Scalar 3D Data

3D Image Processing

Alireza Ghane

Readings

- The Visualization Handbook:
  – Chapter 9 (Multidimensional Transfer Functions for Volume Rendering)
- Marc Levoy: Display of Surfaces from Volume Data, IEEE Computer Graphics and Applications, Vol. 8, No. 3, May, 1988, pp. 29-37
- K. Engel, M. Hadwiger, J. M. Kniss, C. Rezk-Salama, D. Weiskopf: Real-time Volume Graphics, AK Peters, 2006
  – Chapter 4 (Transfer Functions)
  – Chapter 10 (Transfer Functions Reloaded)
  – Chapter 5 (Local Volume Illumination)

Overview

- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Basic Strategies

- Visualization of 1D, 2D, or 3D scalar fields
  - 1D scalar field: $\Omega \in R \rightarrow R$
  - 2D scalar field: $\Omega \in R^2 \rightarrow R$
  - 3D scalar field: $\Omega \in R^3 \rightarrow R$
    $\rightarrow$ **Volume visualization!**

Basic Strategies

- Mapping to geometry
  - Function plots
  - Height fields
  - Isolines and isosurfaces
- Color coding
- Specific techniques for 3D data
  - Indirect volume visualization
  - Direct volume visualization
  - Slicing
- Visualization method depend heavily on dimensionality of domain

Overview

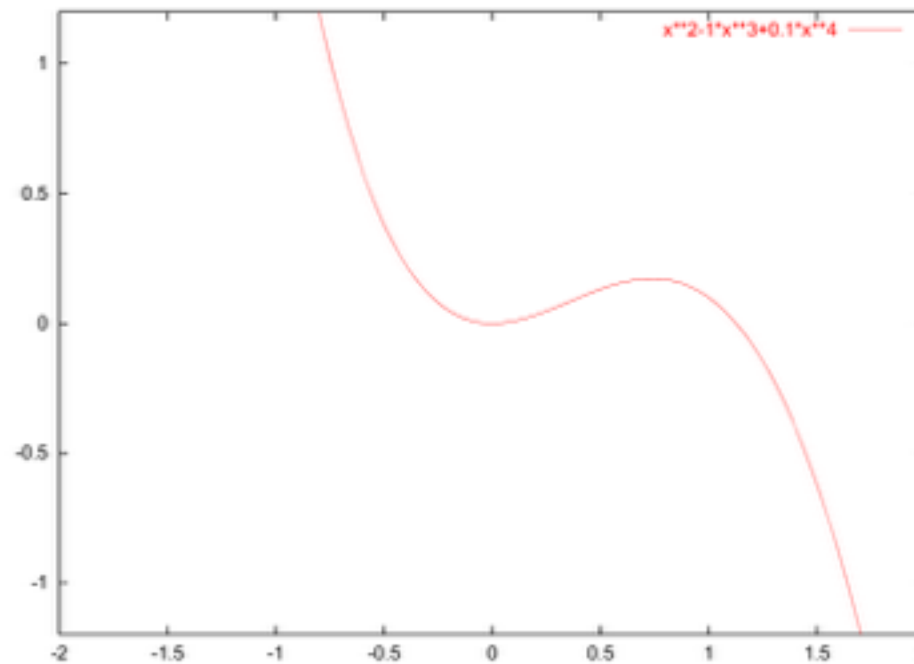
- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Function Plots and Height Fields

- Function plot for a 1D scalar field

$$\{(s, f(s))|s \in R\}$$

  - Points
  - 1D manifold: line
  - Error bars possible



Gnuplot example

Function Plots and Height Fields

- Function plot for a 2D scalar field

$$\{(s, t, f(s,t)) | (s,t) \in R^2\}$$

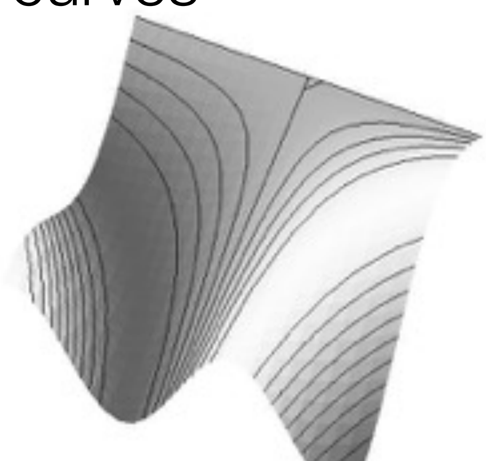
  - Points
  - 2D manifold: surface
- Surface representation
  - Wireframe
  - Hidden lines
  - Shaded surface

