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

Markus Hadwiger, KAUST

King Abdullah University of Science and Technology
KAUST

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 !

OpenGL Tutorial

This week?

Optional, but highly recommended if you haven't used OpenGL before!

We can do another tutorial later, specifically focusing on shaders.

Programming Assignments Schedule (tentative)

Assignment 0:	Lab sign-up: setup piazza + bitbucket account, fork repo	until	**Jan 31**
	Basic OpenGL example		
Assignment 1:	Volume slice viewer	until	**Feb 14**
Assignment 2:	Iso-contours (marching squares)	until	**Feb 28**
Assignment 3:	Iso-surface rendering (marching cubes)	until	**Mar 16**
Assignment 4:	Volume ray-casting, part 1	until	**Apr 1**
	Volume ray-casting, part 2	until	**Apr 8**
Assignment 5:	Flow vis, part 1 (hedgehog plots, streamlines, pathlines)	until	**Apr 22**
Assignment 6:	Flow vis, part 2 (LIC with color coding)	until	**May 6**

Programming Assignment #1: Slice Viewer

Basic tasks

- Download data into 3D volume texture
- Display three different axis-aligned slices using OpenGL texture mapping using the 3D volume texture

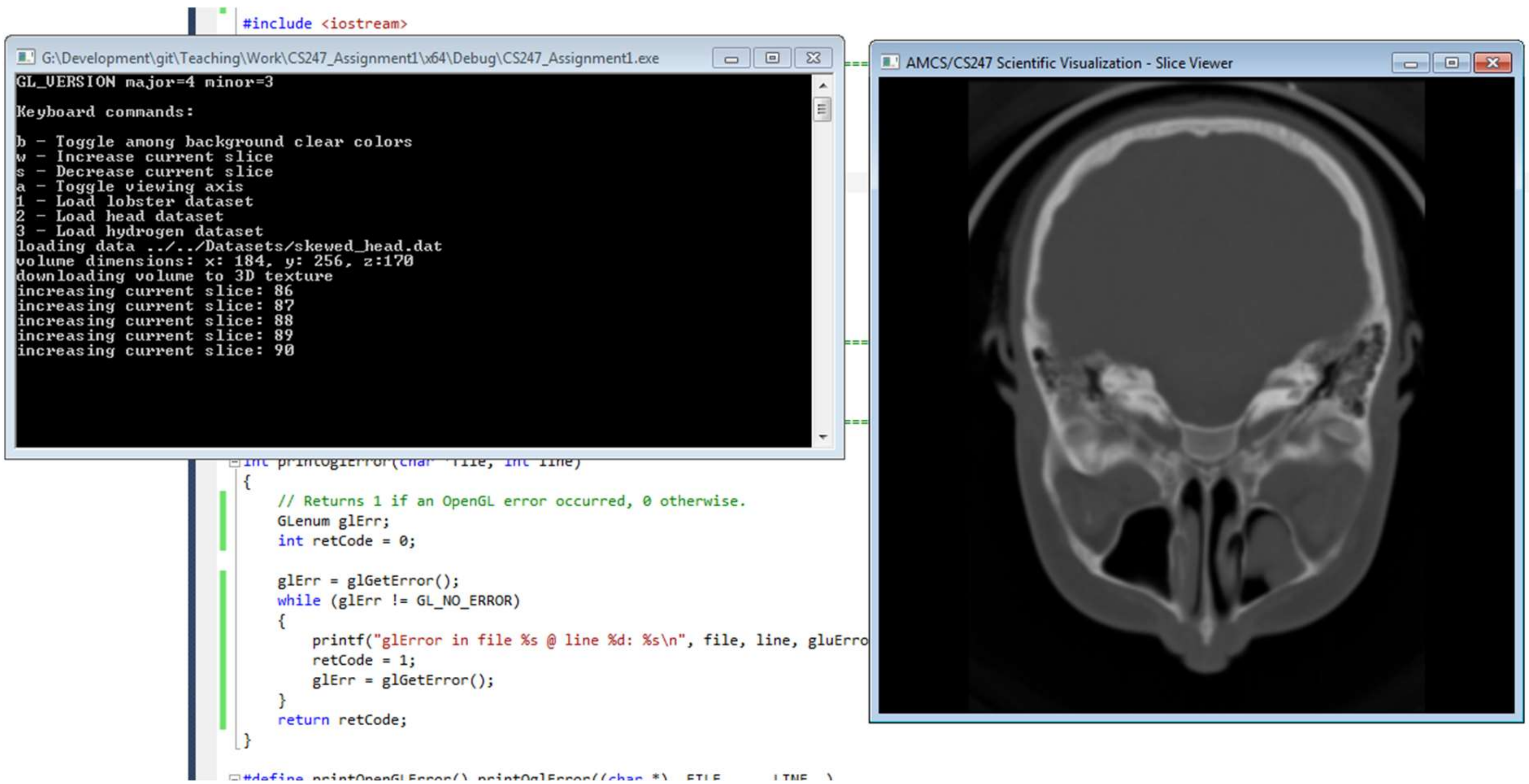
Minimum

- The slice position should be adjustable for each slice view.
- Make sure the aspect ratio of the shown slices is correct.
- If the window is resized, the slice is resized with the correct aspect ratio (no distortions)

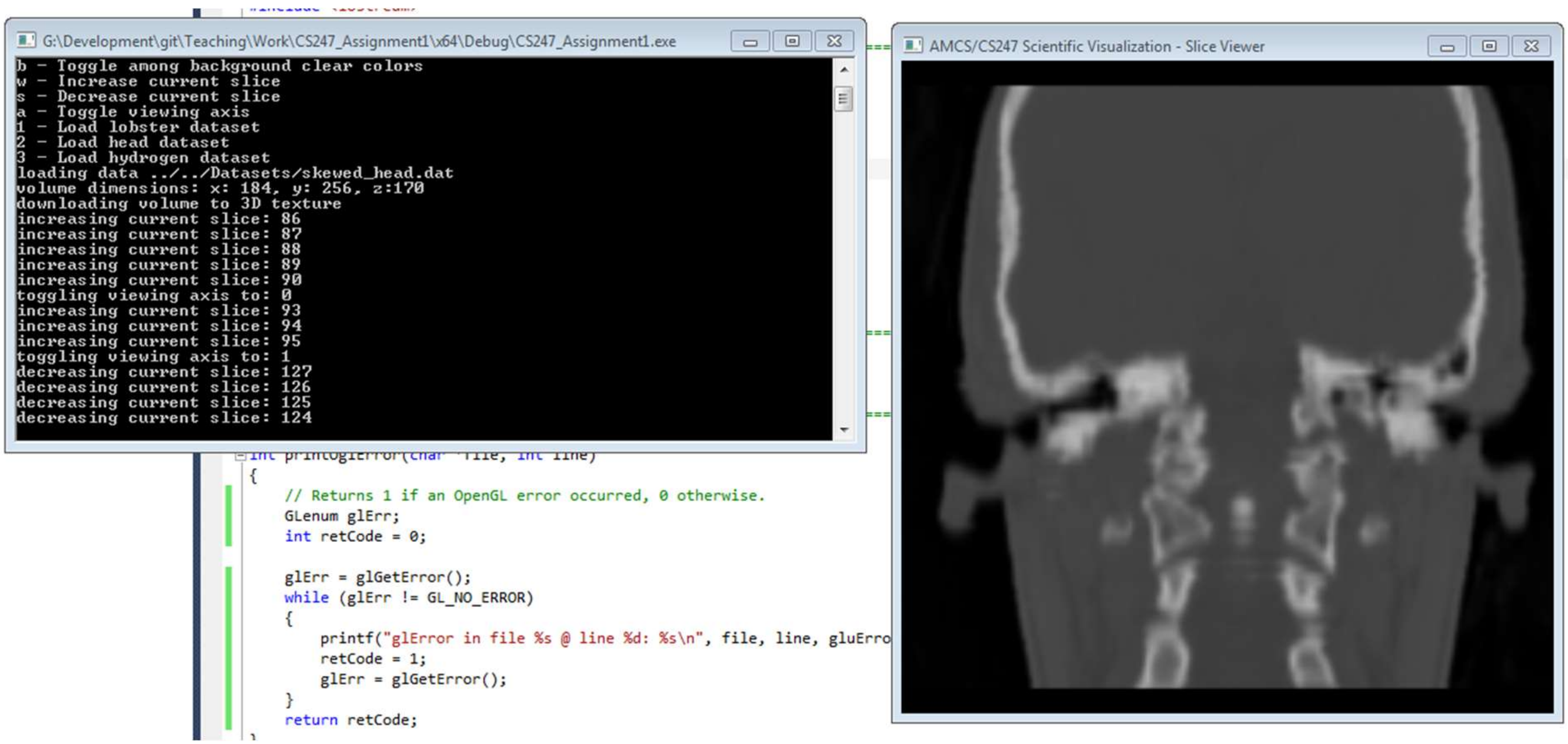
Bonus

- Show all three axis aligned slices at once
- Show arbitrarily aligned slices with an interface to change the arbitrary slice

