



CS 247 – Scientific Visualization

Lecture 4: Data Representation, Pt. 1

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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 Basic OpenGL example [we will offer a tutorial!]	until	Feb 5
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

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



The image shows a screenshot of a C++ program running a 3D visualization of a skull slice. The program is titled "AMCS/CS247 Scientific Visualization - Slice Viewer". The terminal window displays the following output:

```
#include <iostream>

GL_VERSION major=4 minor=3
Keyboard commands:
b - Toggle among background clear colors
w - Increase current slice
s - Decrease current slice
a - Toggle viewing axis
1 - Load lobster dataset
2 - Load head dataset
3 - Load hydrogen dataset
loading data ../Datasets/skewed_head.dat
volume dimensions: x: 184, y: 256, z:170
downloading volume to 3D texture
increasing current slice: 86
increasing current slice: 87
increasing current slice: 88
increasing current slice: 89
increasing current slice: 90
```

The 3D visualization shows a grayscale slice of a skull, viewed from a perspective that shows the top and front of the head. The skull is rendered in a semi-transparent style, allowing the internal structures to be visible. The background is black.

```
int printOpenGLerror(char *file, int line)
{
    // Returns 1 if an OpenGL error occurred, 0 otherwise.
    GLenum glErr;
    int retCode = 0;

    glErr = glGetError();
    while (glErr != GL_NO_ERROR)
    {
        printf("glError in file %s @ line %d: %s\n", file, line, gluError
        retCode = 1;
        glErr = glGetError();
    }
    return retCode;
}

#define printOpenGLError() printOpenGLerror(__FILE__, __LINE__)
```

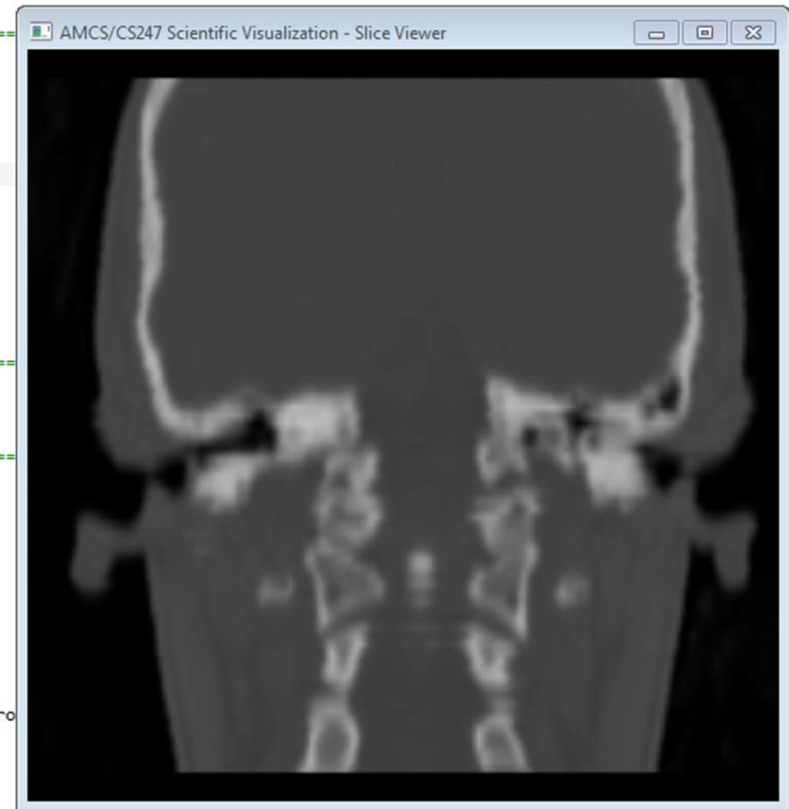
Programming Assignment #1 Example



```
G:\Development\git\Teaching\Work\CS247_Assignment1\64\Debug\CS247_Assignment1.exe
b - Toggle among background clear colors
w - Increase current slice
s - Decrease current slice
a - Toggle viewing axis
1 - Load lobster dataset
2 - Load head dataset
3 - Load hydrogen dataset
loading data ../Datasets/skewed_head.dat
volume dimensions: x: 184, y: 256, z:170
downloading volume to 3D texture
increasing current slice: 86
increasing current slice: 87
increasing current slice: 88
increasing current slice: 89
increasing current slice: 90
toggling viewing axis to: 0
increasing current slice: 93
increasing current slice: 94
increasing current slice: 95
toggling viewing axis to: 1
decreasing current slice: 127
decreasing current slice: 126
decreasing current slice: 125
decreasing current slice: 124
```

```
int printglerror(char *file, int line)
{
    // Returns 1 if an OpenGL error occurred, 0 otherwise.
    GLenum glErr;
    int retCode = 0;

    glErr = glGetError();
    while (glErr != GL_NO_ERROR)
    {
        printf("glError in file %s @ line %d: %s\n", file, line, gluError);
        retCode = 1;
        glErr = glGetError();
    }
    return retCode;
}
```



