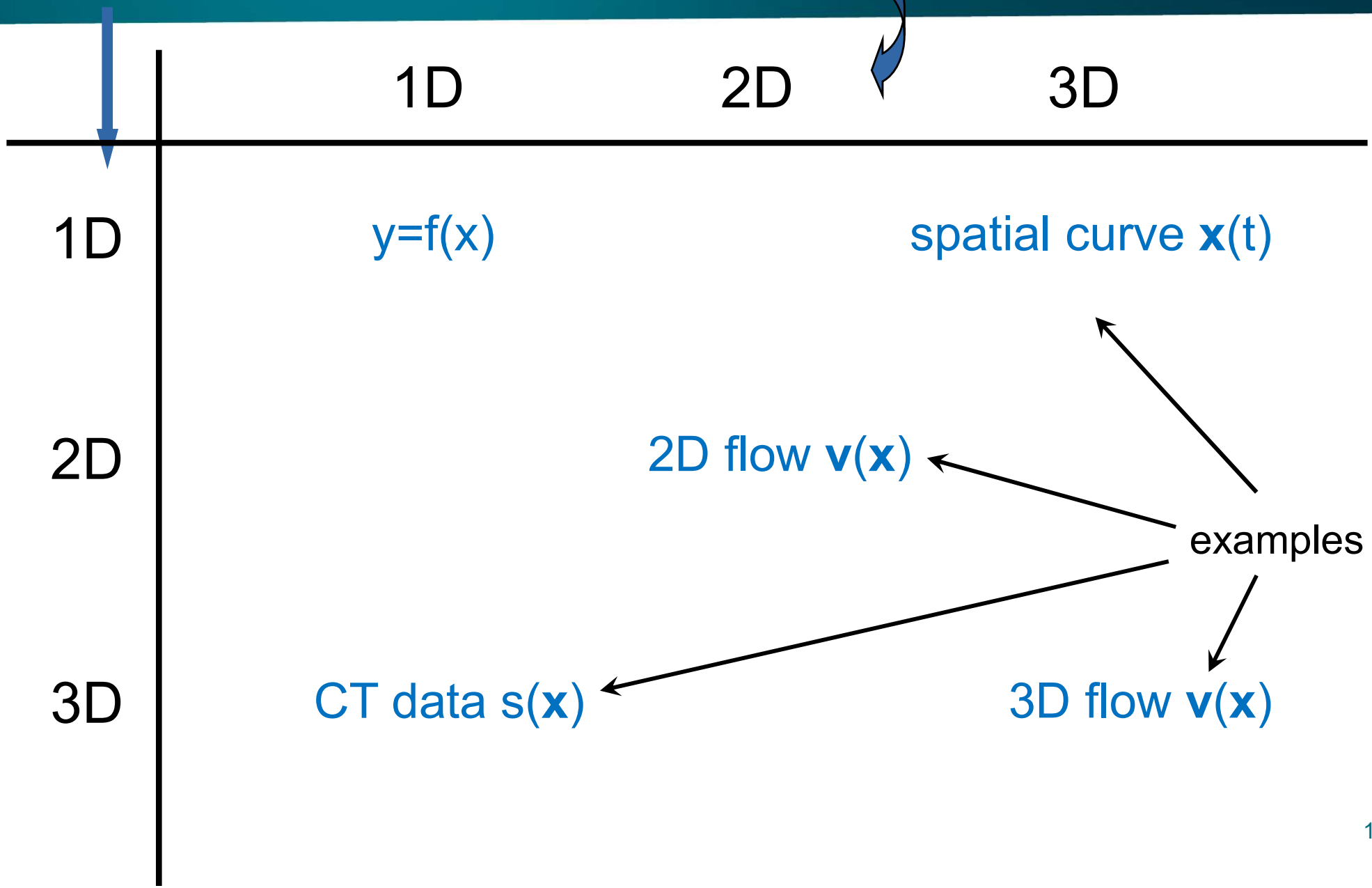
- Inherent spatial domain (**SciVis**):
  - 2D/3D data space given
  - examples: medical data, flow simulation data, GIS data, etc.
- No inherent spatial reference (**InfoVis**):
  - abstract data,
    spatial embedding through visualization
  - example: data bases, deep neural nets
- **Aspects**: dimensionality,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



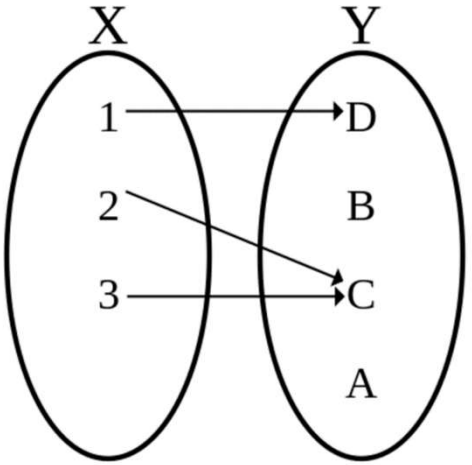
Data == Functions

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):

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

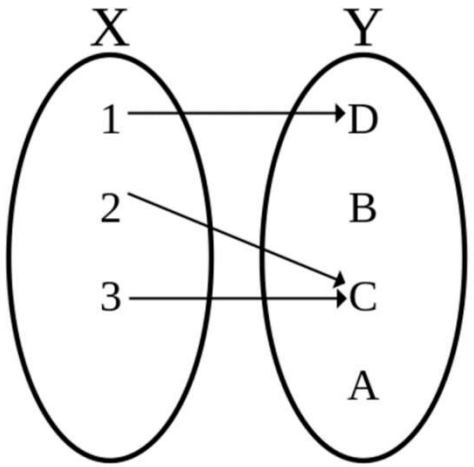
Mathematical Functions

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)