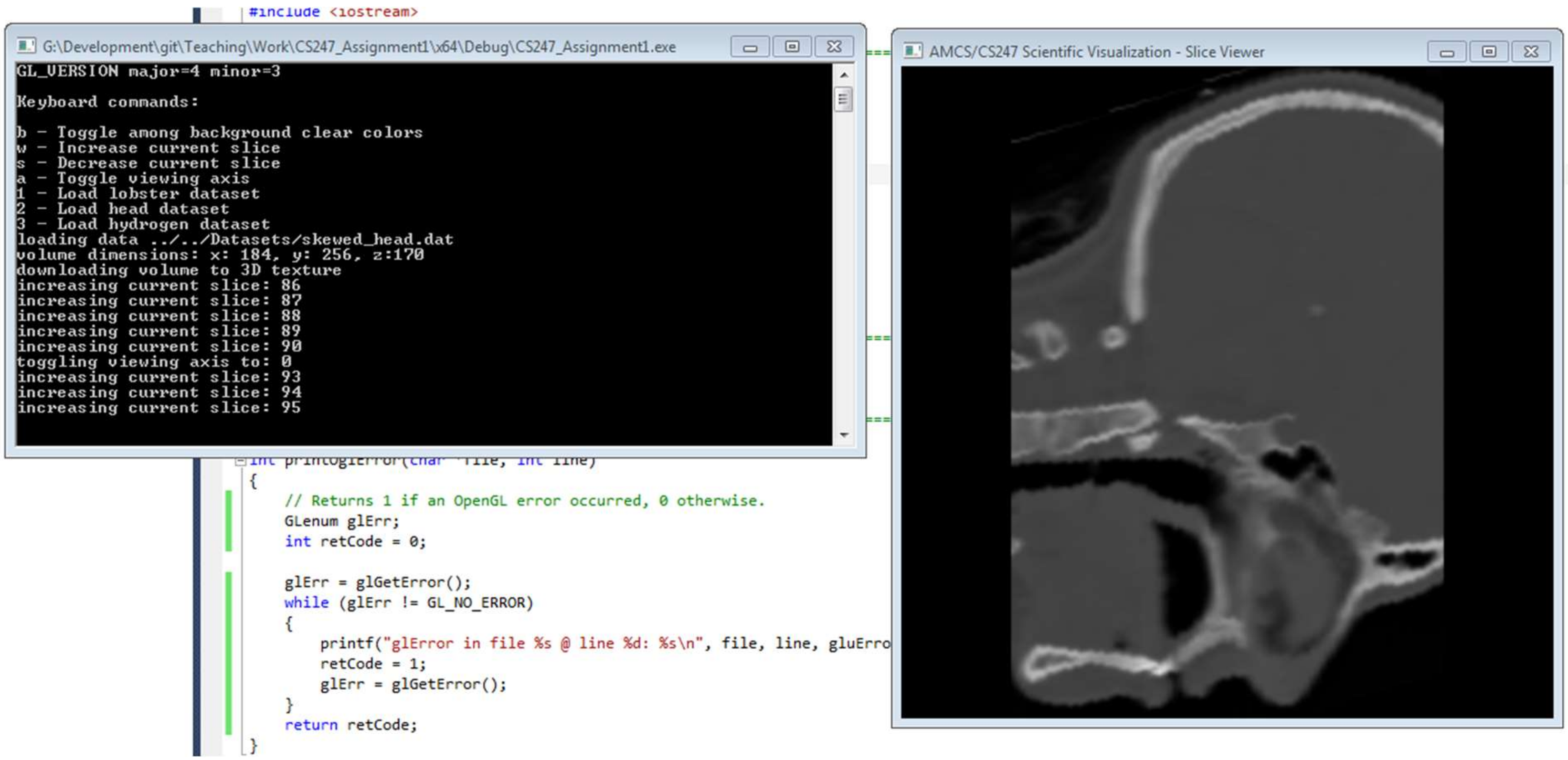
Programming Assignment #1 Example



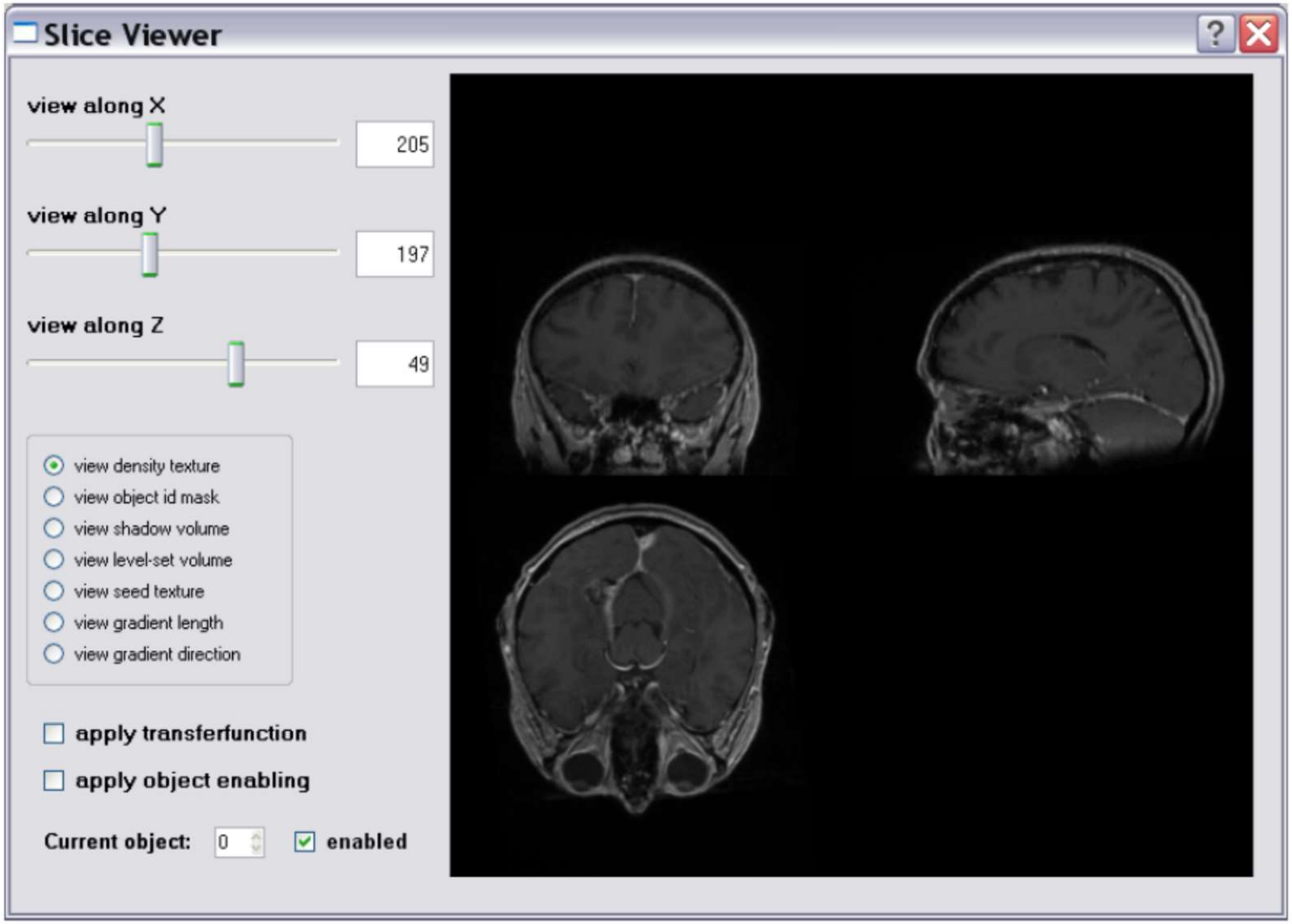
Programming Assignment #1 Example



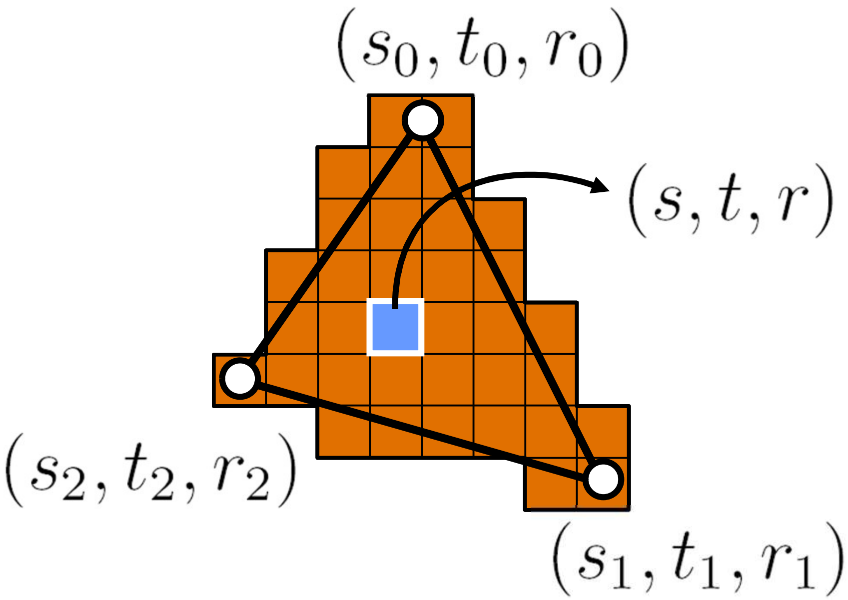
Programming Assignment #1 Example

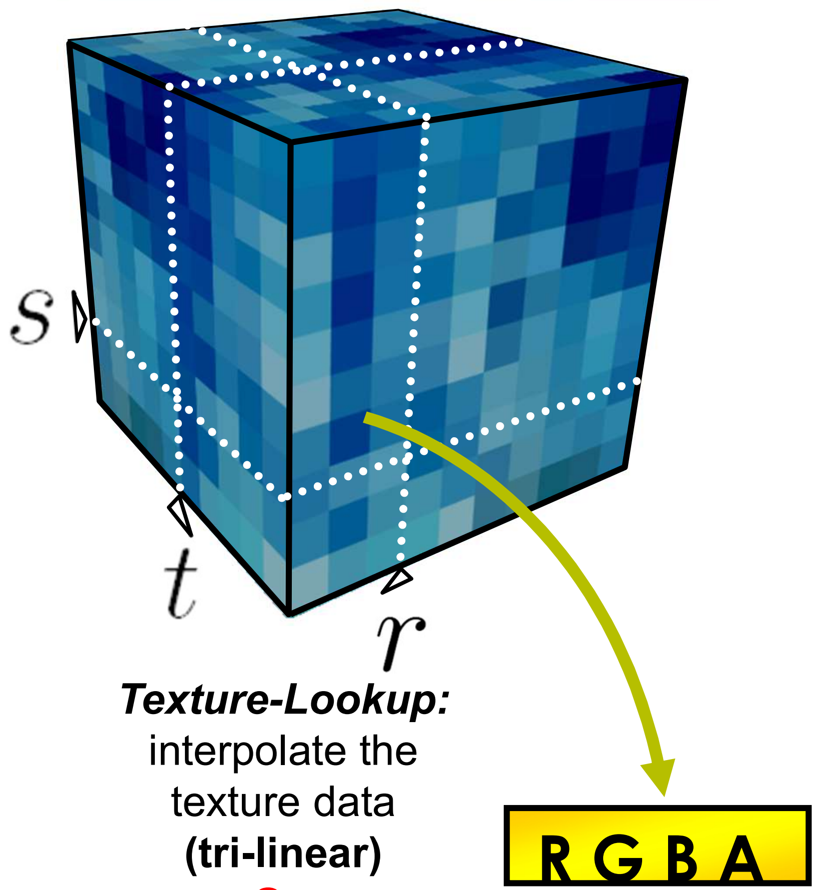


Programming Assignment #1 Example



3D Texture Mapping





For each fragment:
interpolate the
texture coordinates
(barycentric)
Or:
Use arbitrary, computed coordinates

Texture-Lookup:
interpolate the
texture data
(tri-linear)
Or:
Nearest-neighbor for “array lookup”

Data Representation

Data – General Information

Data:

- Focus of visualization,
  everything is centered around the data
- Driving factor (besides user) in choice and attribution of the visualization technique
- Important questions:
  - Where do the data “live” (**data space**)
  - **Type** of the data
  - Which **representation** makes sense
    (secondary aspect)

Data Space

Where do the data "live"?