Programming Assignment #1 Example



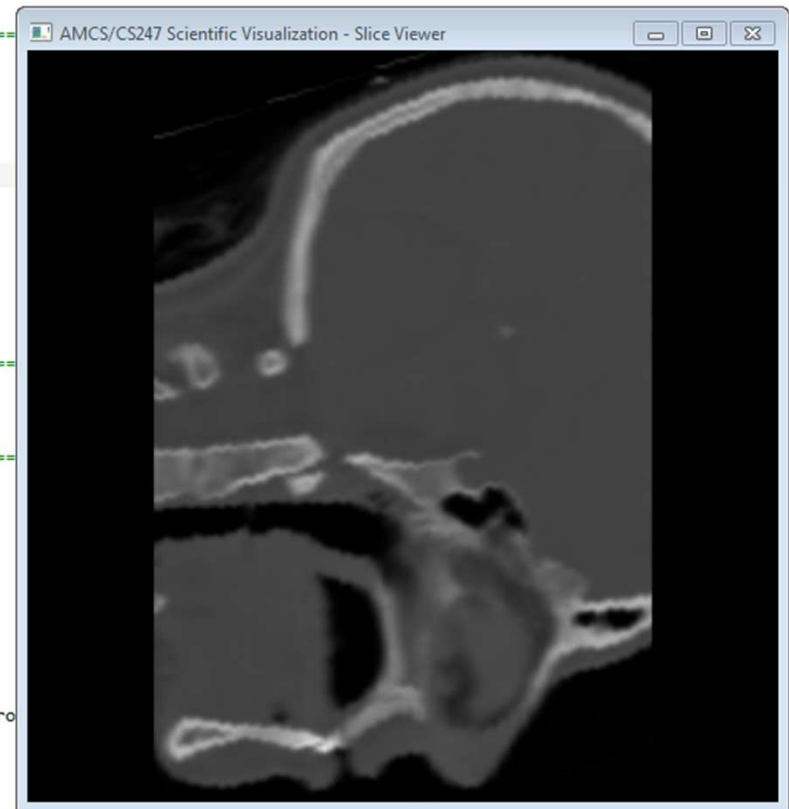
```
#include <iostream>

GL_VERSION major=4 minor=3

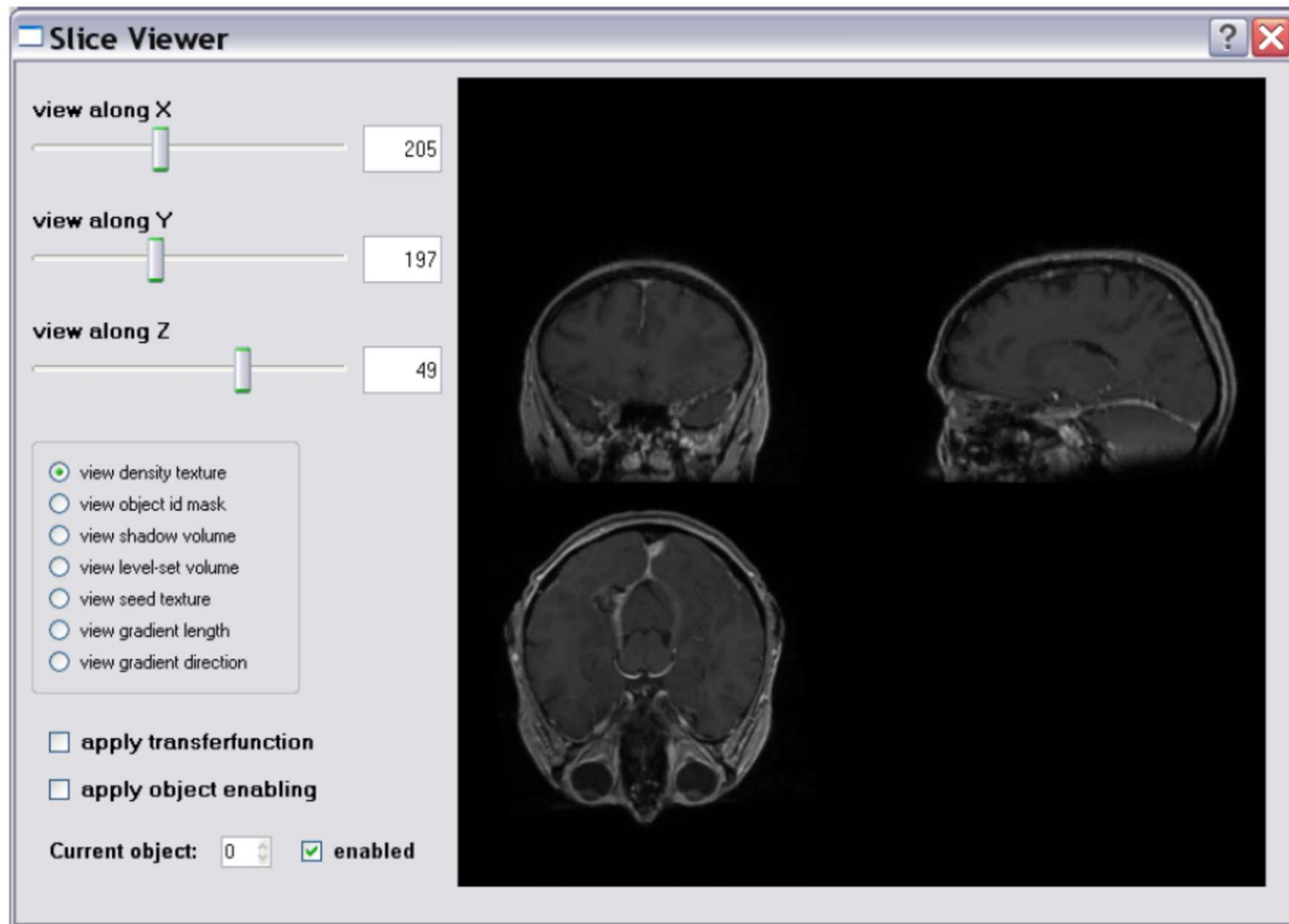
Keyboard commands:
b - Toggle among background clear colors
w - Increase current slice
s - Decrease current slice
a - Toggle viewing axis
1 - Load lobster dataset
2 - Load head dataset
3 - Load hydrogen dataset
loading data ../Datasets/skewed_head.dat
volume dimensions: x: 184, y: 256, z:170
downloading volume to 3D texture
increasing current slice: 86
increasing current slice: 87
increasing current slice: 88
increasing current slice: 89
increasing current slice: 90
toggling viewing axis to: 0
increasing current slice: 93
increasing current slice: 94
increasing current slice: 95
```

```
int printOpenGLError(char *file, int line)
{
    // Returns 1 if an OpenGL error occurred, 0 otherwise.
    GLenum glErr;
    int retCode = 0;

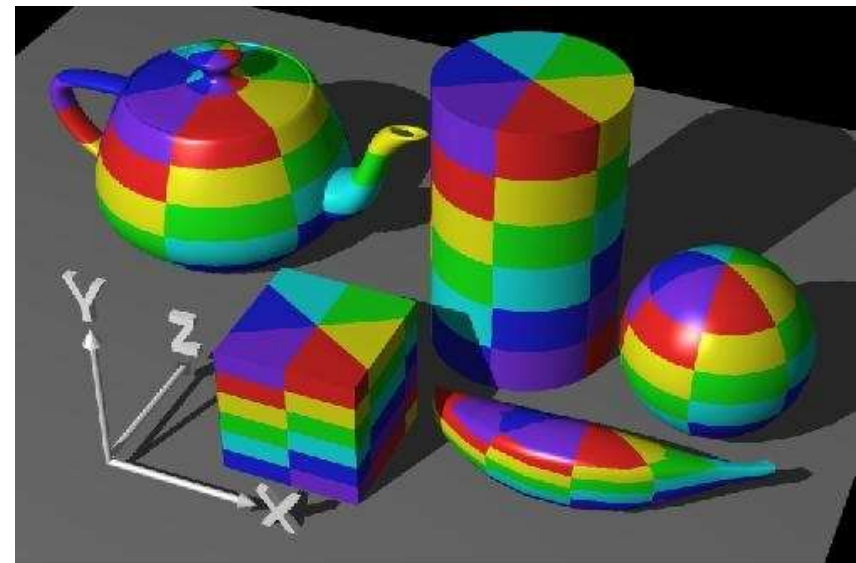
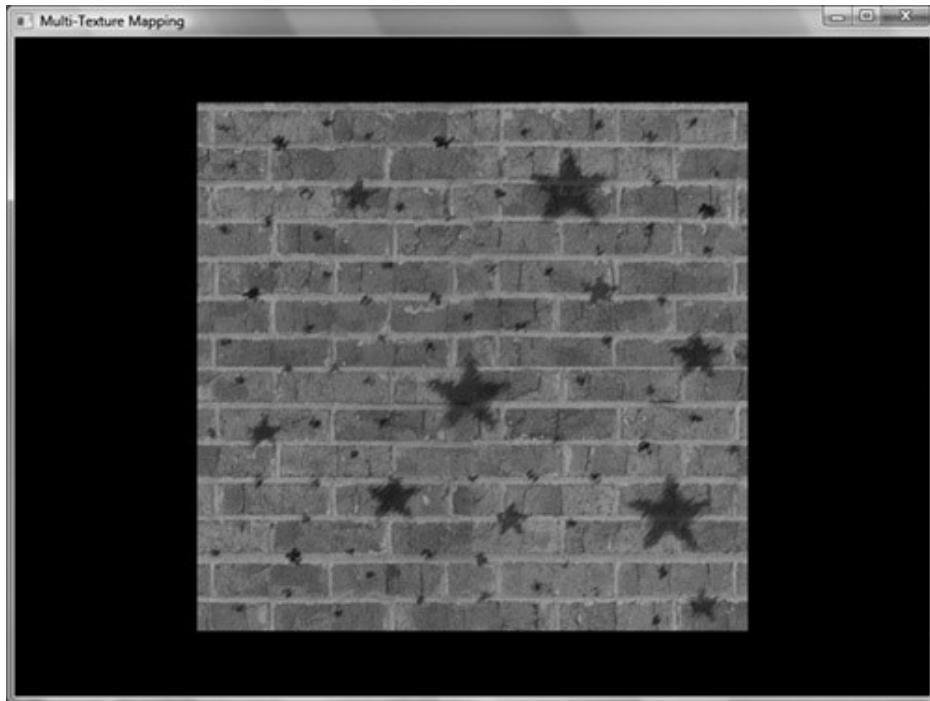
    glErr = glGetError();
    while (glErr != GL_NO_ERROR)
    {
        printf("glError in file %s @ line %d: %s\n", file, line, gluError);
        retCode = 1;
        glErr = glGetError();
    }
    return retCode;
}
```



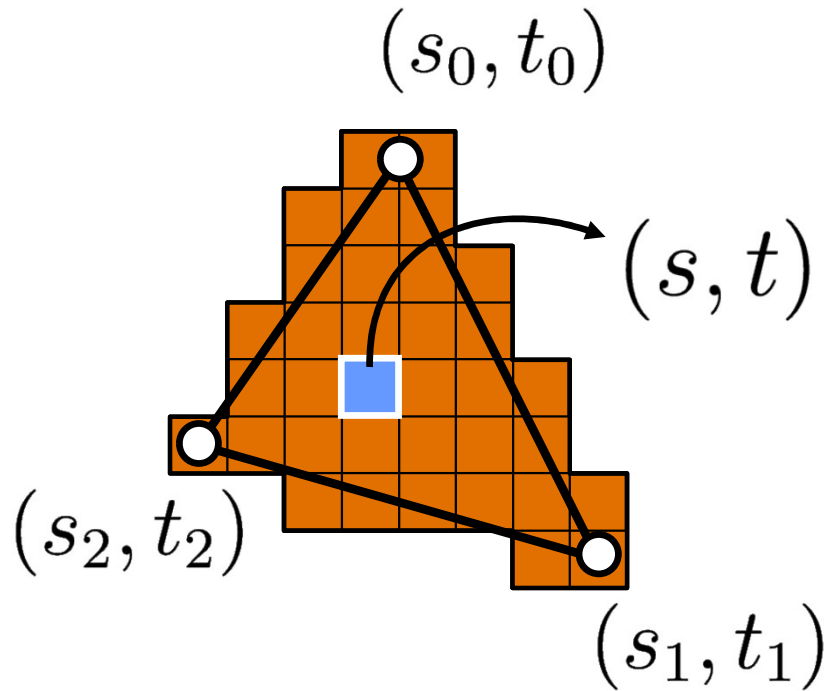
Programming Assignment #1 Example



Texture Mapping



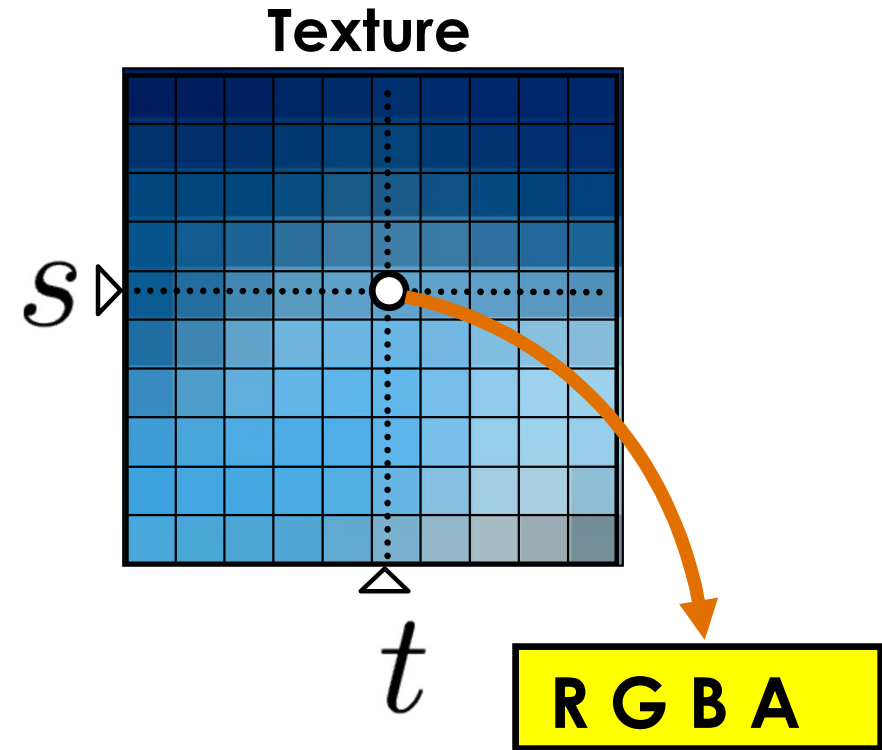
2D Texture Mapping



For each fragment:
interpolate the
texture coordinates
(barycentric)