$$f: \mathbb{R}^n \to \mathbb{R}^m$$

$$x \mapsto f(x)$$



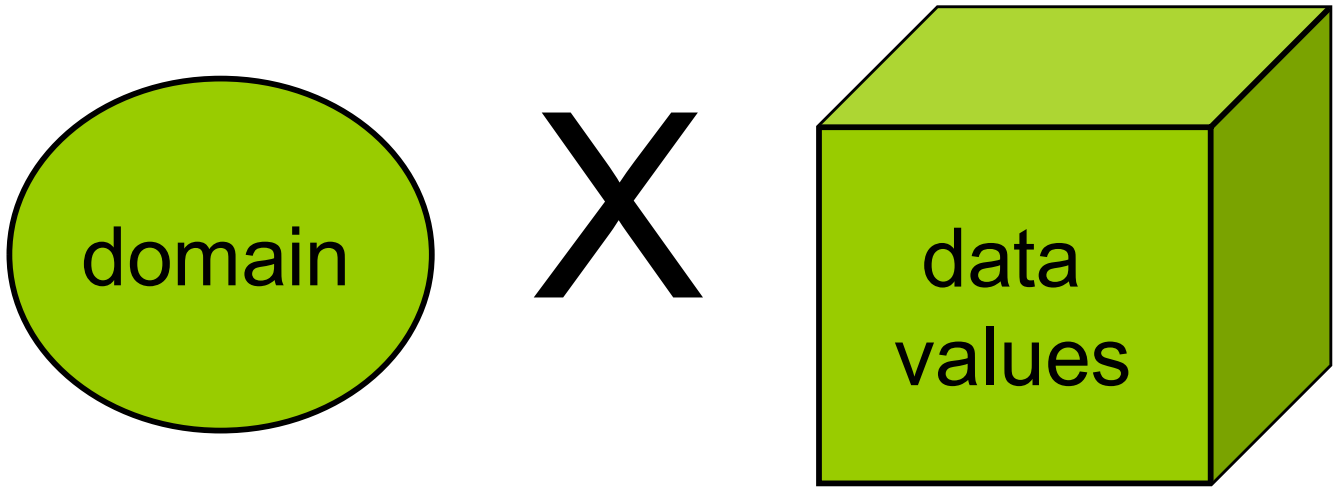
Also important: *range/image*; *preimage*; continuity, differentiability, dimensionality, ...