- 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
- **Aspects**: dimensionality, domain, coordinates,
  region of influence (local, global)

Data Type

What type of data?

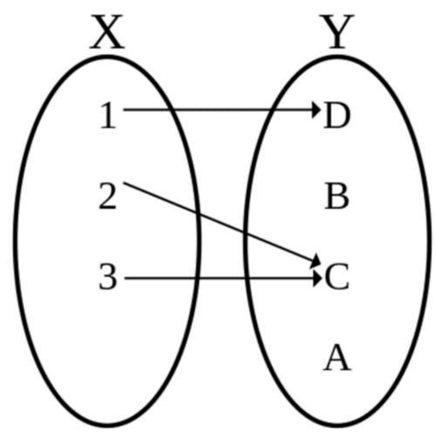
- **Data types**:
  - Scalar = numerical value
    (natural, integer, rational, real, complex numbers)
  - Non-numerical (categorical) values (e.g., blood type)
  - Multi-dimensional values, i.e., codomain (n-dim. vectors, second-order ($n \times n$) tensors, higher-order tensors, ...)
  - Multi-modal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

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, ...

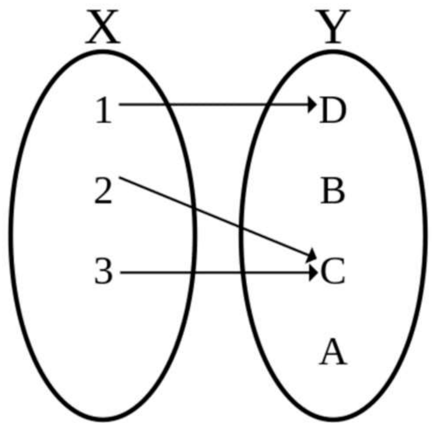
Graph of a function (mathematical definition):

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

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)



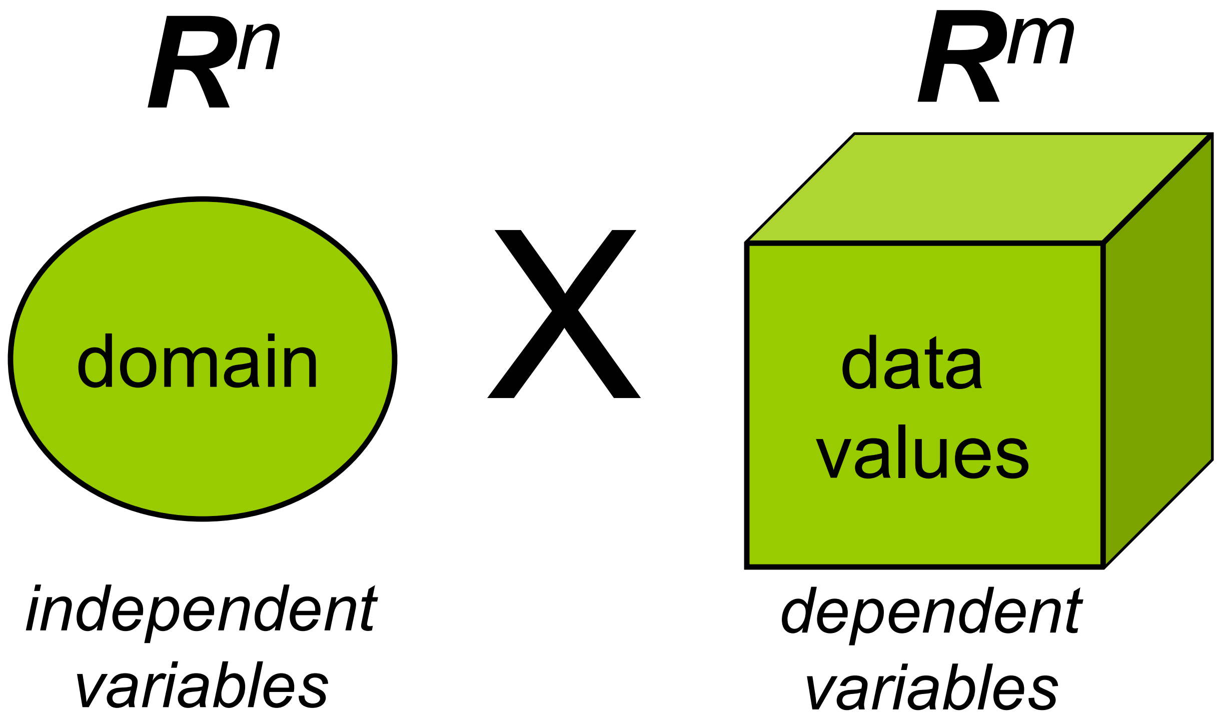
$$f : \mathbb{R}^n \to \mathbb{R}^m$$
$$x \mapsto f(x)$$