Or:

Use arbitrary, computed coordinates

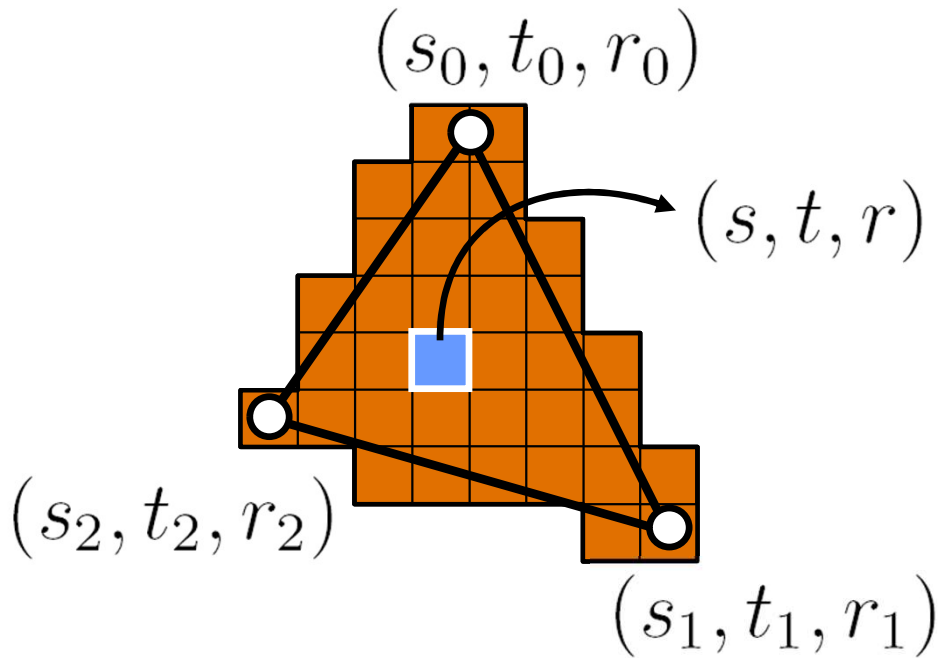


Texture-Lookup:
interpolate the
texture data
(bi-linear)

Or:

Nearest-neighbor for "array lookup"

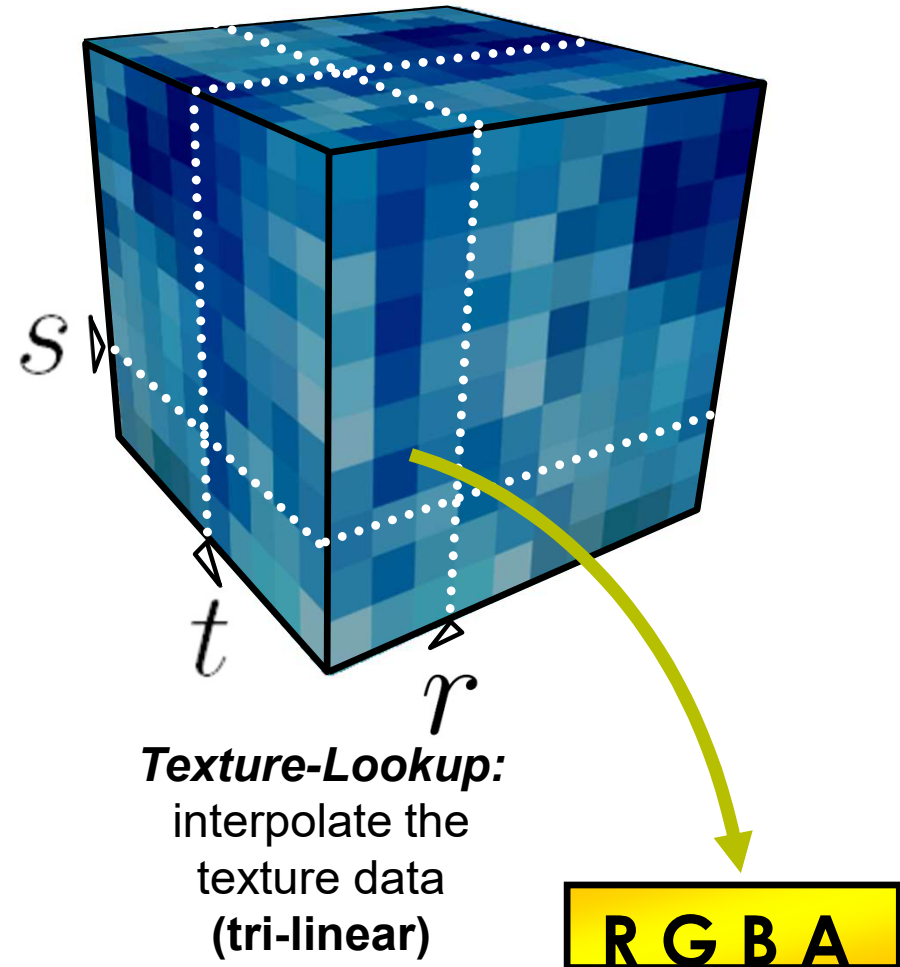
3D Texture Mapping



For each fragment:
interpolate the
texture coordinates
(barycentric)

Or:

Use arbitrary, computed coordinates



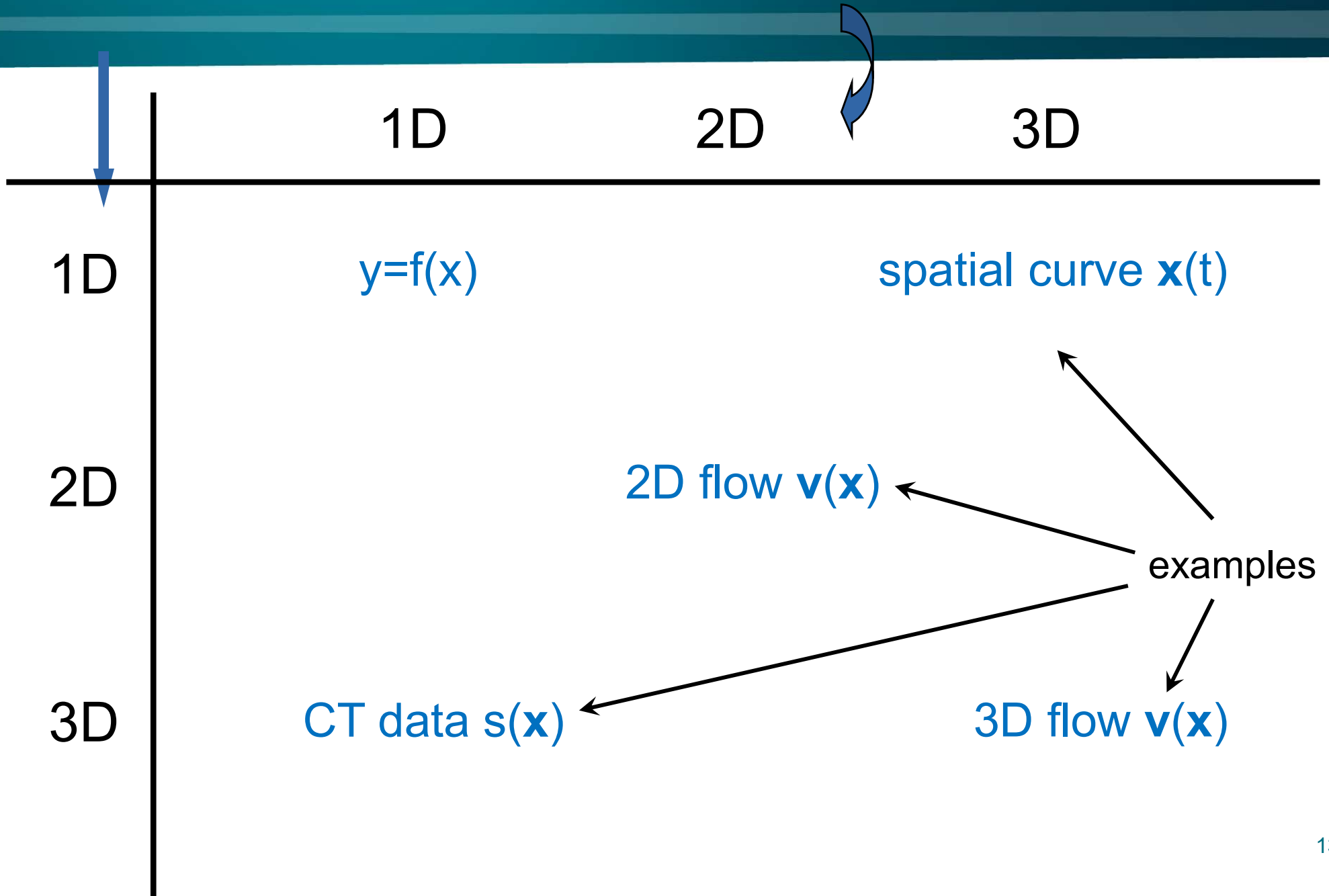
Texture-Lookup:
interpolate the
texture data
(tri-linear)