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

R^n R^m



independent variables

dependent variables

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

Example: Scalar Fields

2D scalar field

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

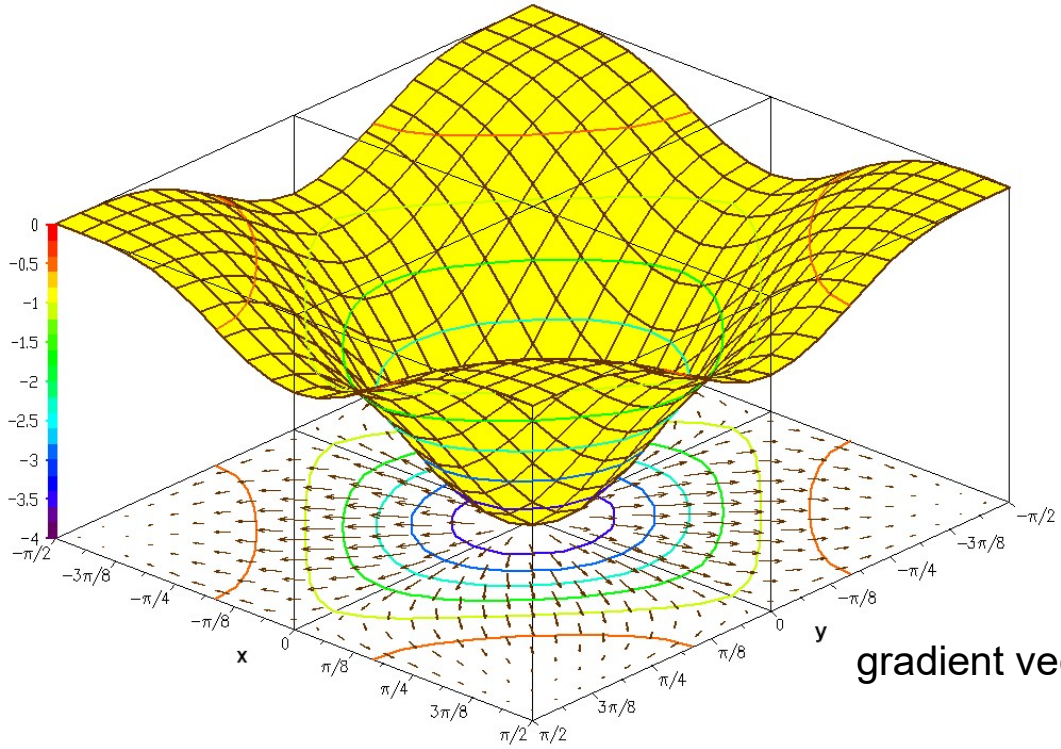
pre-image

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

iso-contour