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



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

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

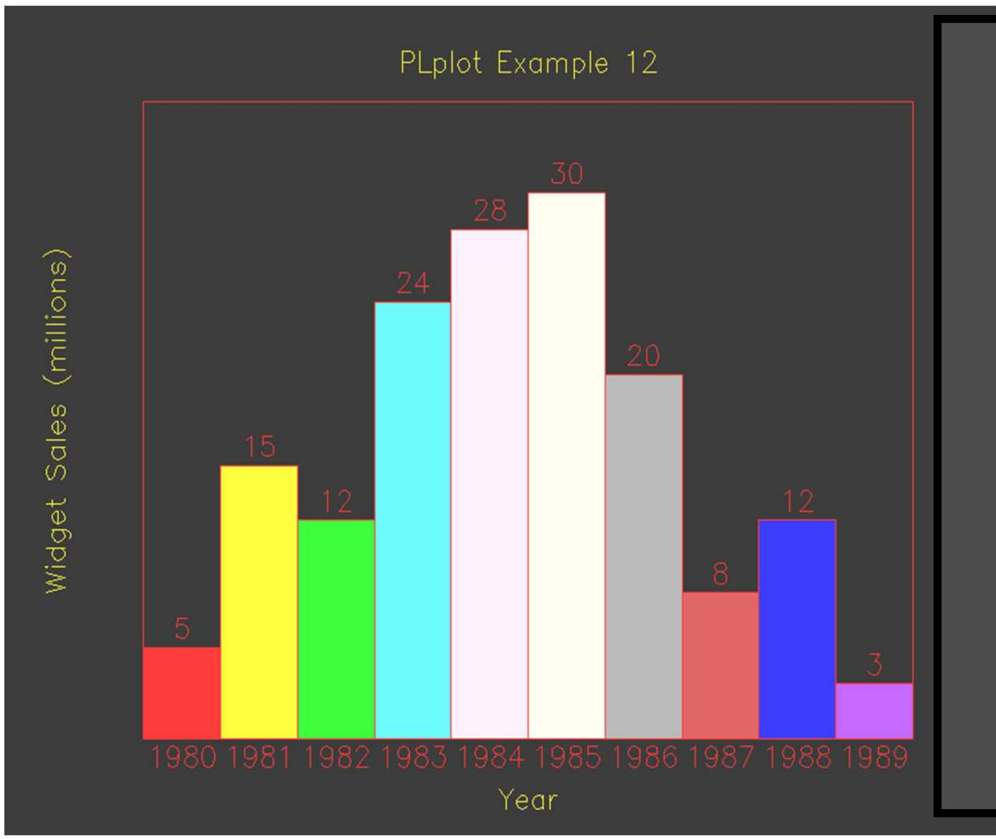
Data Space (Domain) vs. Data Type (Codomain)

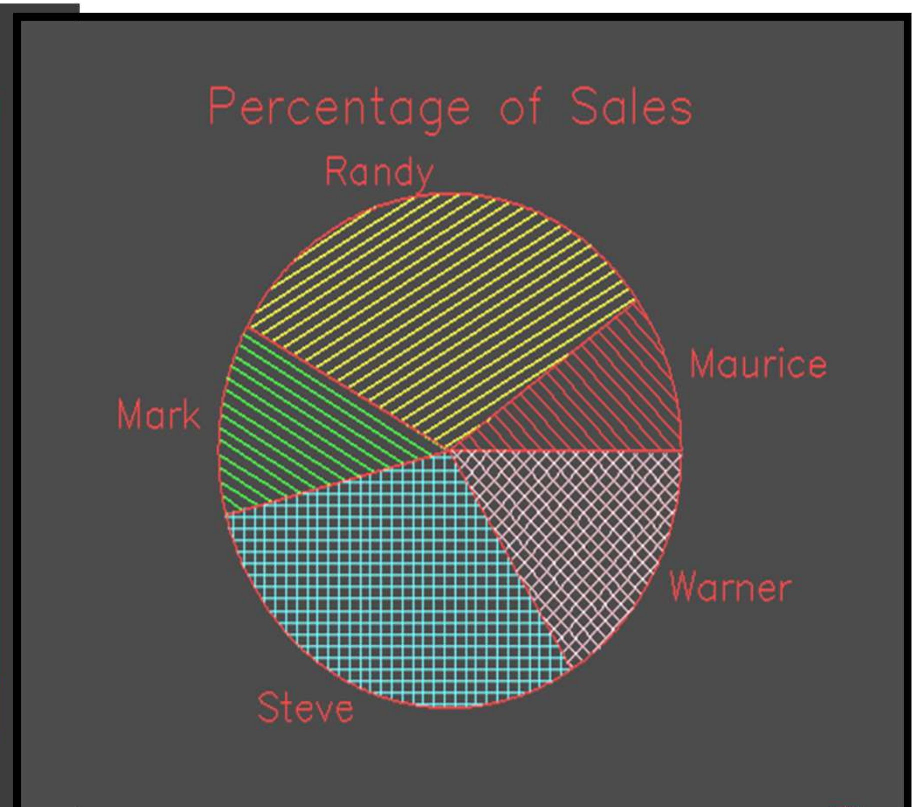
	1D	2D	3D
1D	$y=f(x)$		spatial curve $\mathbf{x}(t)$
2D		2D flow $\mathbf{v}(\mathbf{x})$	
3D	CT data $d(\mathbf{x})$		

Examples

Visualization Examples

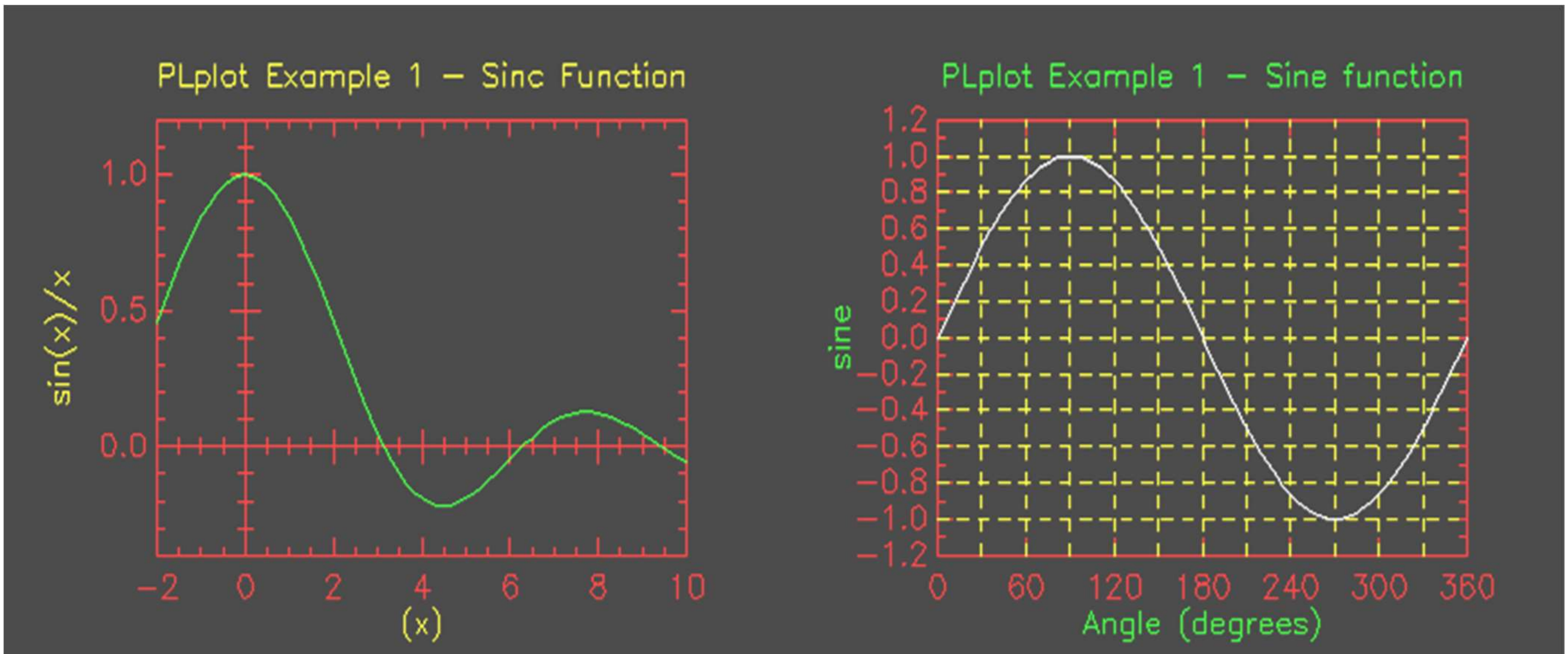
data	description	visualization example
$N^1 \rightarrow R^1$	value series	bar chart, pie chart, etc.