Or:

Nearest-neighbor for "array lookup"

Data Representation

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



Data == Functions

Mathematical Functions

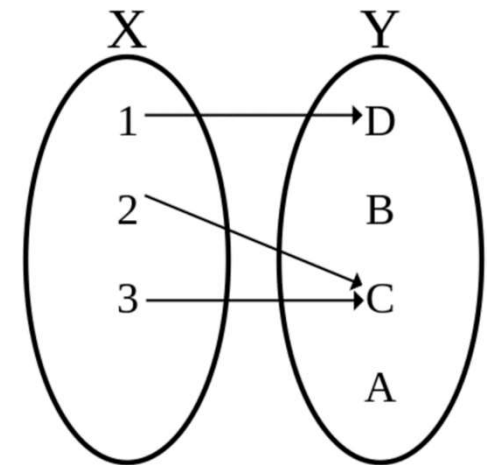


Associates every element of a set (e.g., X) with *exactly one* element of another set (e.g., Y)

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

$$f: X \rightarrow Y$$

$$x \mapsto f(x)$$



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

Graph of a function (mathematical definition):

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

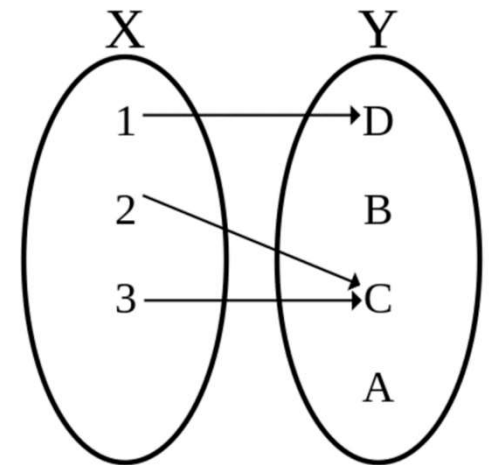
Mathematical Functions



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)

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

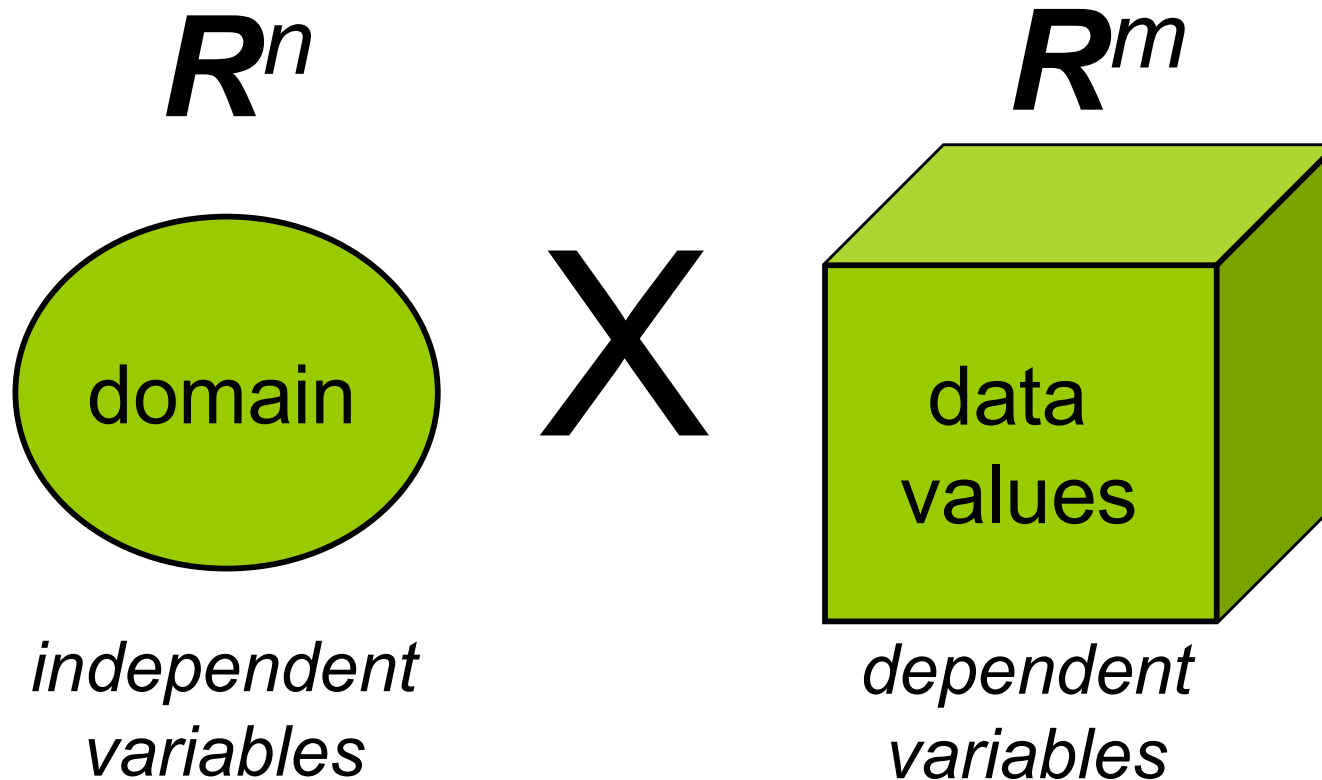


Also important: *range/image*; *preimage*;
continuity, differentiability, dimensionality, ...

Graph of a function (mathematical definition):

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

Data Representation



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

Example: Scalar Fields



2D scalar field

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

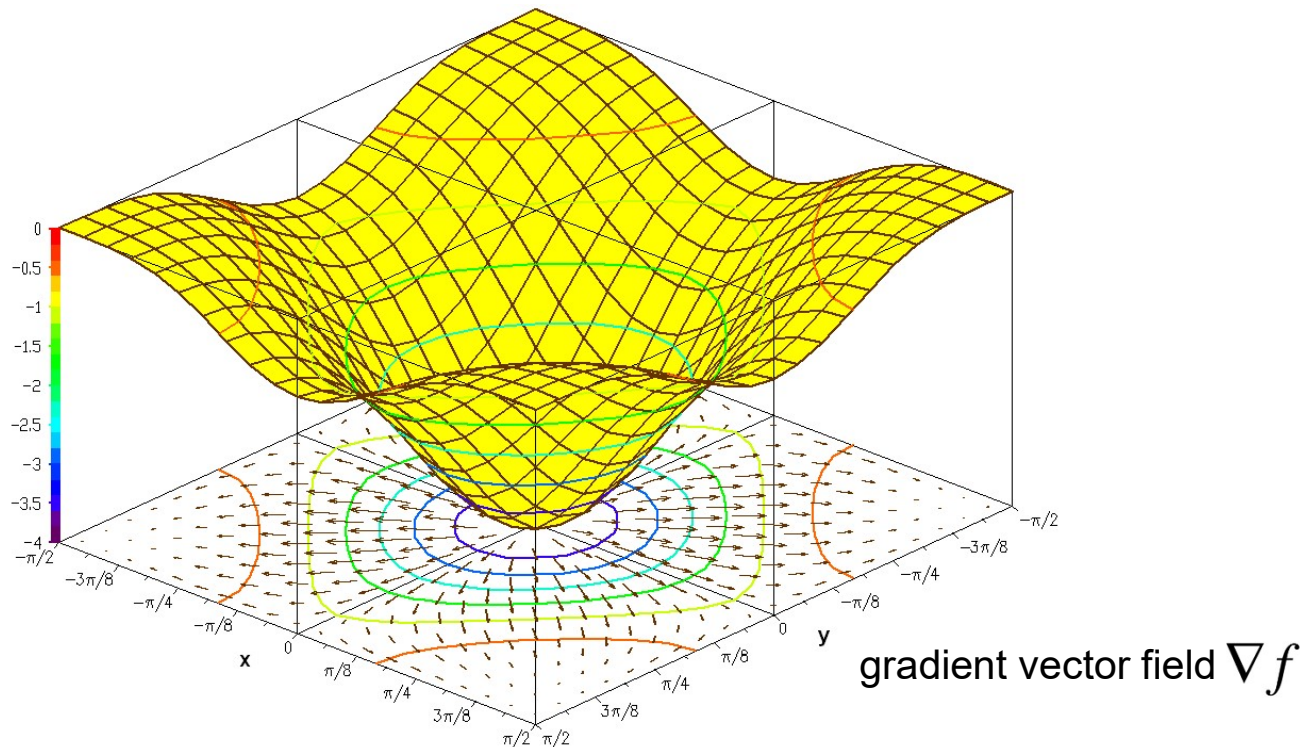
Graph: $G(f) := \{(x, f(x)) \mid x \in \mathbb{R}^2\} \subset \mathbb{R}^2 \times \mathbb{R} \simeq \mathbb{R}^3$