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

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

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

Visualization Examples

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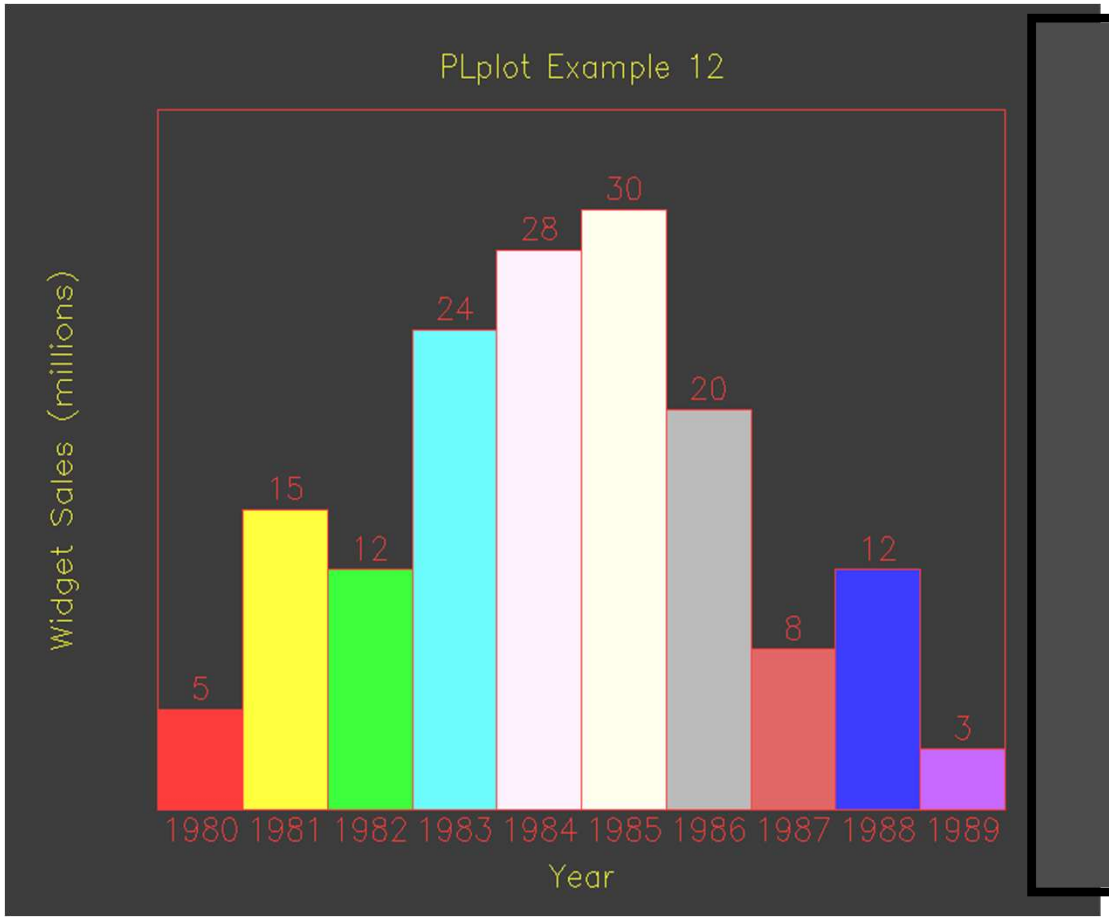
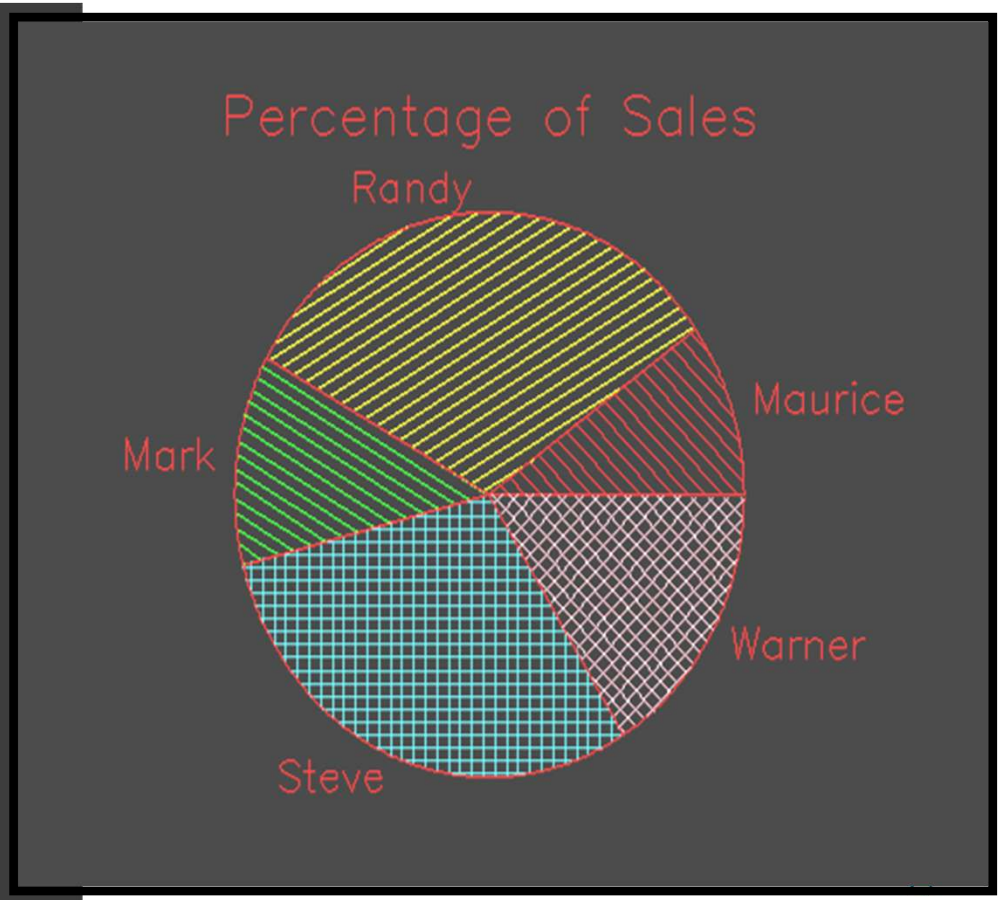
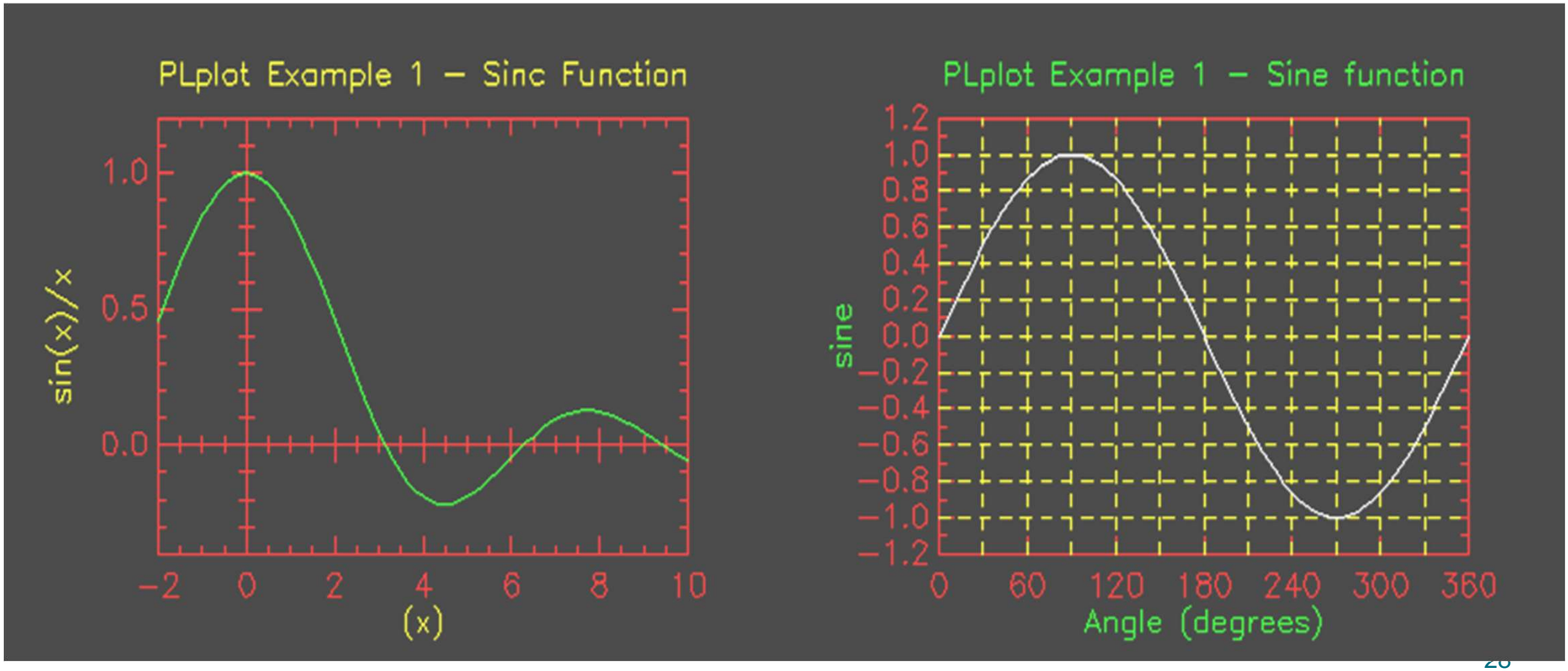
$N^1 \rightarrow R^1$	value series	bar chart, pie chart, etc.