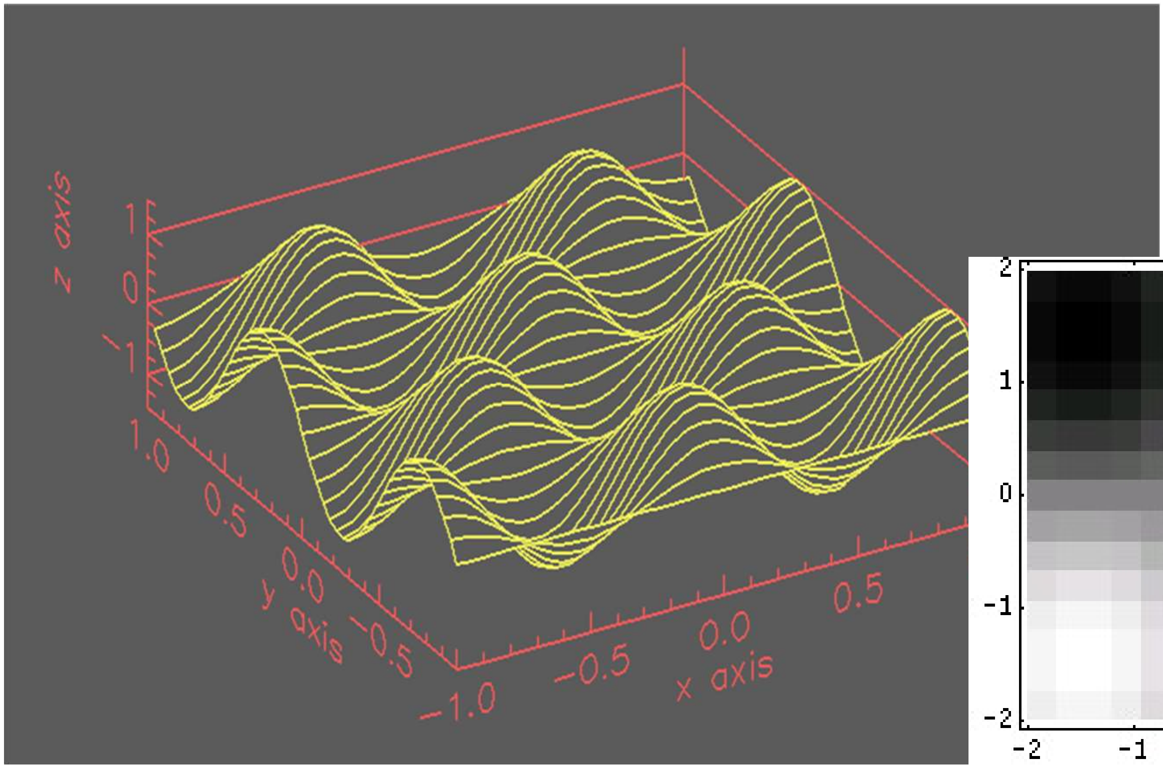
Visualization Examples

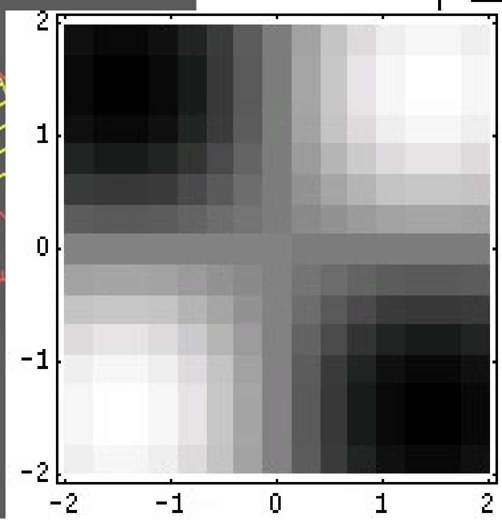
data	description	visualization example
$R^1 \rightarrow R^1$	function over R	(line) graph

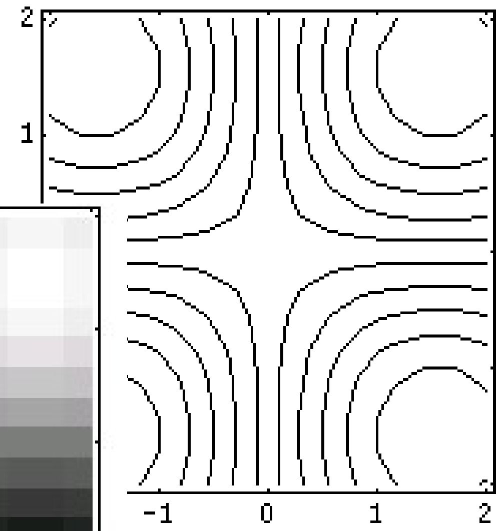


Visualization Examples

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)