pre-image

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

iso-contour

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



Example: Scalar Fields



3D scalar field

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

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

pre-image

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

iso-surface

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



Visualization Examples



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

Visualization Examples



data

description

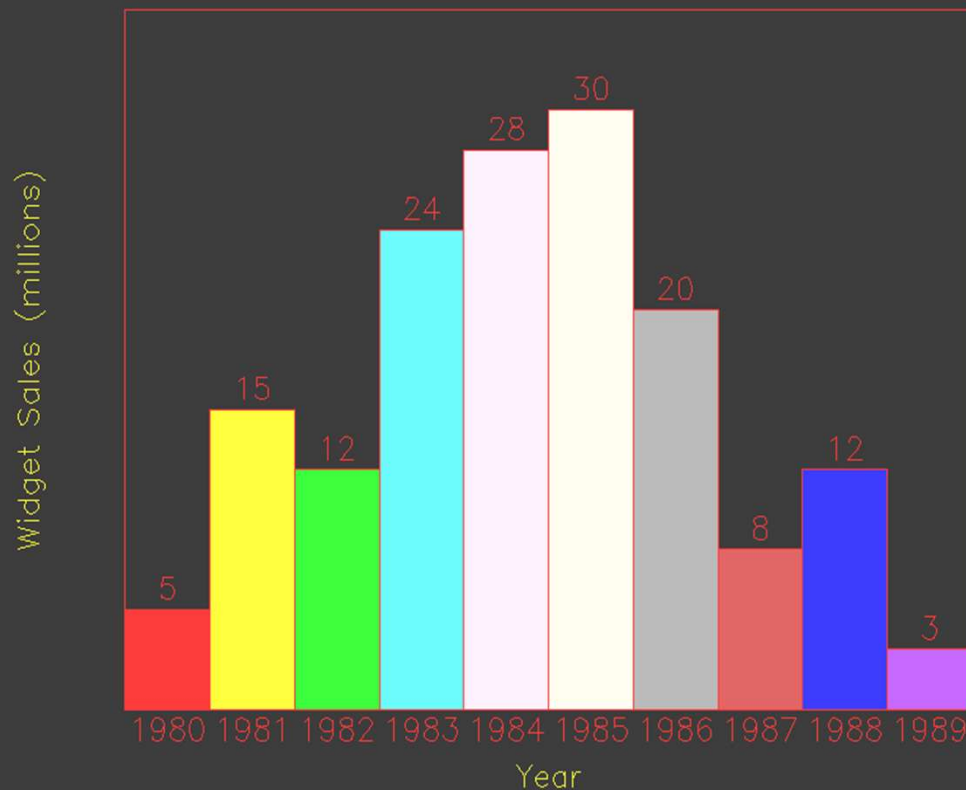
visualization example

$N^1 \rightarrow R^1$

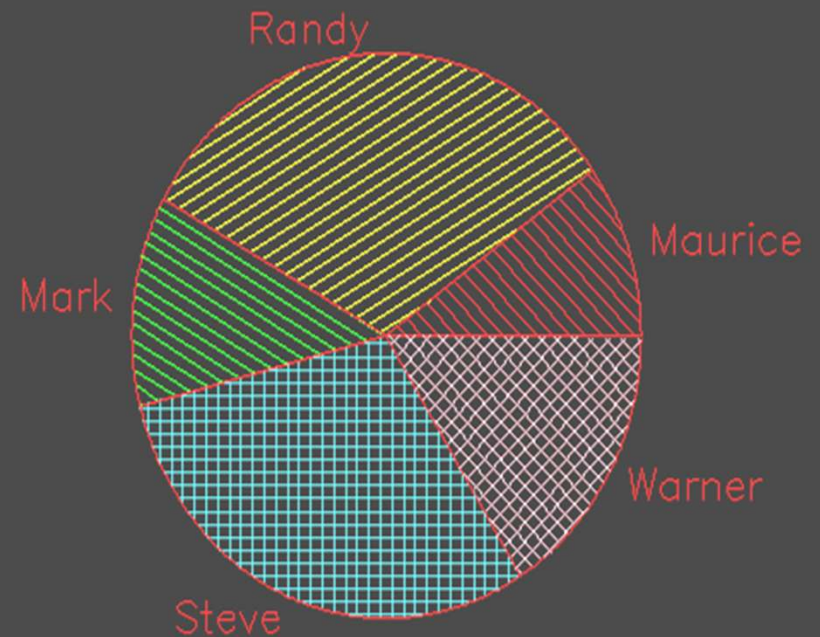
value series

bar chart, pie chart, etc.