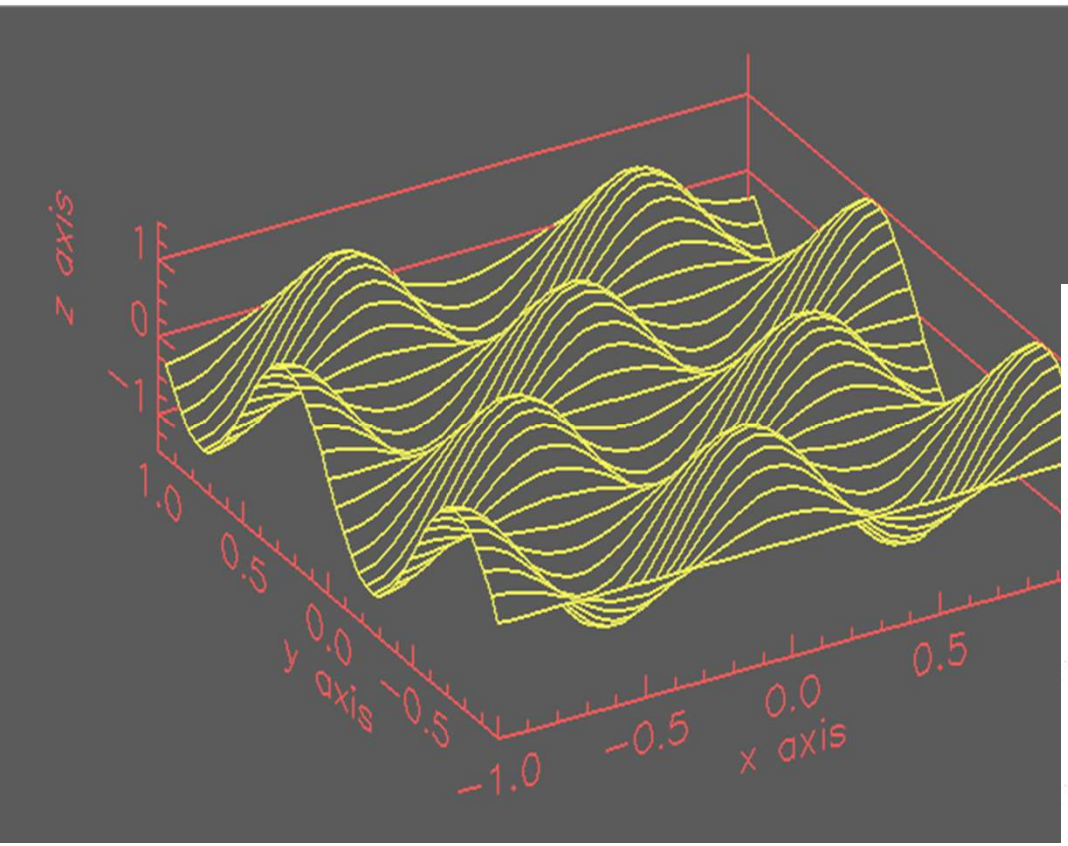
Visualization Examples

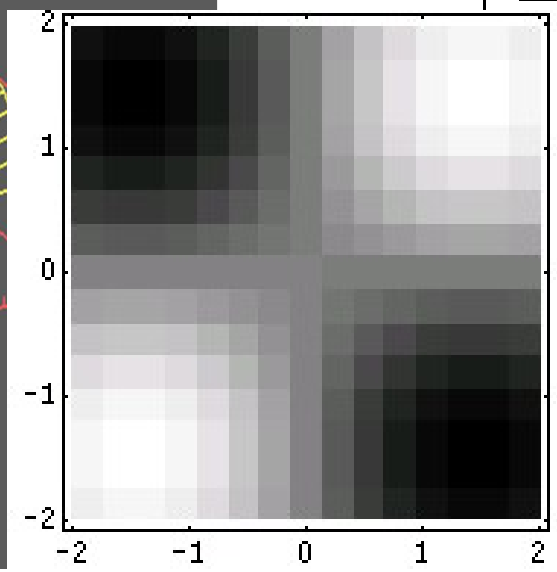
data	description	visualization example
$R^1 \rightarrow R^1$	function over R	(line) graph