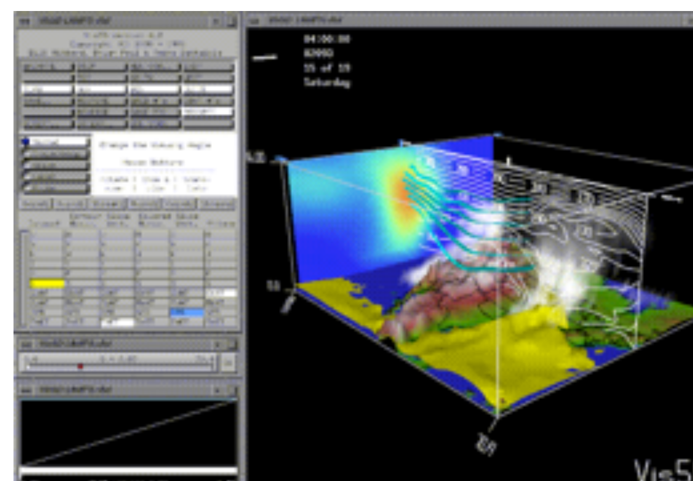
Overview

- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

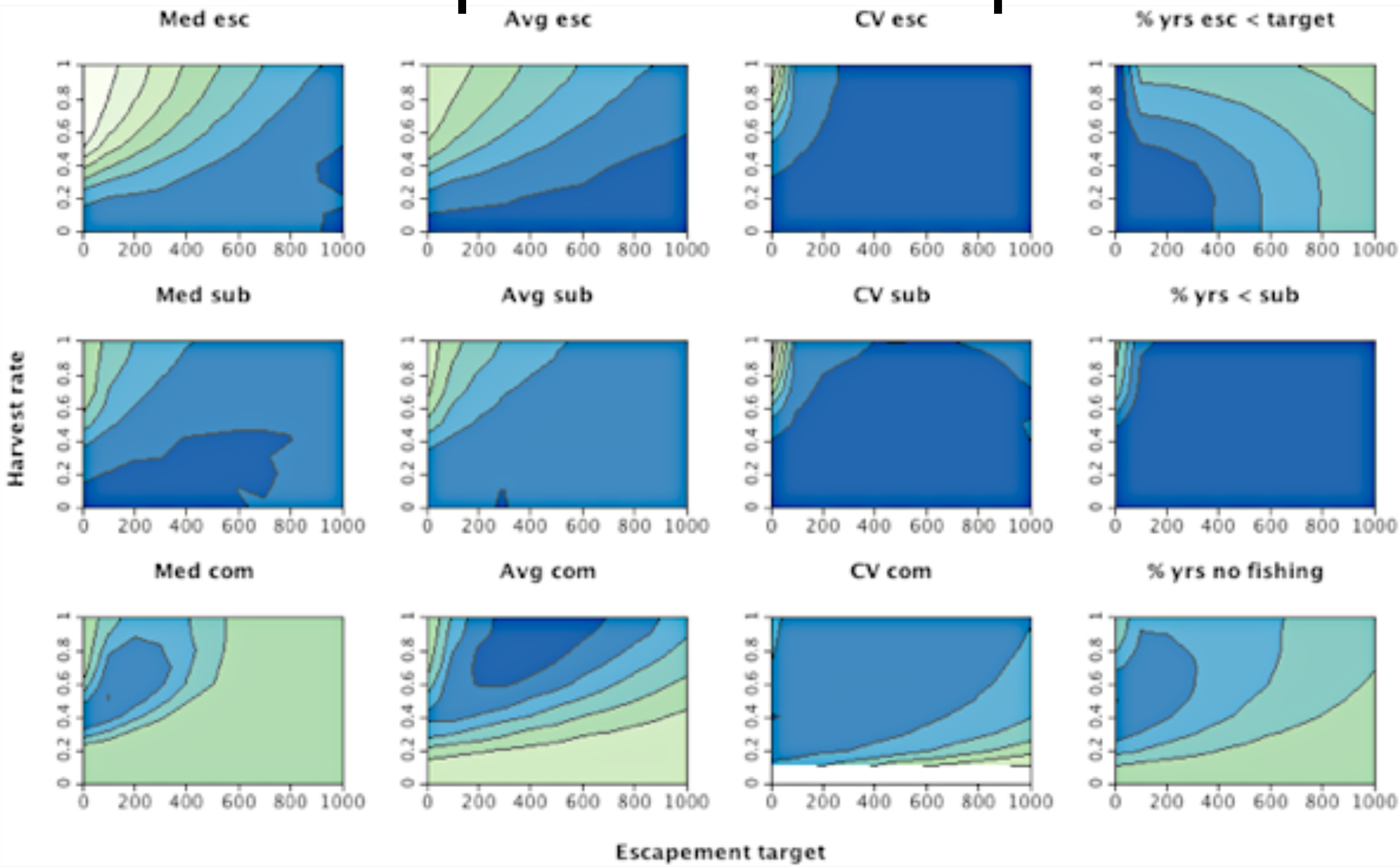
Isolines

- Visualization of 2D scalar fields
- Given a scalar function $f : \Omega \rightarrow R$ and a scalar value $c \in R$
- Isoline consists of points $\{(x,y) | f(x,y) = c\}$
- If *f*() is differentiable and *grad*(*f*) ≠ 0, then isolines are curves
- Contour lines