PLplot Example 12



Percentage of Sales



Visualization Examples



data

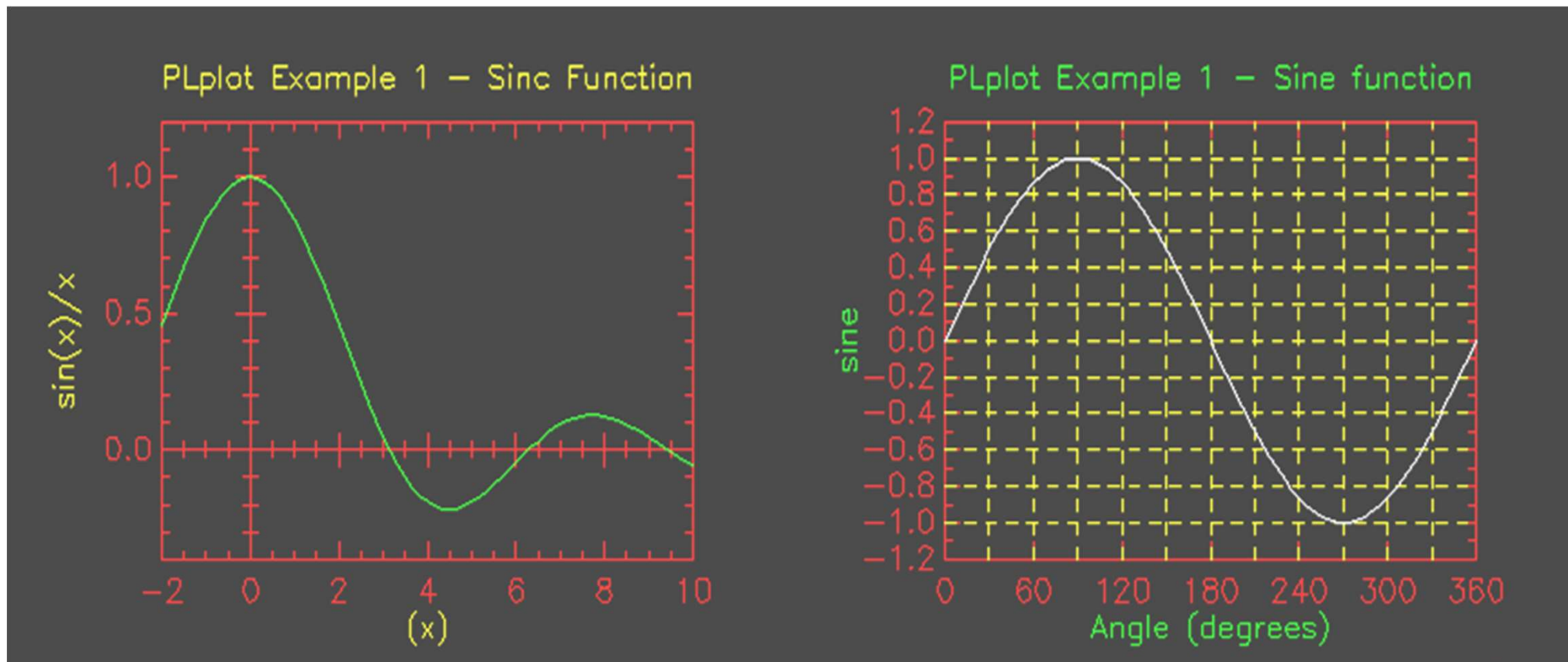
description

visualization example

$\mathbb{R}^1 \rightarrow \mathbb{R}^1$

function over \mathbb{R}

(line) graph



Visualization Examples



data

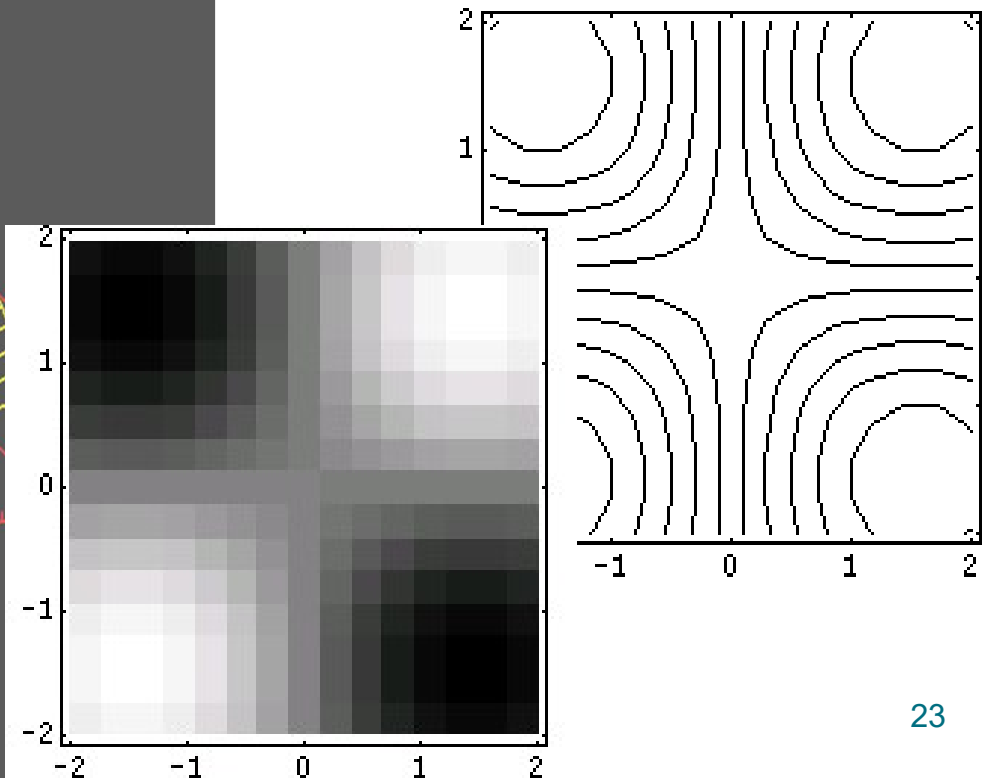
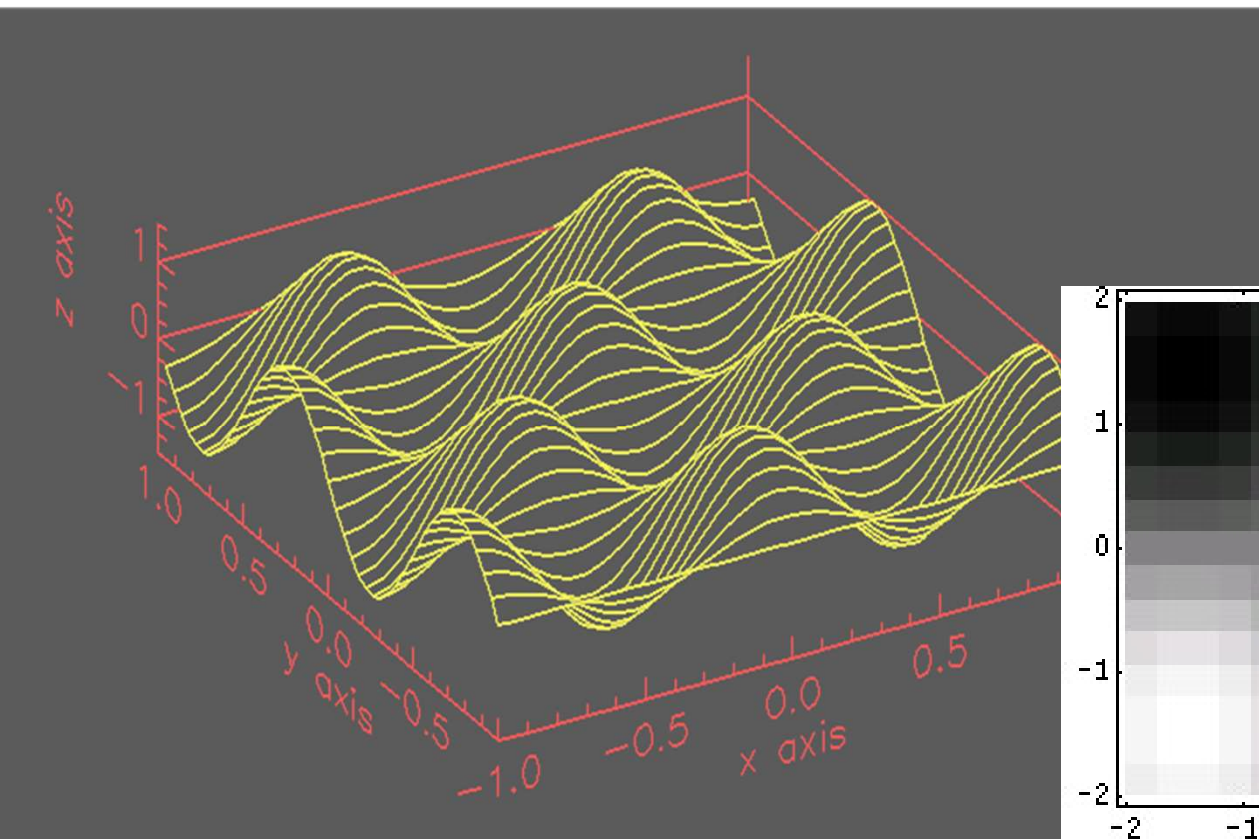
description

visualization example

$\mathbb{R}^2 \rightarrow \mathbb{R}^1$

function over \mathbb{R}^2

2D-height map in 3D,
contour lines in 2D,
false colors (heat map)



Visualization Examples



data

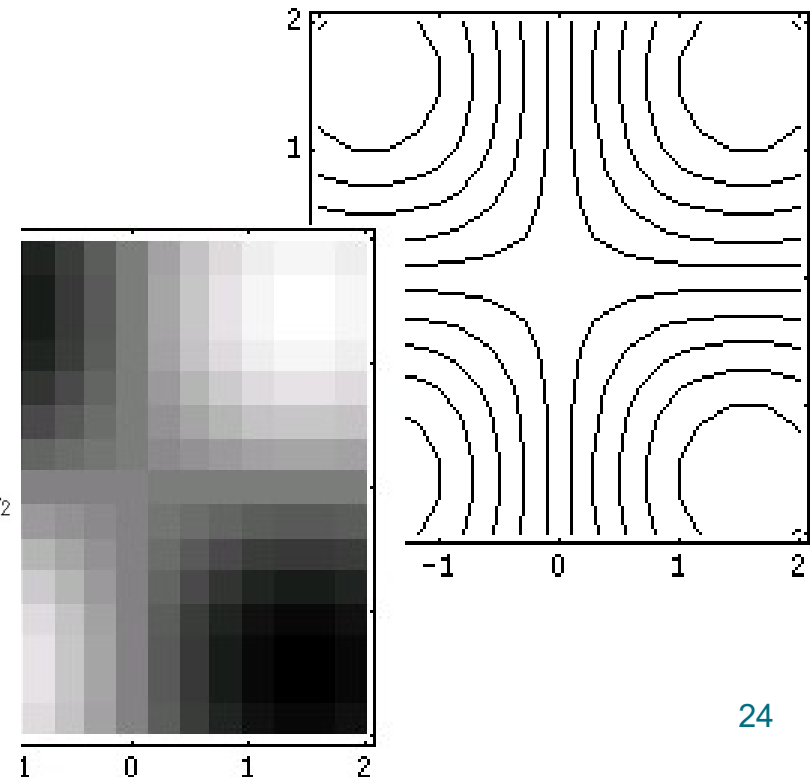
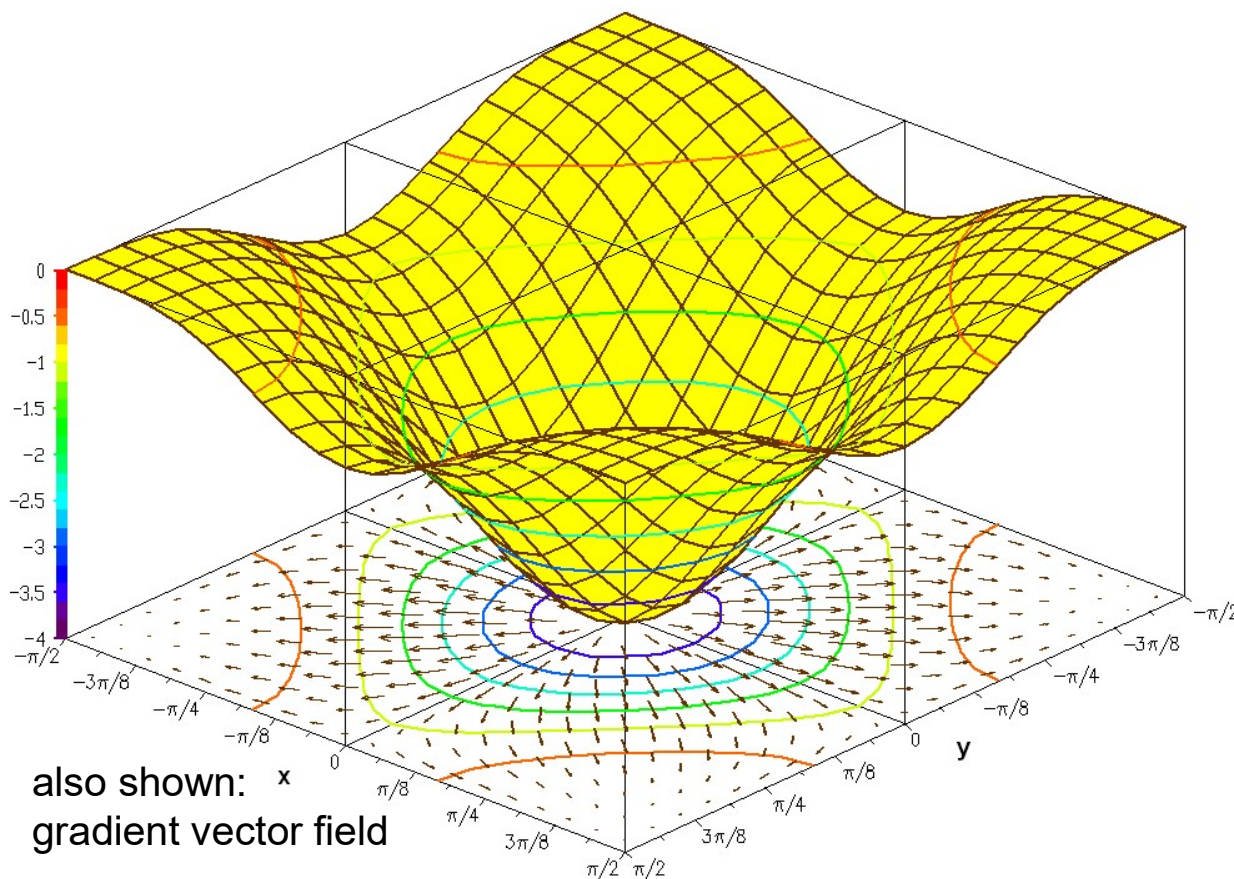
description