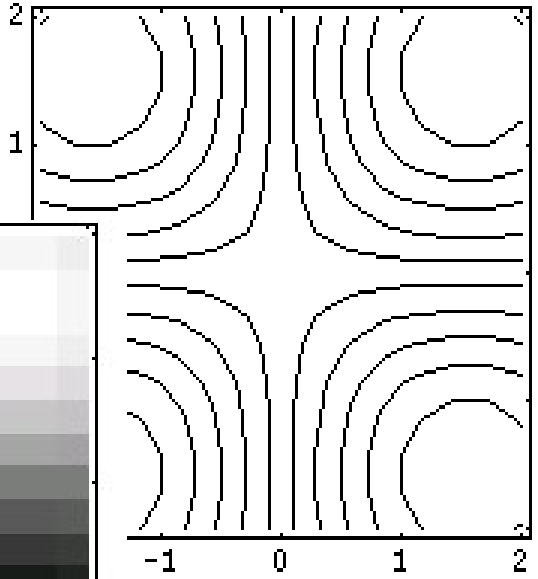


Visualization Examples

data	description	visualization example
$R^2 \rightarrow R^1$	function over R^2	2D-height map in 3D, contour lines in 2D, false colors (heat map)







Visualization Examples

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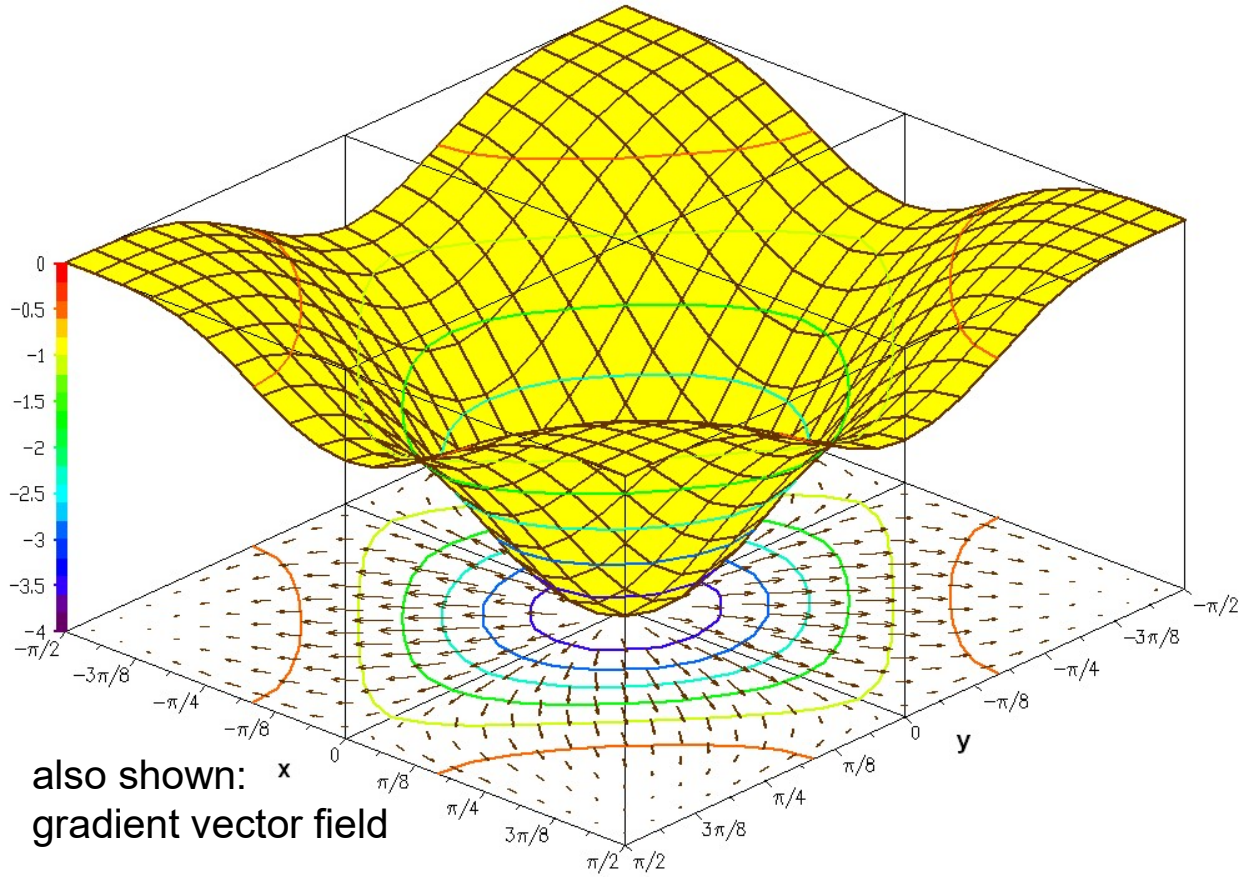
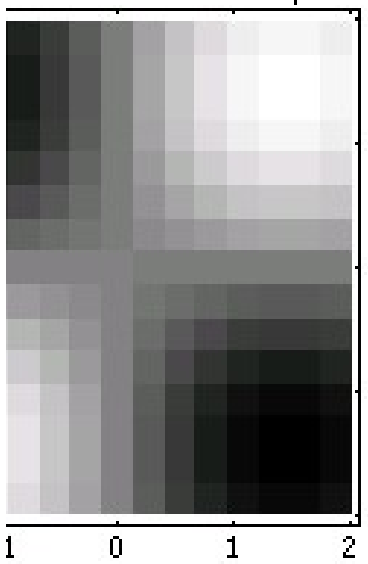
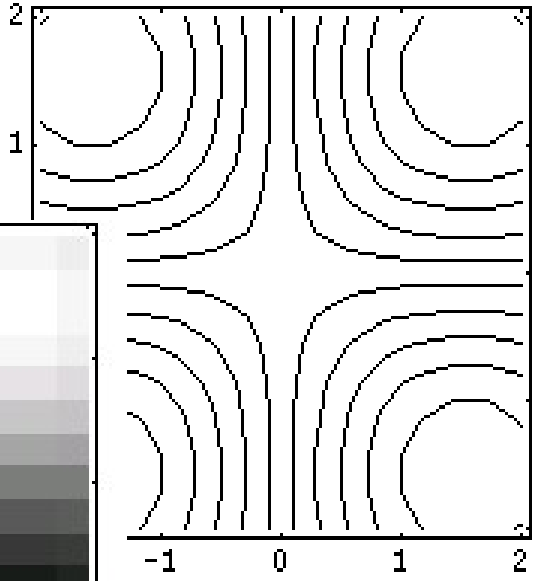