Colorpleth / Isopleth

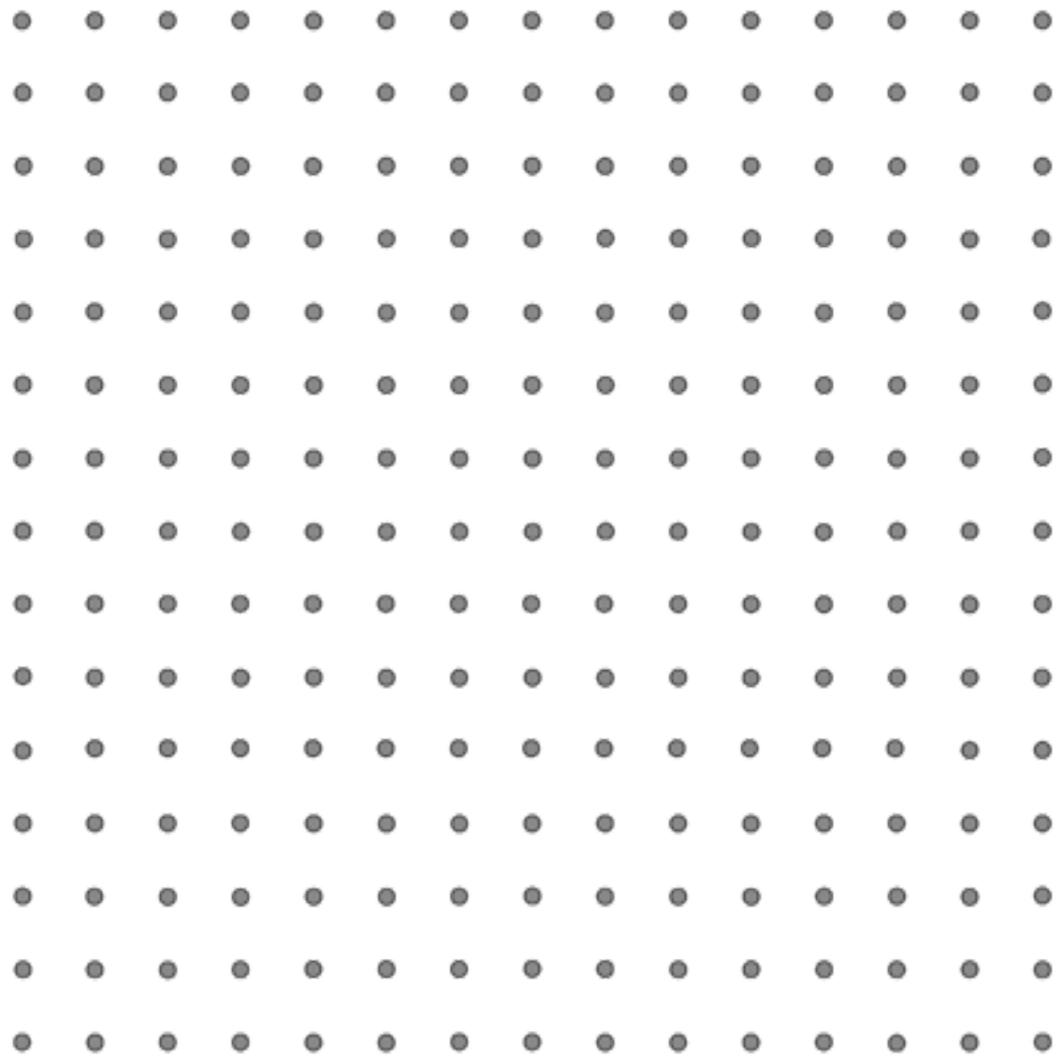


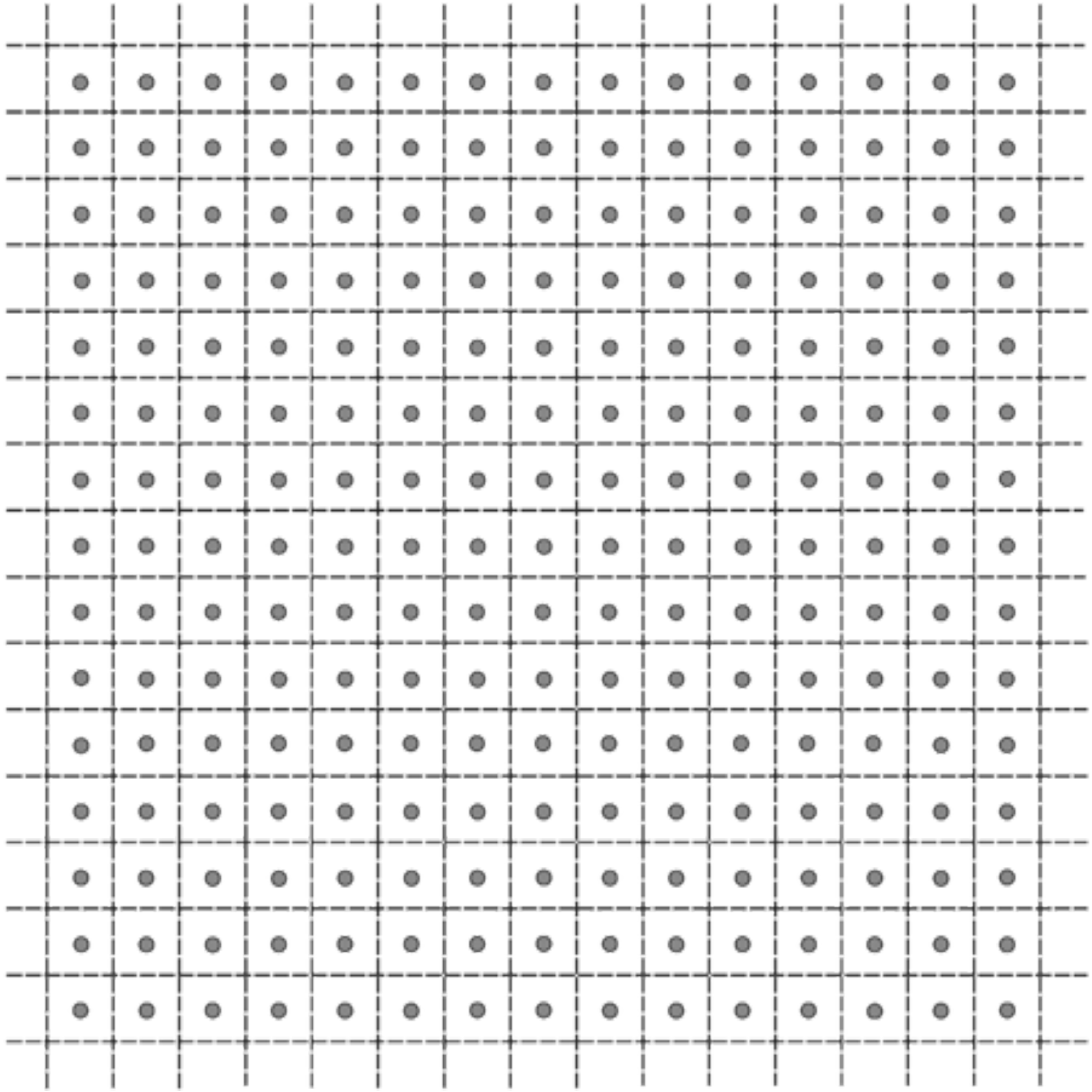
Isolines

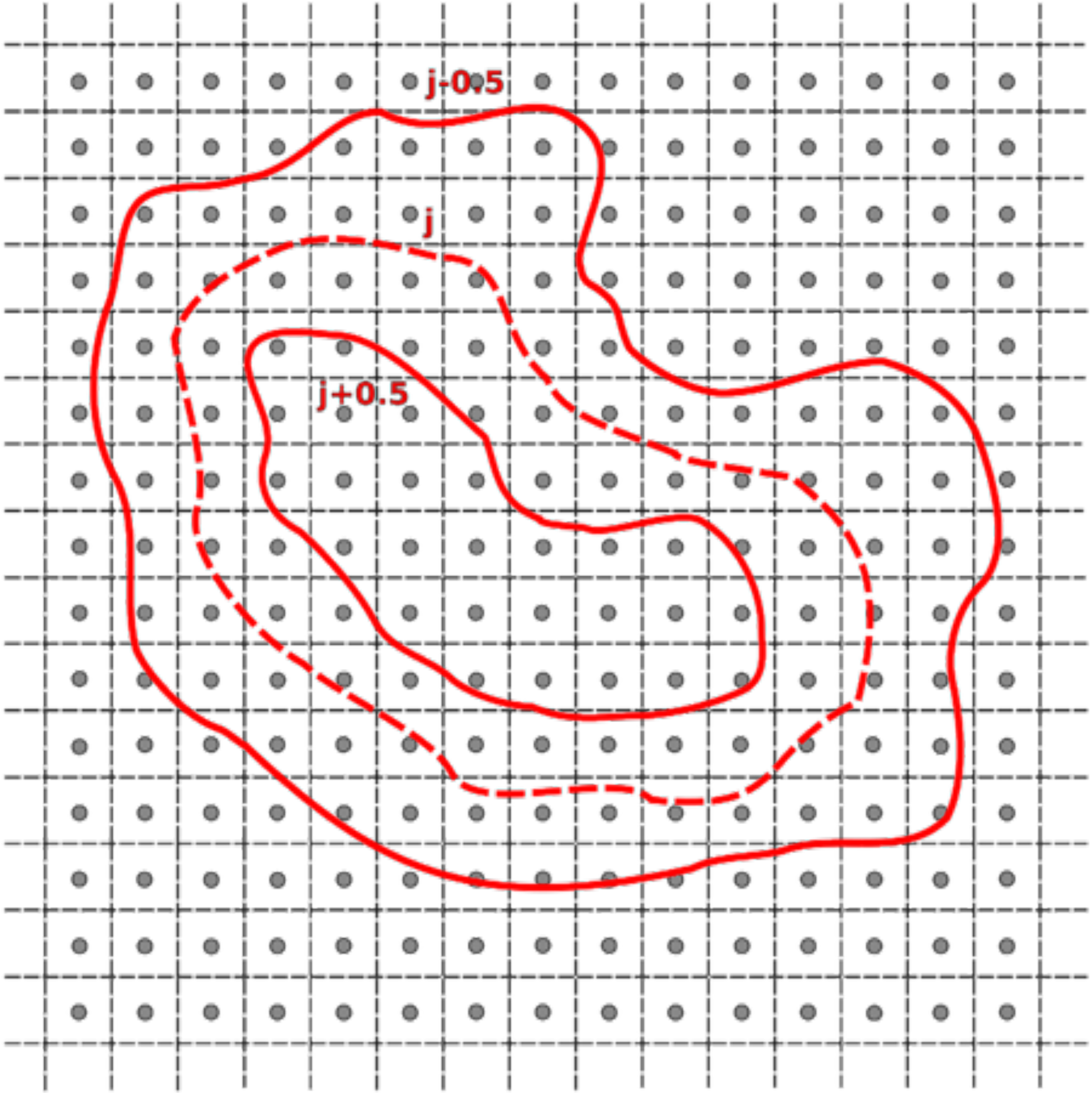
- Pixel by pixel contouring
- Straightforward approach: scanning all pixels for equivalence with isovalue
- Input
  - $f : (1,\ldots,x_{max}) \times (1,\ldots,y_{max}) \rightarrow \mathbf{R}$
  - Isovalues $I_1,\ldots, I_n$ and isocolors $c_1,\ldots,c_n$
- Algorithm