visualization example

$\mathbb{R}^2 \rightarrow \mathbb{R}^1$

function over \mathbb{R}^2

2D-height map in 3D,
contour lines in 2D,
false colors (heat map)



Visualization Examples



data

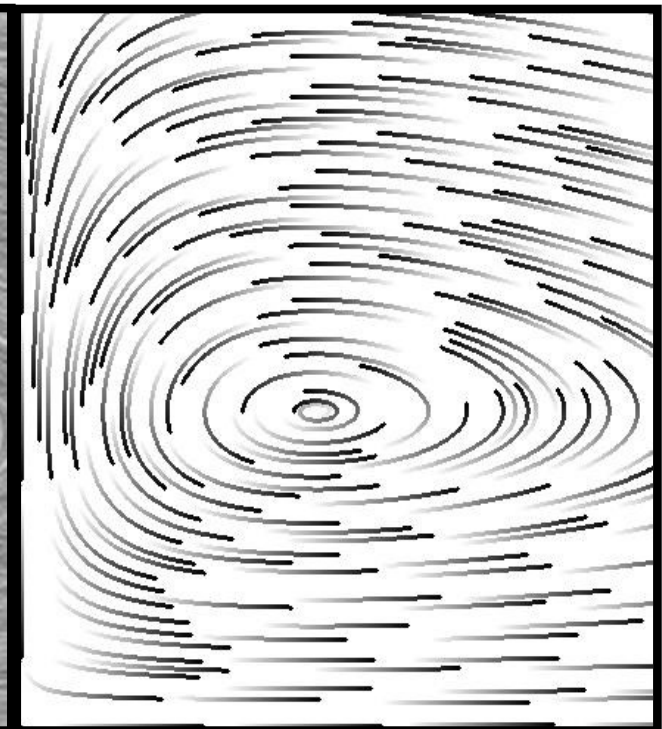
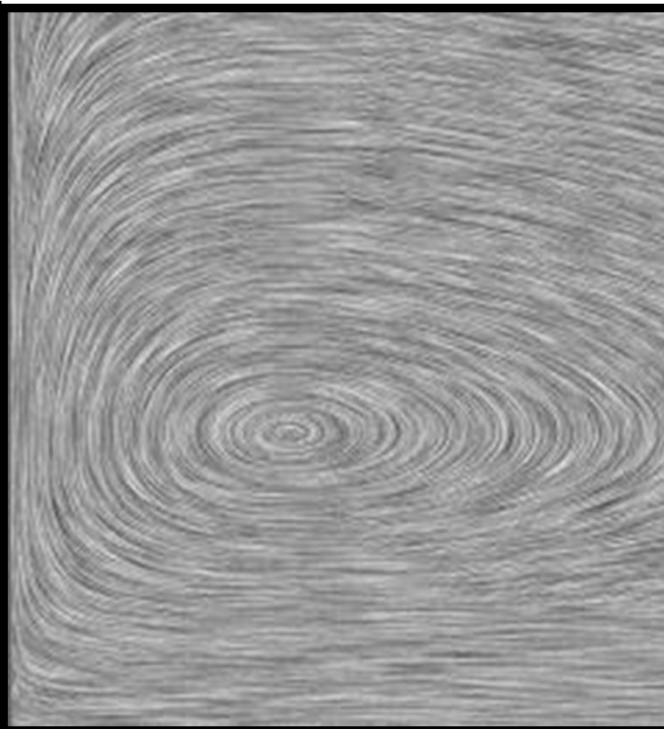
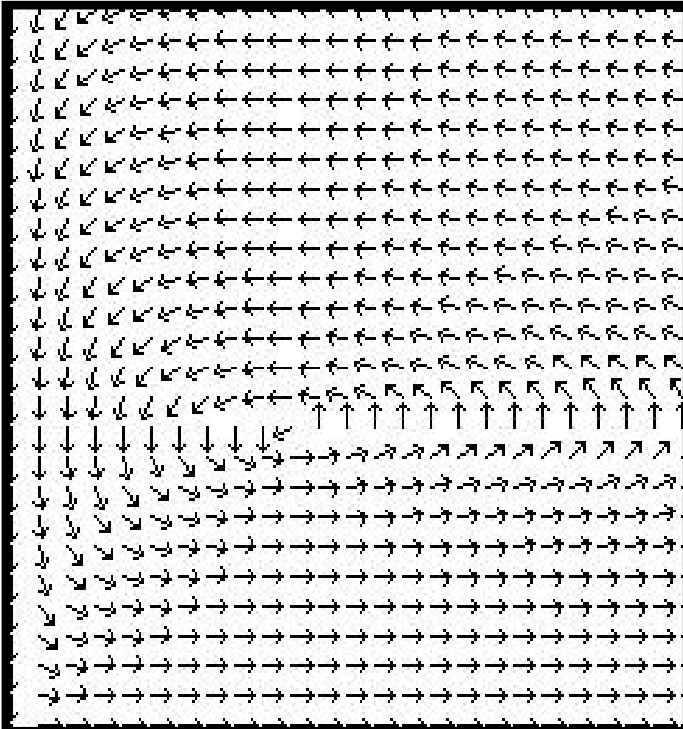
description