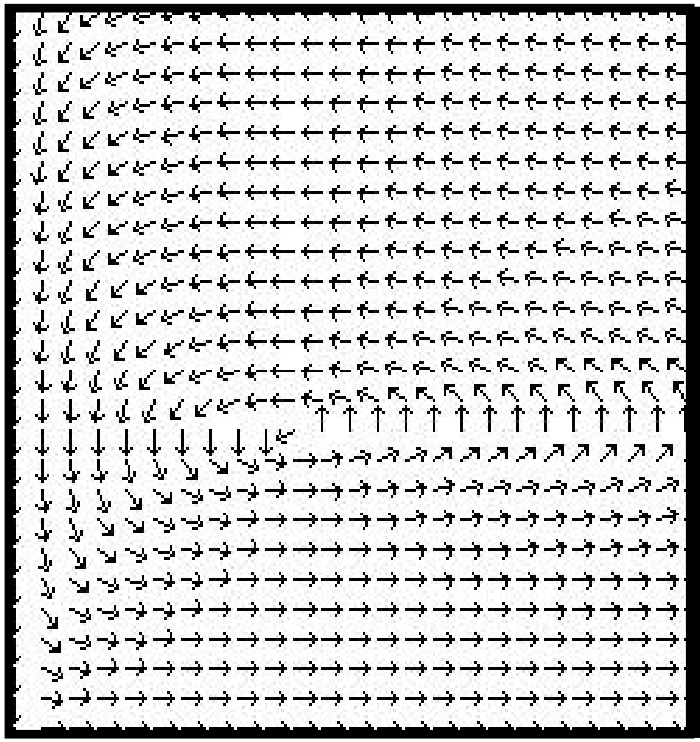
also shown:
gradient vector field

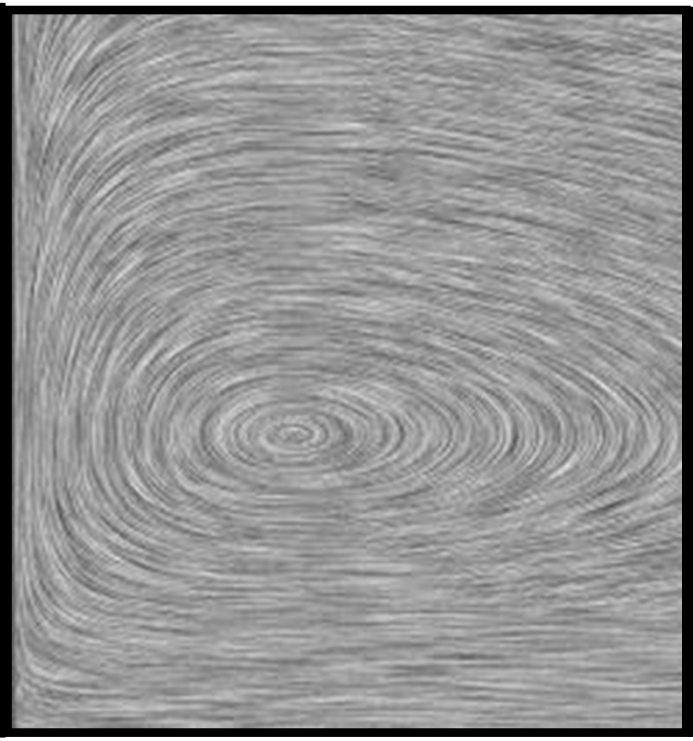


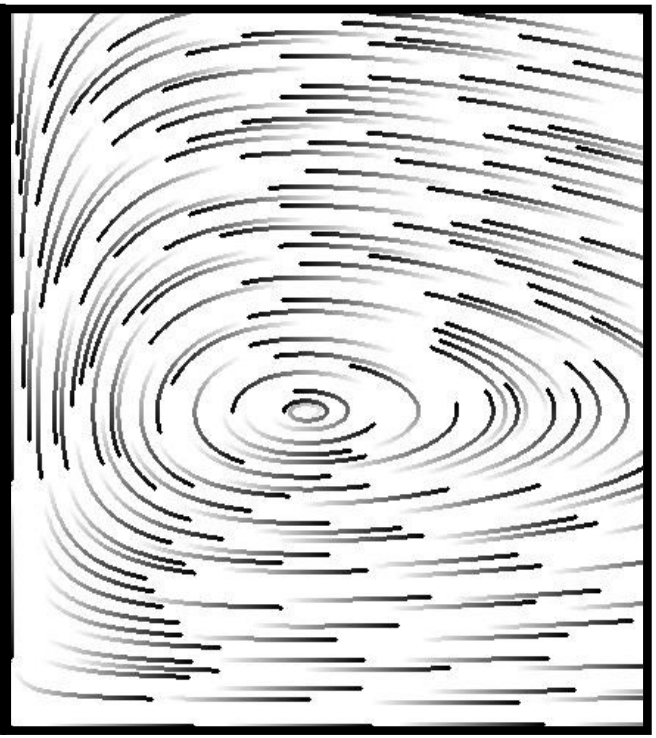


Visualization Examples

data	description	visualization example
$R^2 \rightarrow R^2$	2D-vector field	hedgehog plot, LIC, streamlets, etc