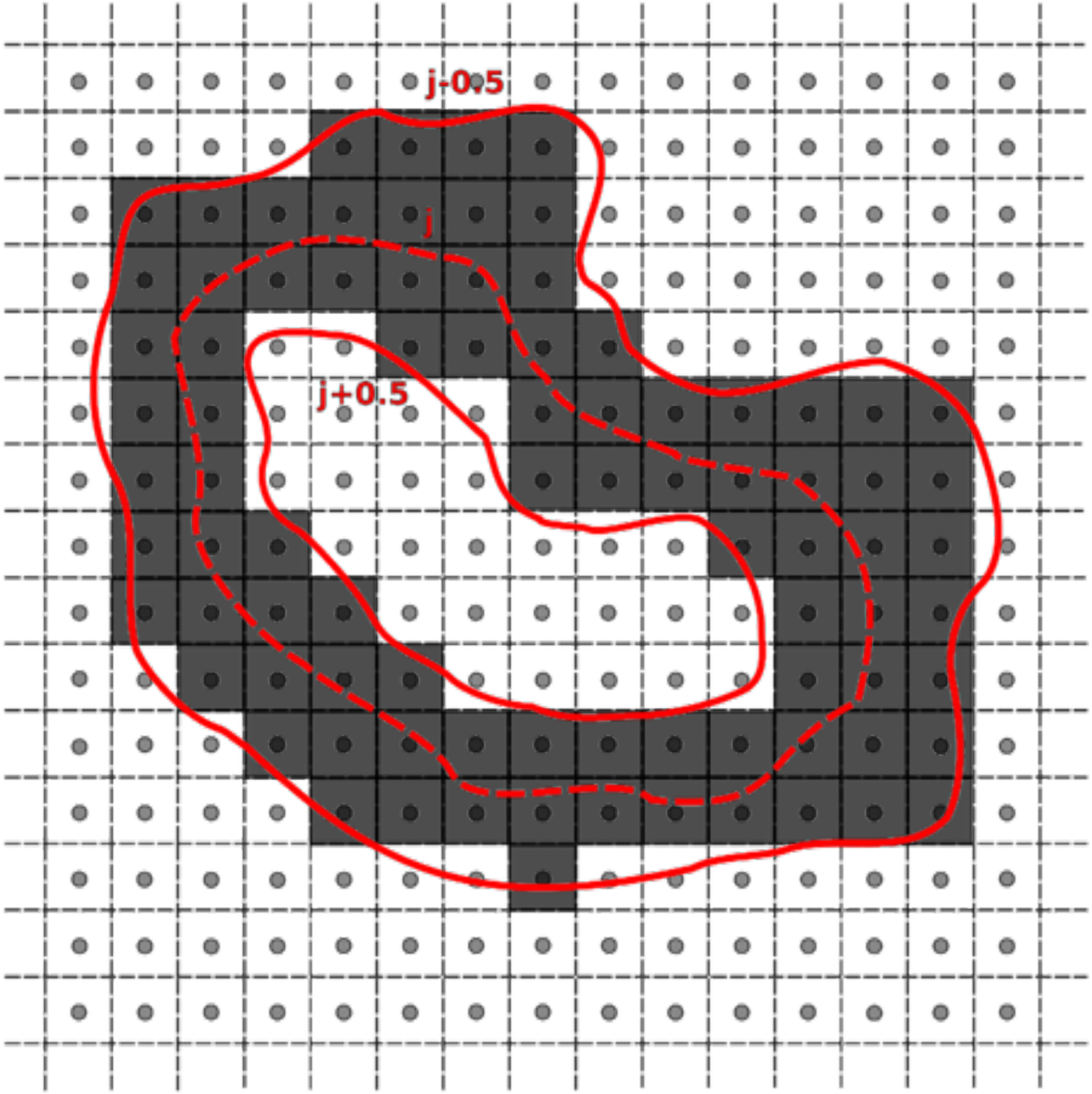
```
for all (x,y) ∈ (1,...,x_max) x (1,...,y_max) do
    for all k∈ { 1,...,n} do
        if |f(x,y)-I_k| < ε then
            draw(x,y,c_k)
```