visualization example

$\mathbb{R}^2 \rightarrow \mathbb{R}^2$

2D-vector field

hedgehog plot, LIC, streamlets, etc



Visualization Examples



data

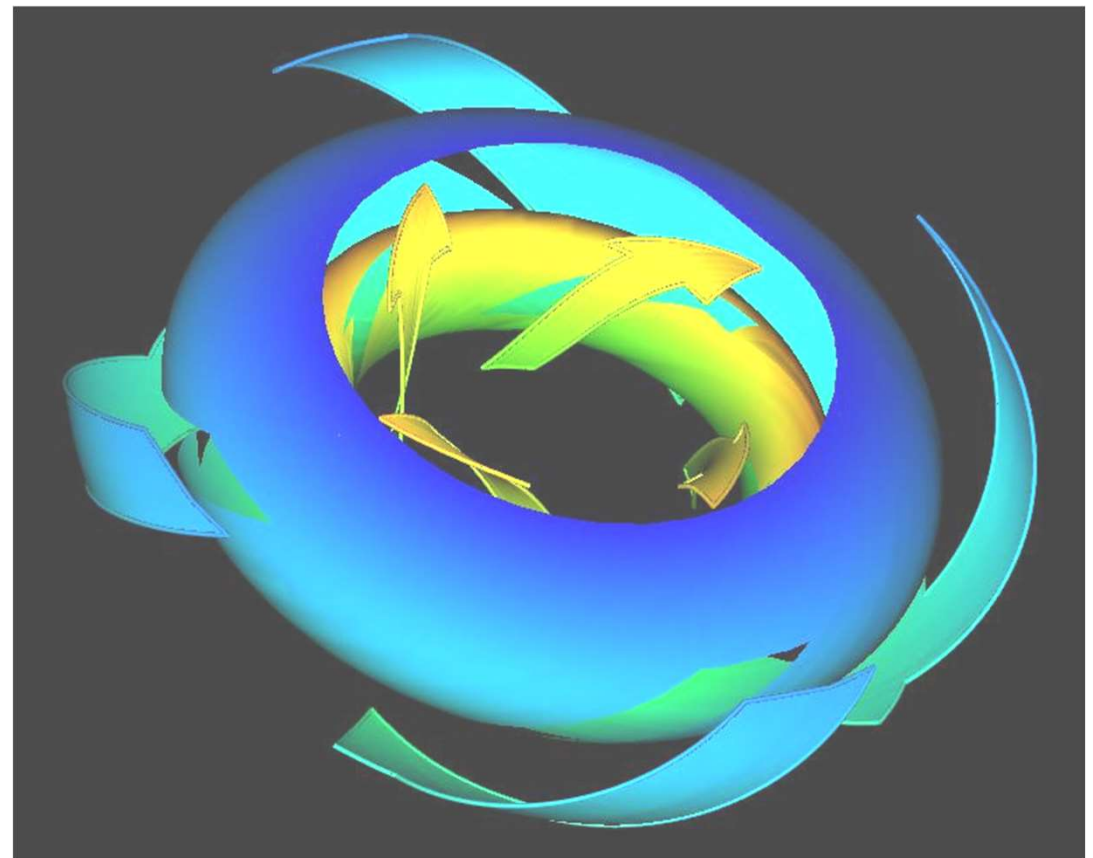
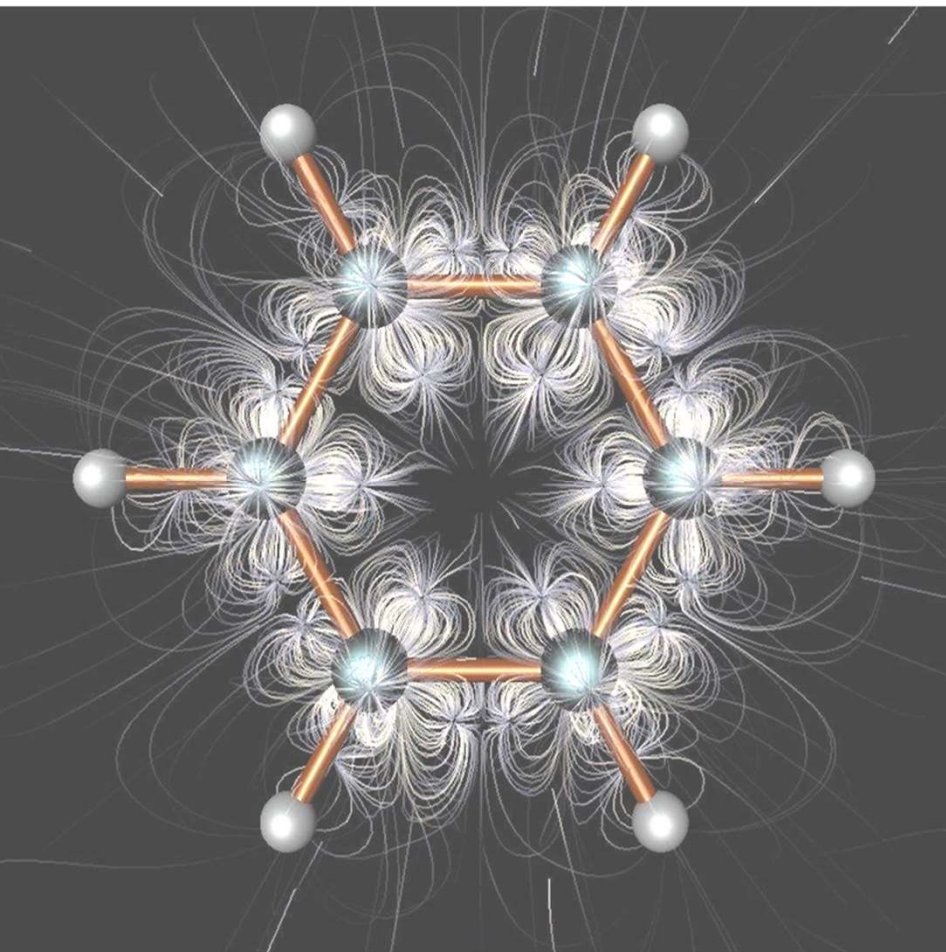
description

visualization example

$\mathbb{R}^3 \rightarrow \mathbb{R}^3$

3D-flow

streamlines,
streamsurfaces



Visualization Examples



data

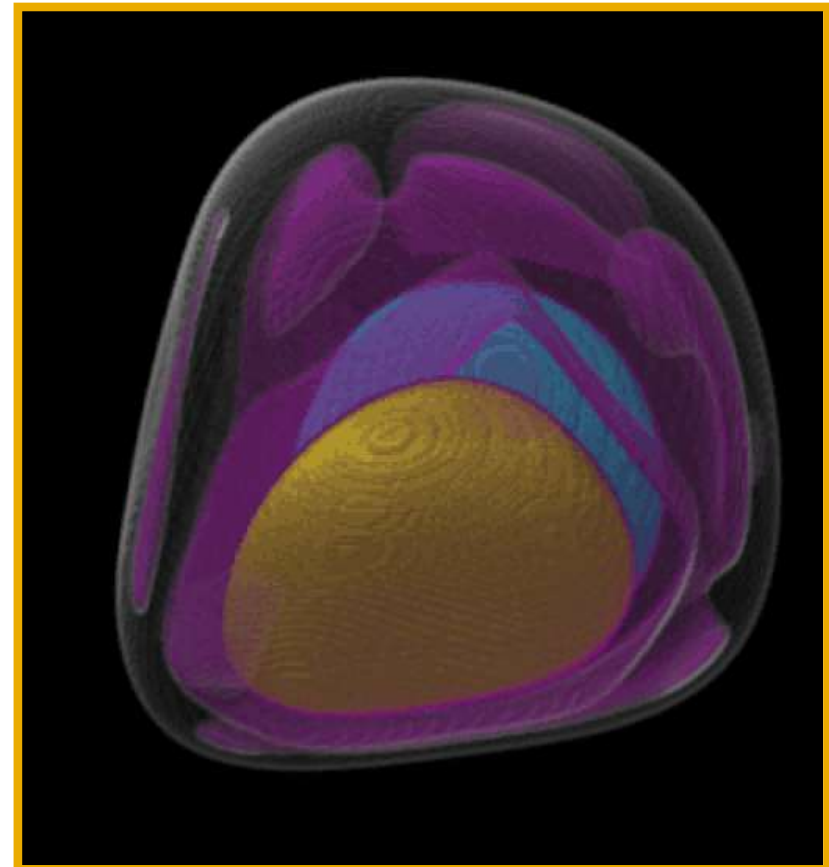
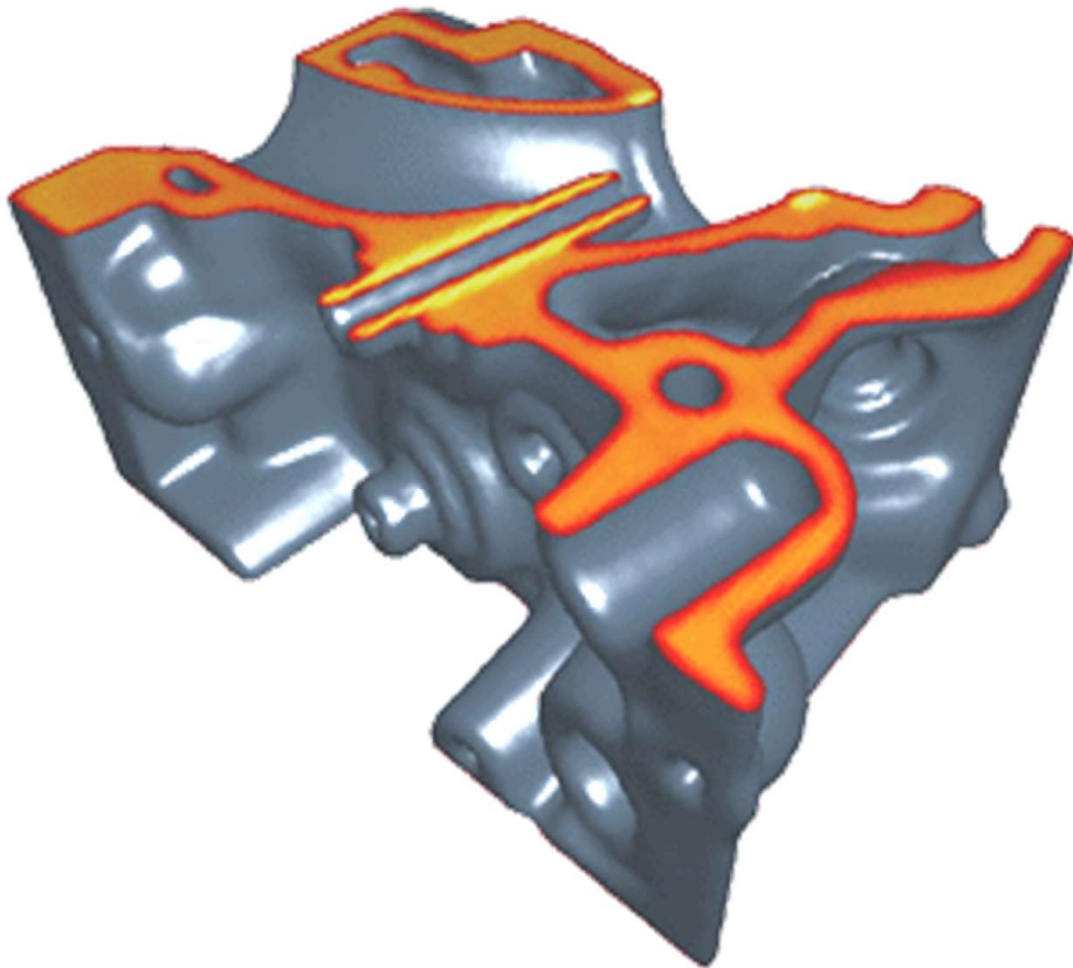
description

visualization example

$\mathbb{R}^3 \rightarrow \mathbb{R}^1$

3D-densities

iso-surfaces in 3D,
volume rendering



Thank you.

Thanks for material

- Helwig Hauser
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- Ronny Peikert
- Philipp Muigg
- Christof Rezk-Salama