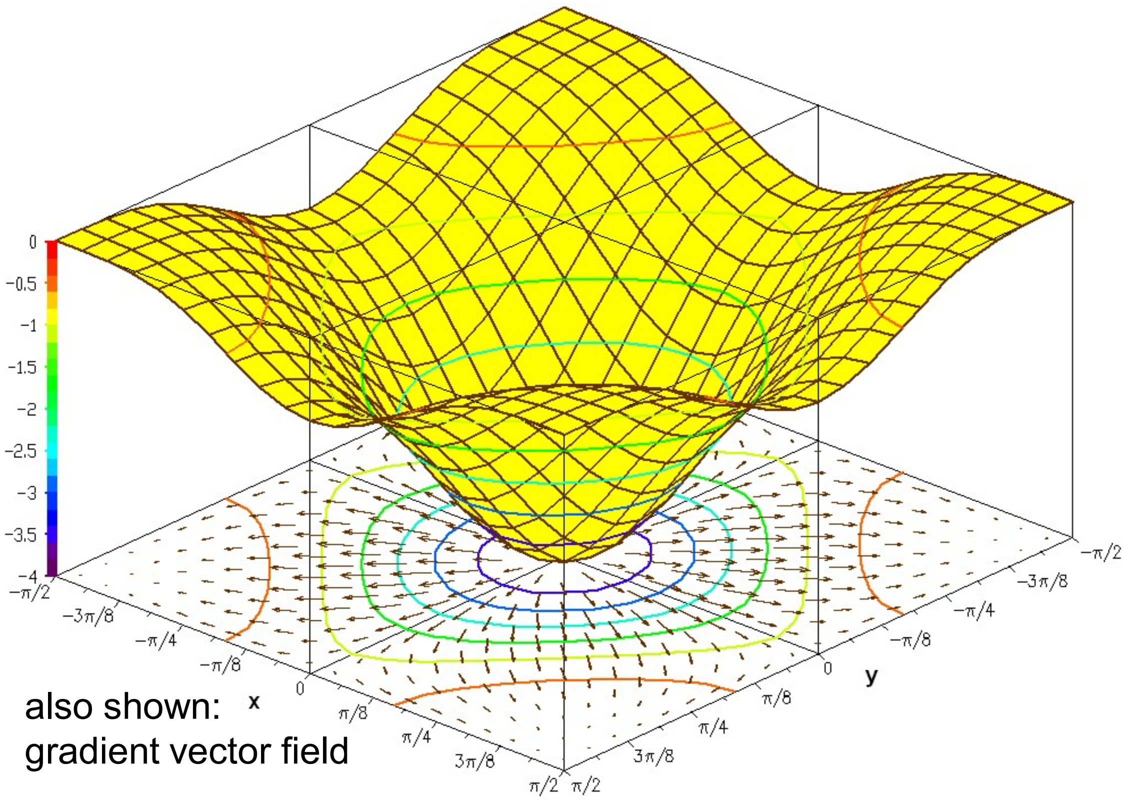




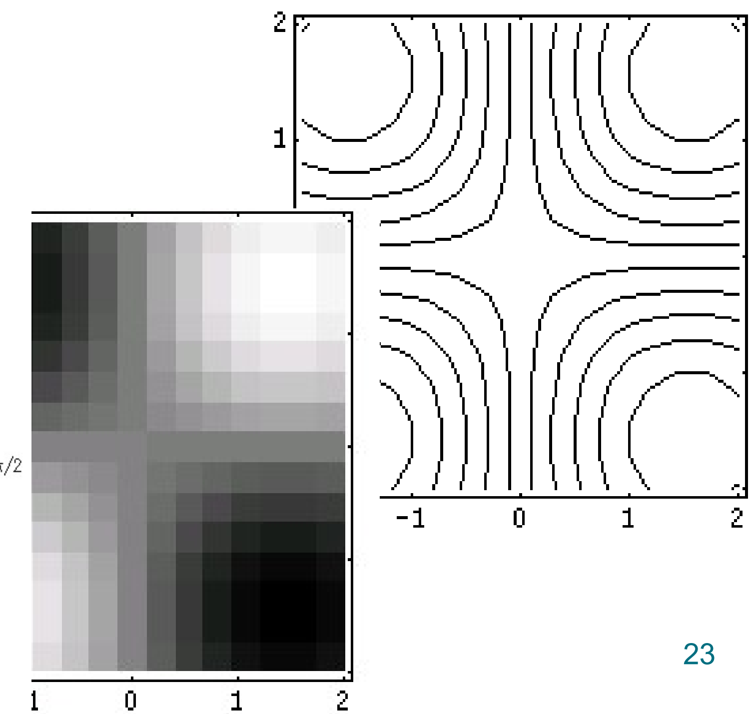


Visualization Examples

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)

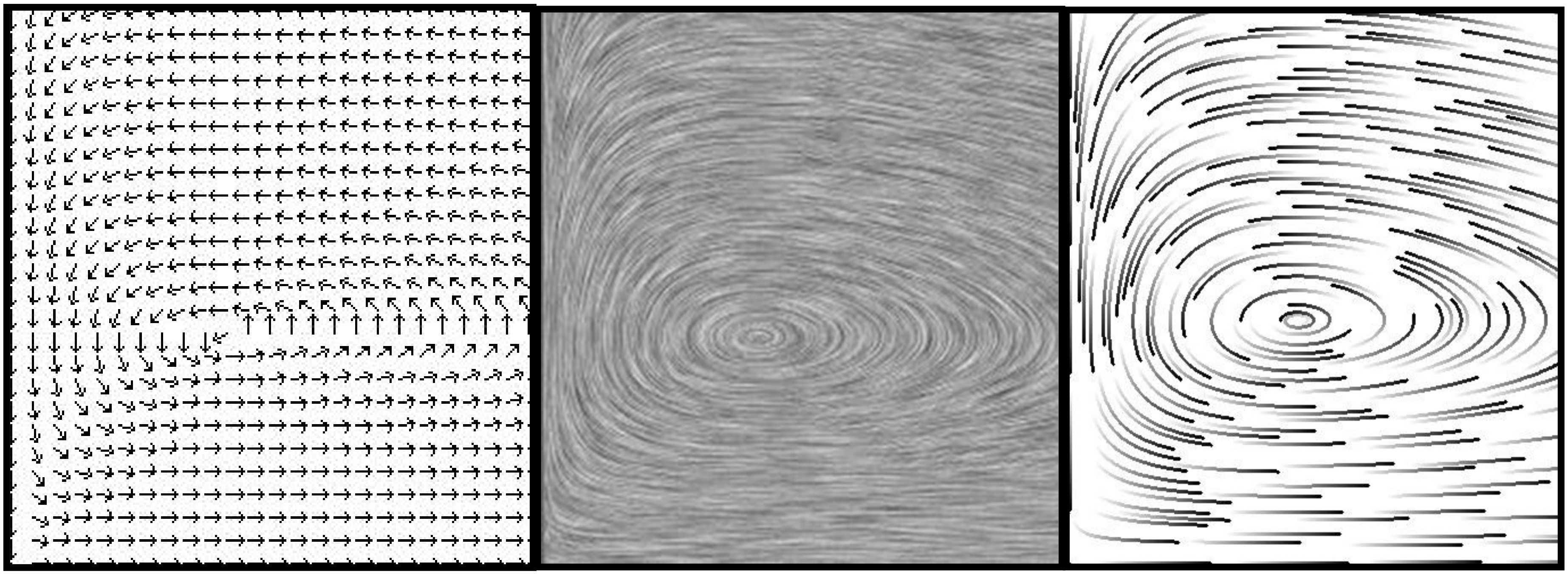


also shown:
gradient vector field



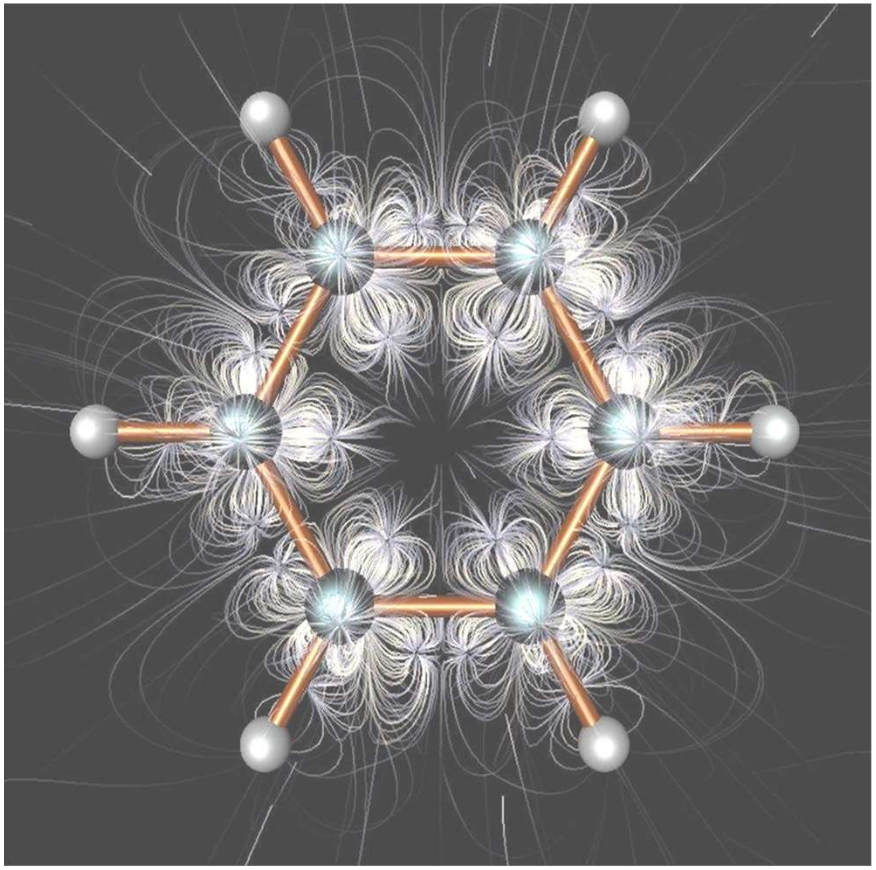
Visualization Examples

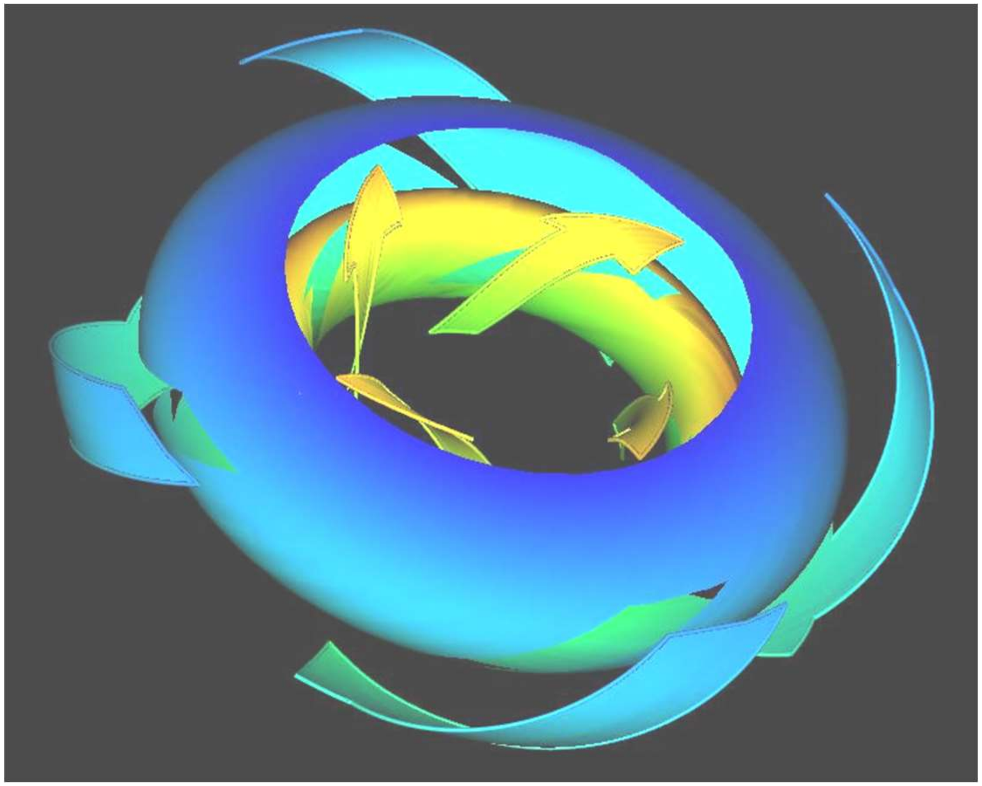
data	description	visualization example
$R^2 \rightarrow R^2$	2D-vector field	hedgehog plot, LIC, streamlets, etc