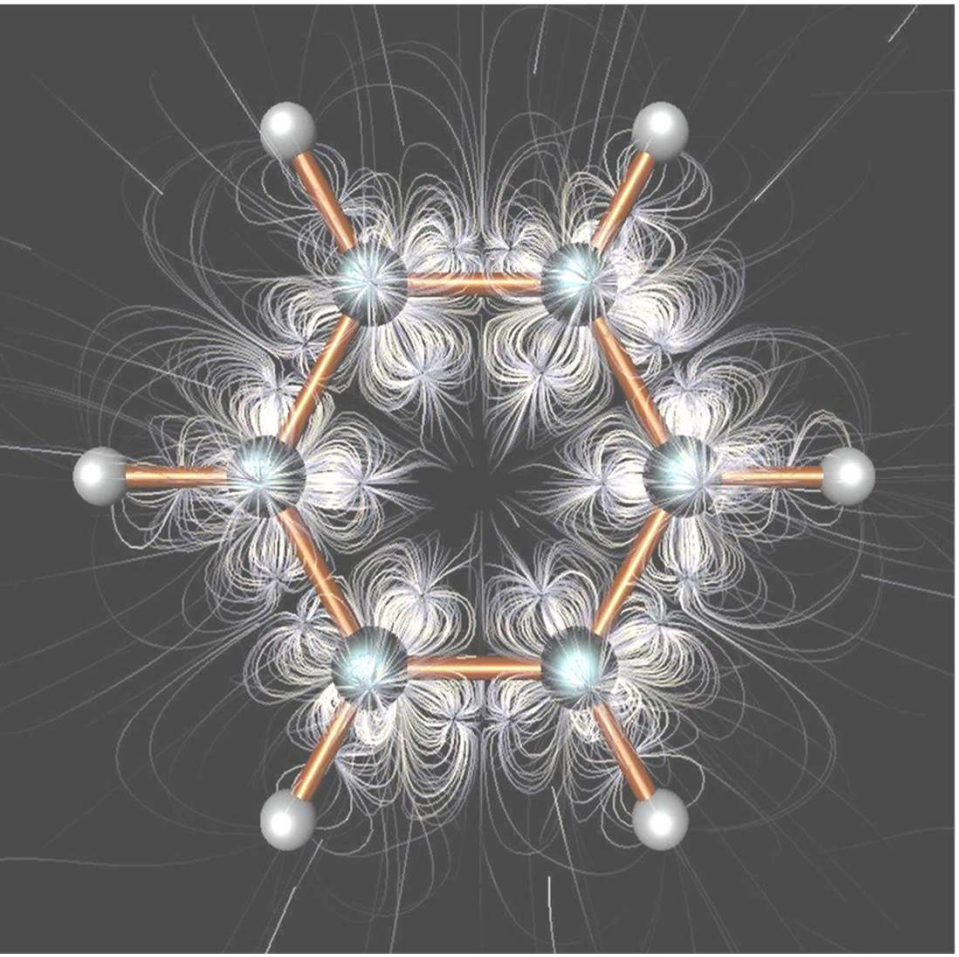


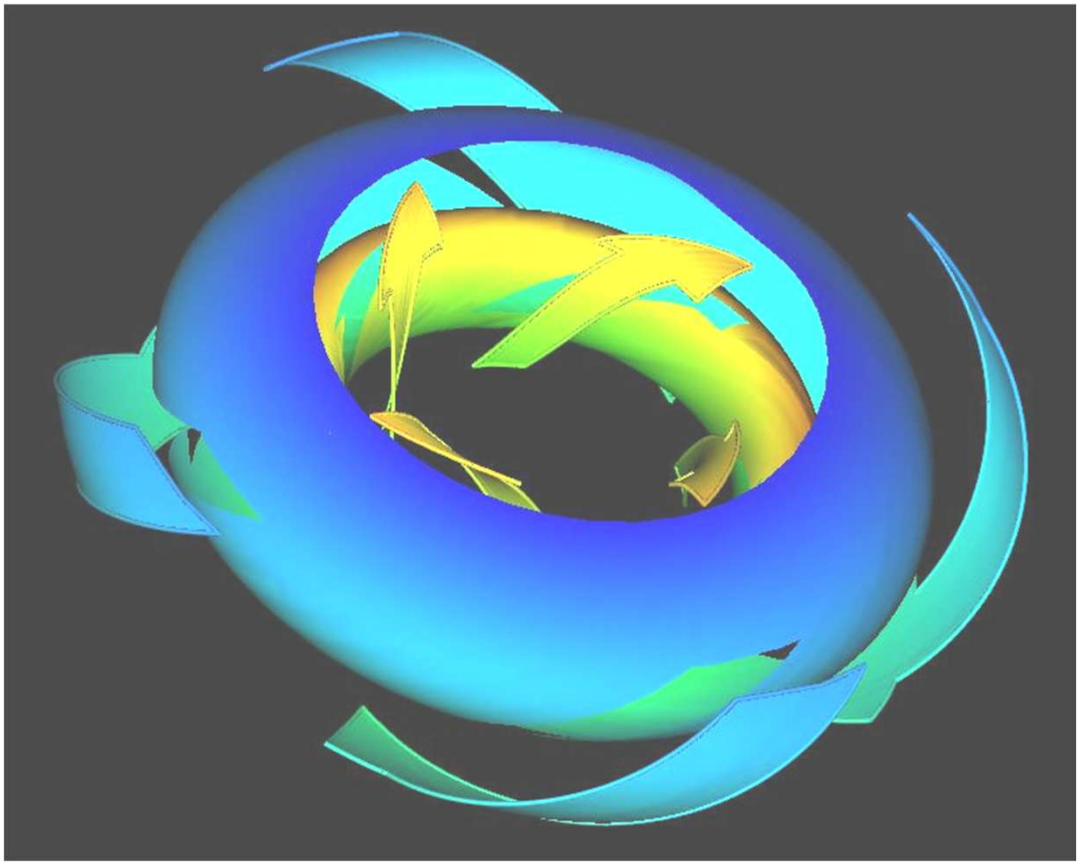




Visualization Examples

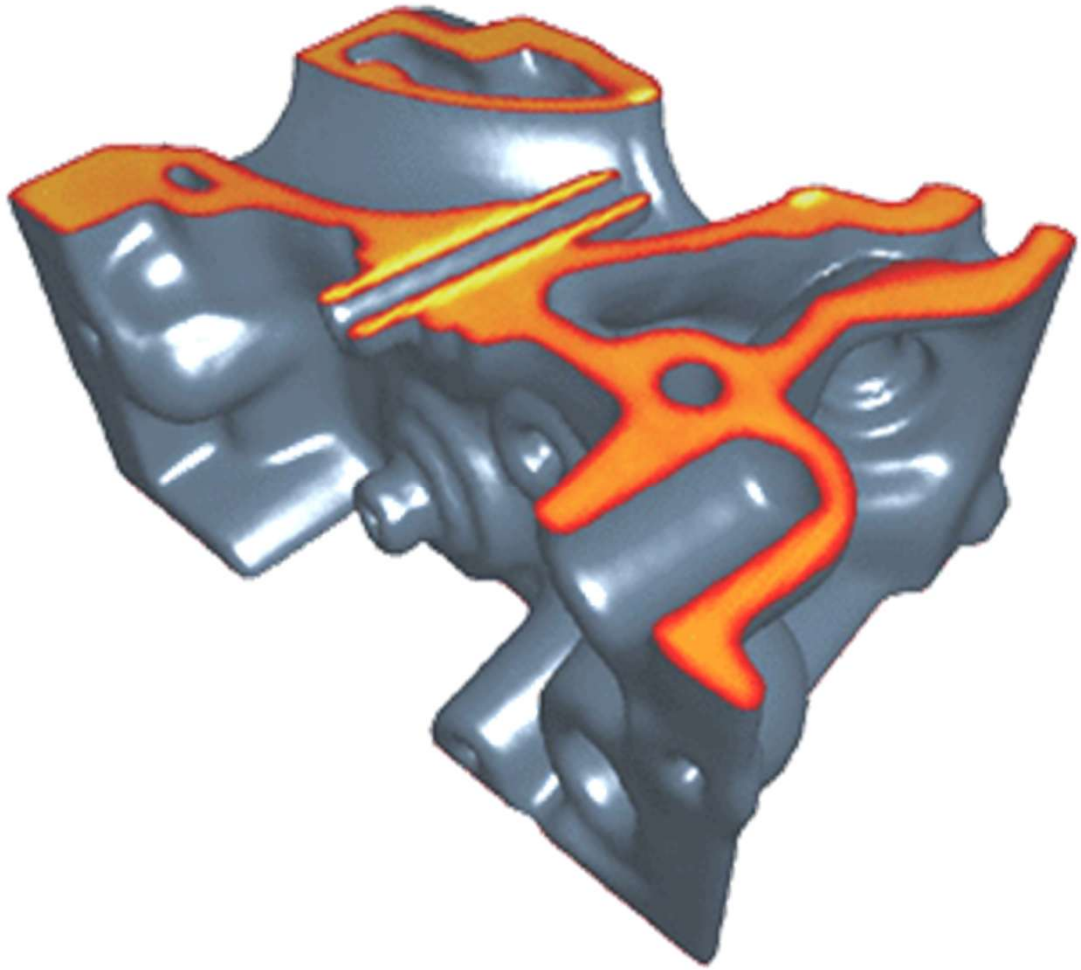
data	description	visualization example
$R^3 \rightarrow R^3$	3D-flow	streamlines, streamsurfaces

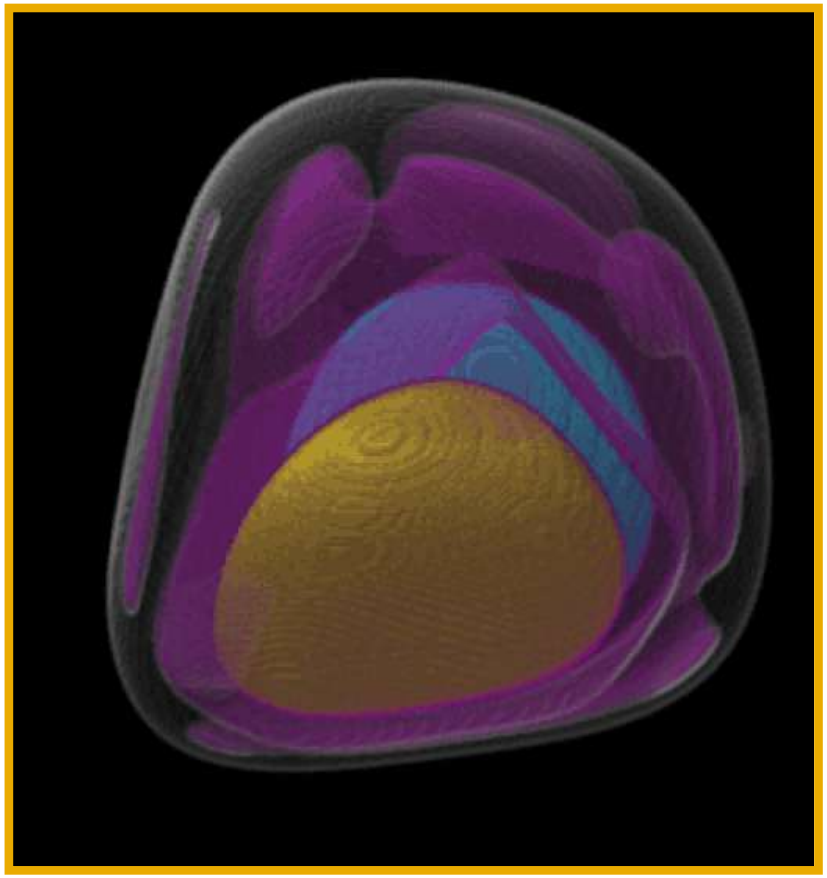




Visualization Examples

data	description	visualization example
$R^3 \rightarrow R^1$	3D-densities	iso-surfaces in 3D, volume rendering





Thank you.

Thanks for material

- Helwig Hauser
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- Philipp Muigg
- Christof Rezk-Salama