Visualization Examples

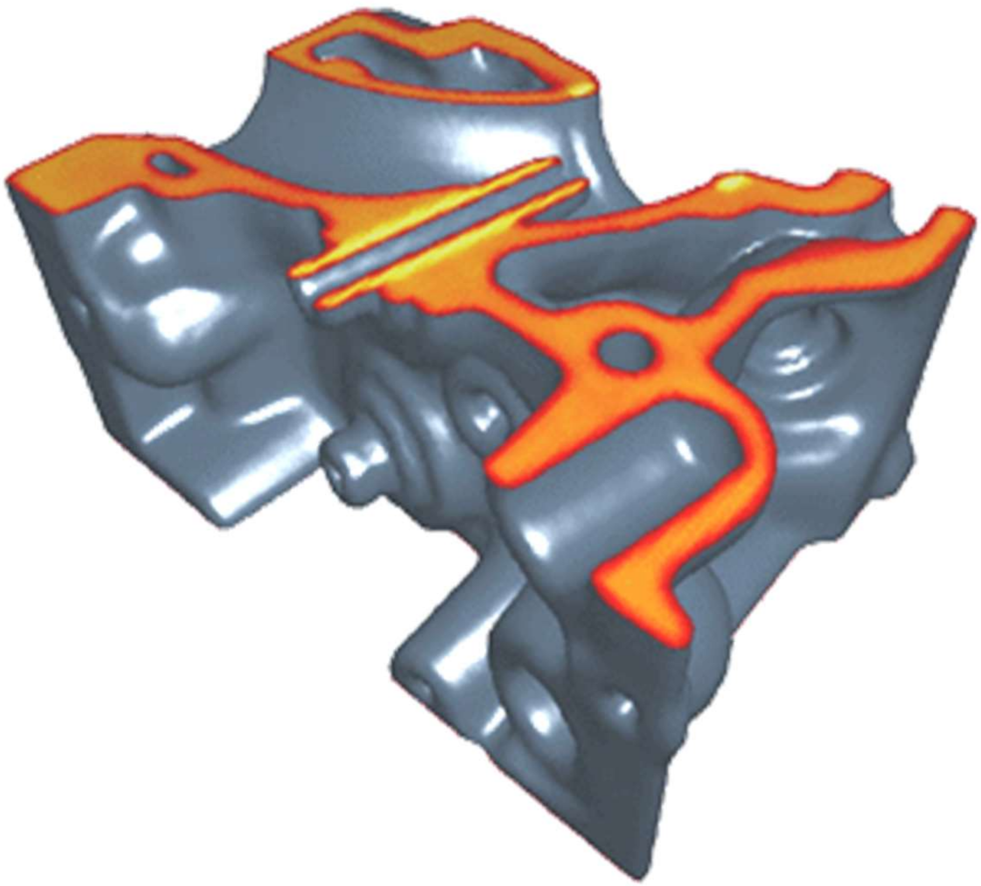
data	description	visualization example
$R^3 \rightarrow R^3$	3D-flow	streamlines, streamsurfaces

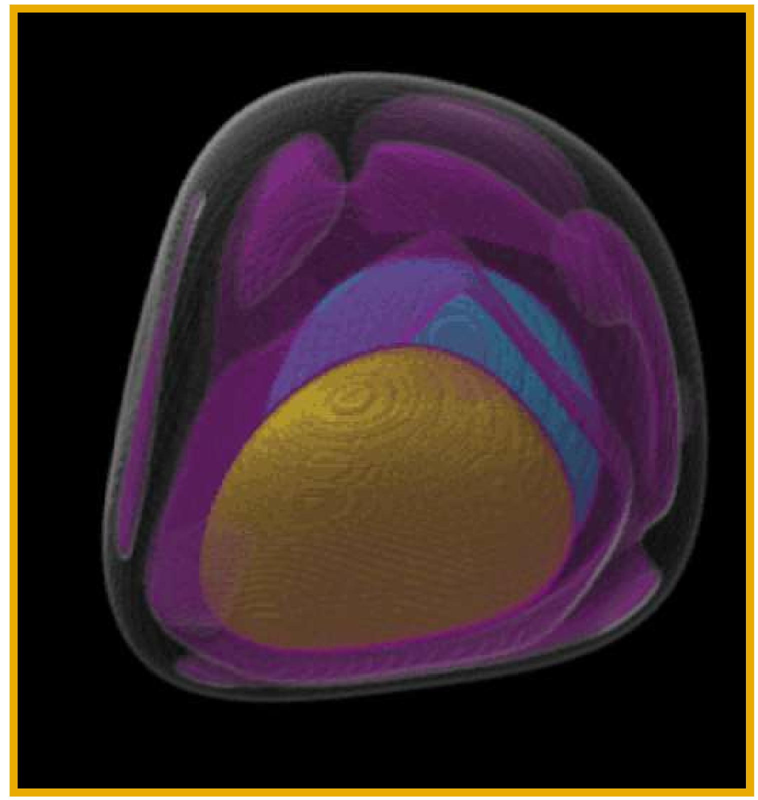




Visualization Examples

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





Data Representation

- Discrete (sampled) representations
  - The objects we want to visualize are often ‘continuous’
  - But in most cases, the visualization data is given only at discrete locations in space and/or time
  - Discrete structures consist of samples, from which grids/meshes consisting of cells are generated
- Primitives in different dimensions

dimension	cell	mesh
0D	points	
1D	lines (edges)	polyline(–gon)
2D	triangles, quadrilaterals (rectangles)	2D mesh
3D	tetrahedra, prisms, hexahedra	3D mesh

Grids – General Questions

Important questions:

- Which data organization is optimal?
- Where do the data come from?
- Is there a neighborhood relationship?
- How is the neighborhood info stored?
- How is navigation within the data possible?
- What calculations with the data are possible ?
- Are the data structured (regular/irregular topology)?

Domain

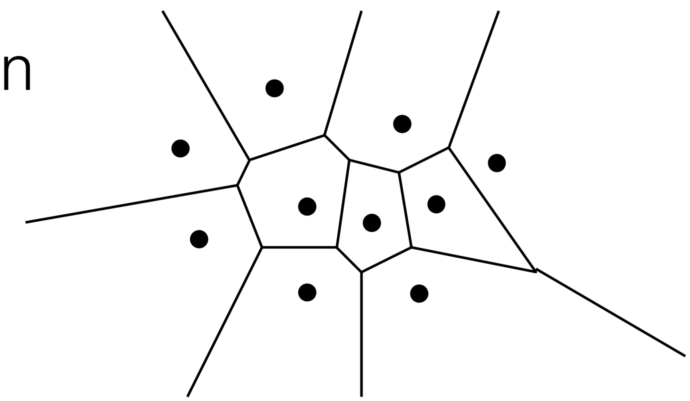
- The (geometric) shape of the domain is determined by the positions of sample points
- Domain is characterized by
  - Dimensionality: 0D, 1D, 2D, 3D, 4D, …
  - Influence: How does a data point influence its neighborhood?
  - Structure: Are data points connected? How? (Topology)

Domain

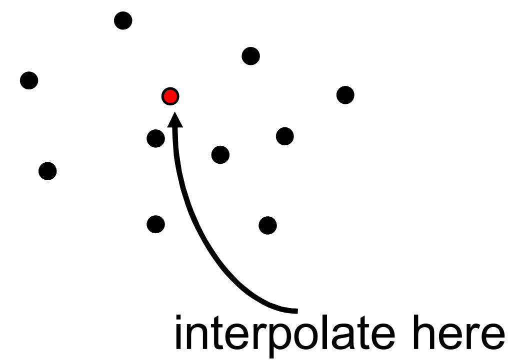
- Influence of data points
  - Values at sample points influence the data distribution in a certain region around these samples
  - To reconstruct the data at arbitrary points within the domain, the distribution of all samples has to be calculated
- Point influence
  - Only influence on point itself
- Local influence
  - Only within a certain region
    - Voronoi diagram
    - Cell-wise interpolation (see later in course)
- Global influence
  - Each sample might influence any other point within the domain
    - Material properties for whole object
    - Scattered data interpolation

Domain

- Voronoi diagram
  - Construct a region around each sample point that covers all points that are closer to that sample than to every other sample
  - Each point within a certain region gets assigned the value of the sample point
  - Nearest-neighbor interpolation



Domain



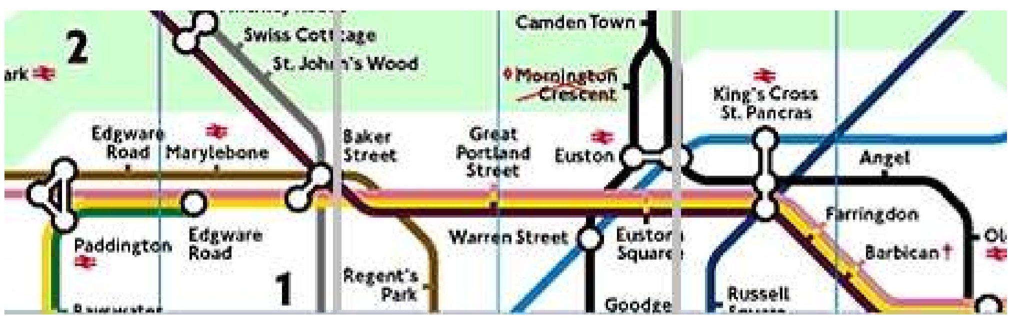
- Scattered data interpolation
  - At each point the weighted average of all sample points in the domain is computed
  - Weighting functions determine the support of each sample point
    - Radial basis functions simulate decreasing influence with increasing distance from samples
  - Schemes might be non-interpolating and expensive in terms of numerical operations

Data Structures

- Requirements:
  - Efficiency of accessing data
  - Space efficiency
  - Lossless vs. lossy
  - Portability
    - Binary – less portable, more space/time efficient
    - Text – human readable, portable, less space/time efficient
- Definition
  - If points are arbitrarily distributed and no connectivity exists between them, the data is called scattered
  - Otherwise, the data is composed of cells bounded by grid lines
  - Topology specifies the structure (connectivity) of the data
  - Geometry specifies the position of the data

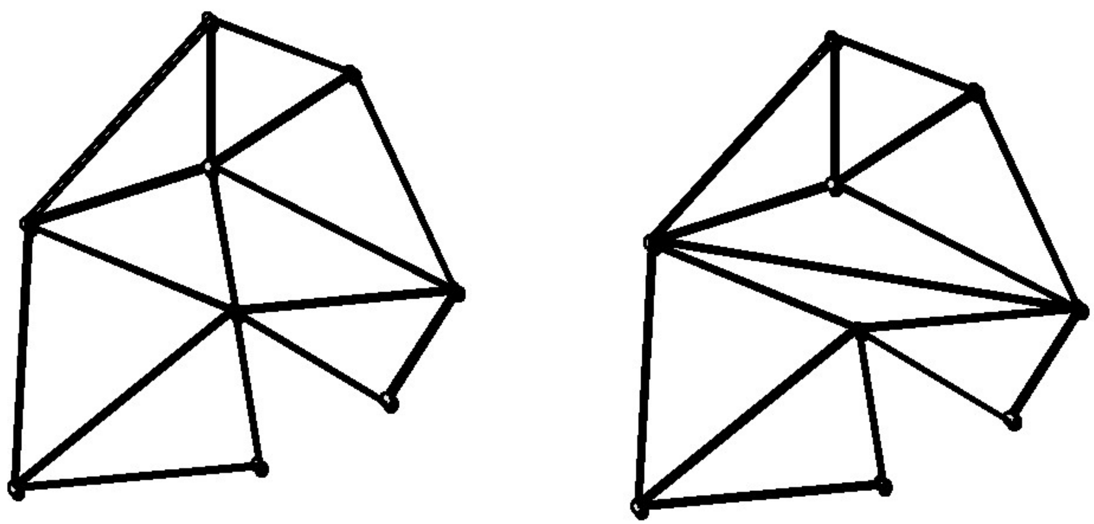
Data Structures

- Some definitions concerning topology and geometry
  - In topology, qualitative questions about geometrical structures are the main concern
    - Does it have any holes in it?
    - Is it all connected together?
    - Can it be separated into parts?
- Underground map does not tell you how far one station is from the other, but rather how the lines are connected (topological map)



Data Structures

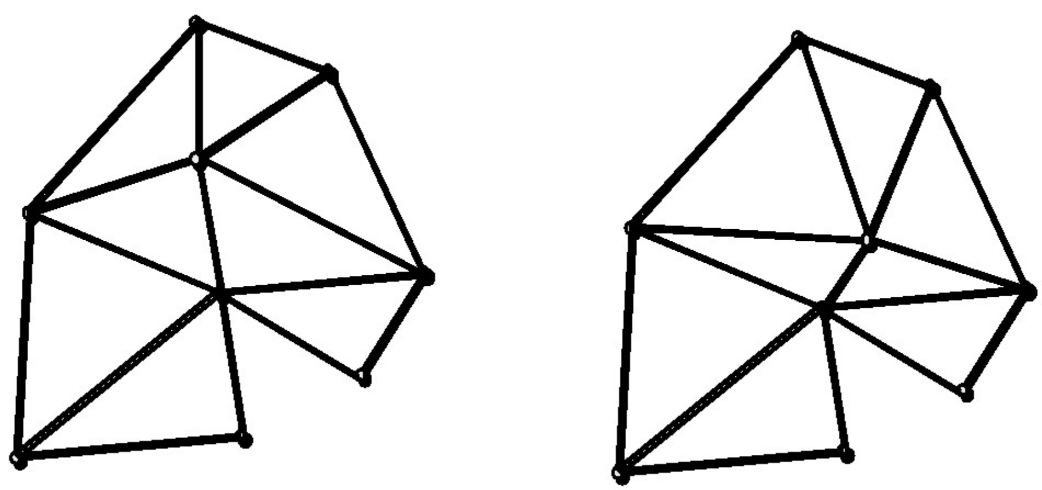
- Topology
  - Properties of geometric shapes that remain unchanged even when under distortion



Same geometry (vertex positions), different topology (connectivity)

Data Structures

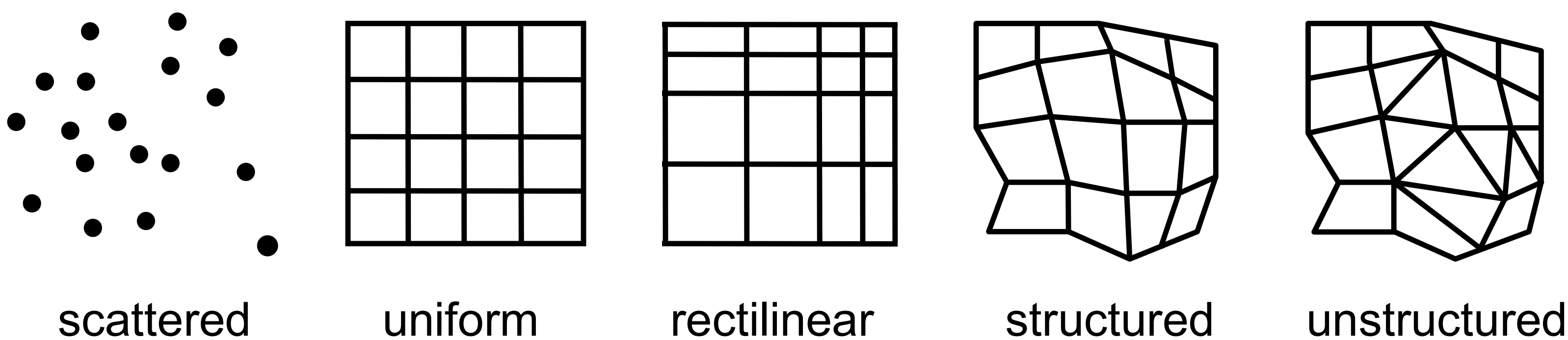
- Topologically equivalent
  - Things that can be transformed into each other by stretching and squeezing, without tearing or sticking together bits which were previously separated



topologically equivalent

Data Structures

- Grid types
  - Grids differ substantially in the cells (basic building blocks) they are constructed from and in the way the topological information is given



Thank you.

Thanks for material

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