- Problem: Isoline can be missed if the gradient of *f()* is too large (despite range ε)

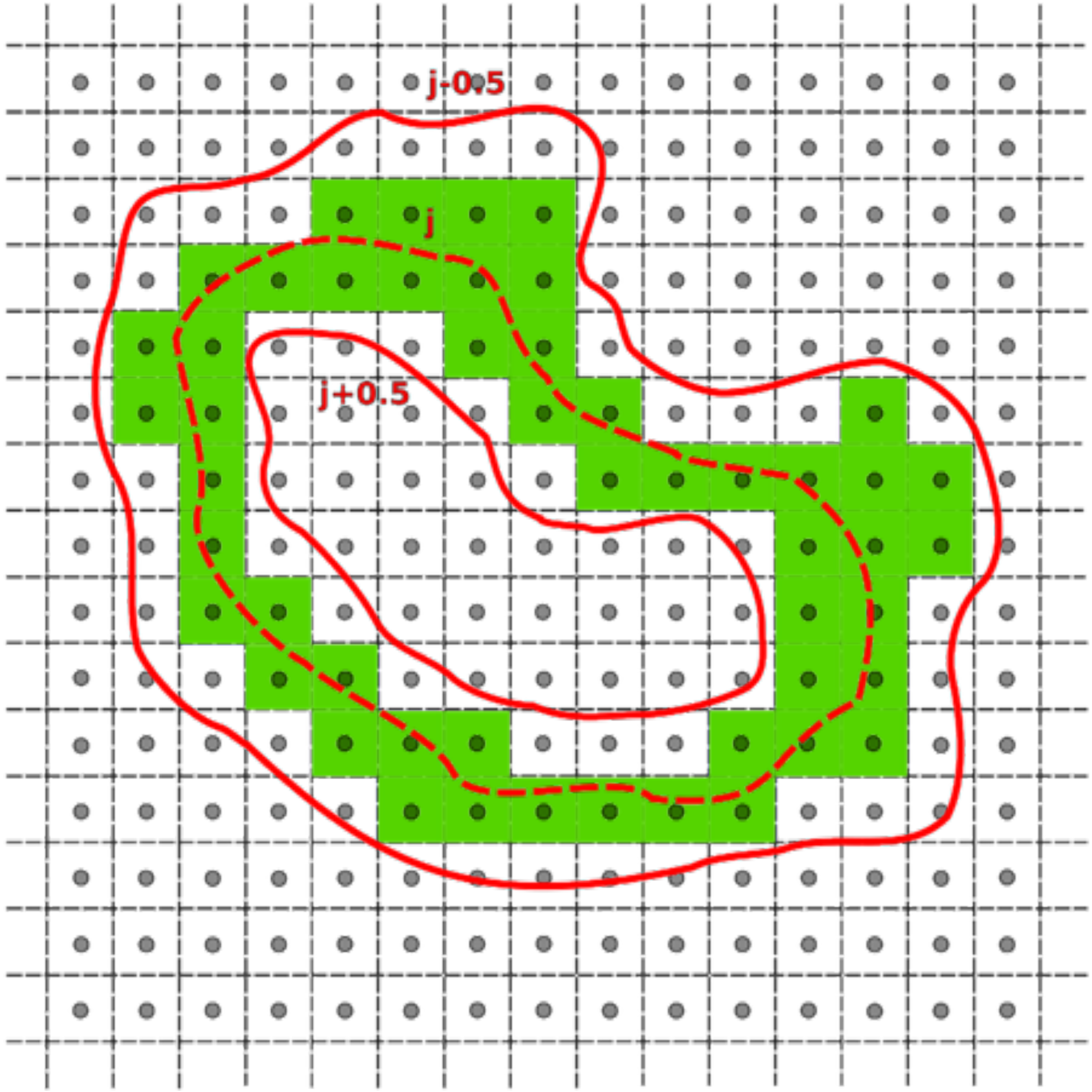


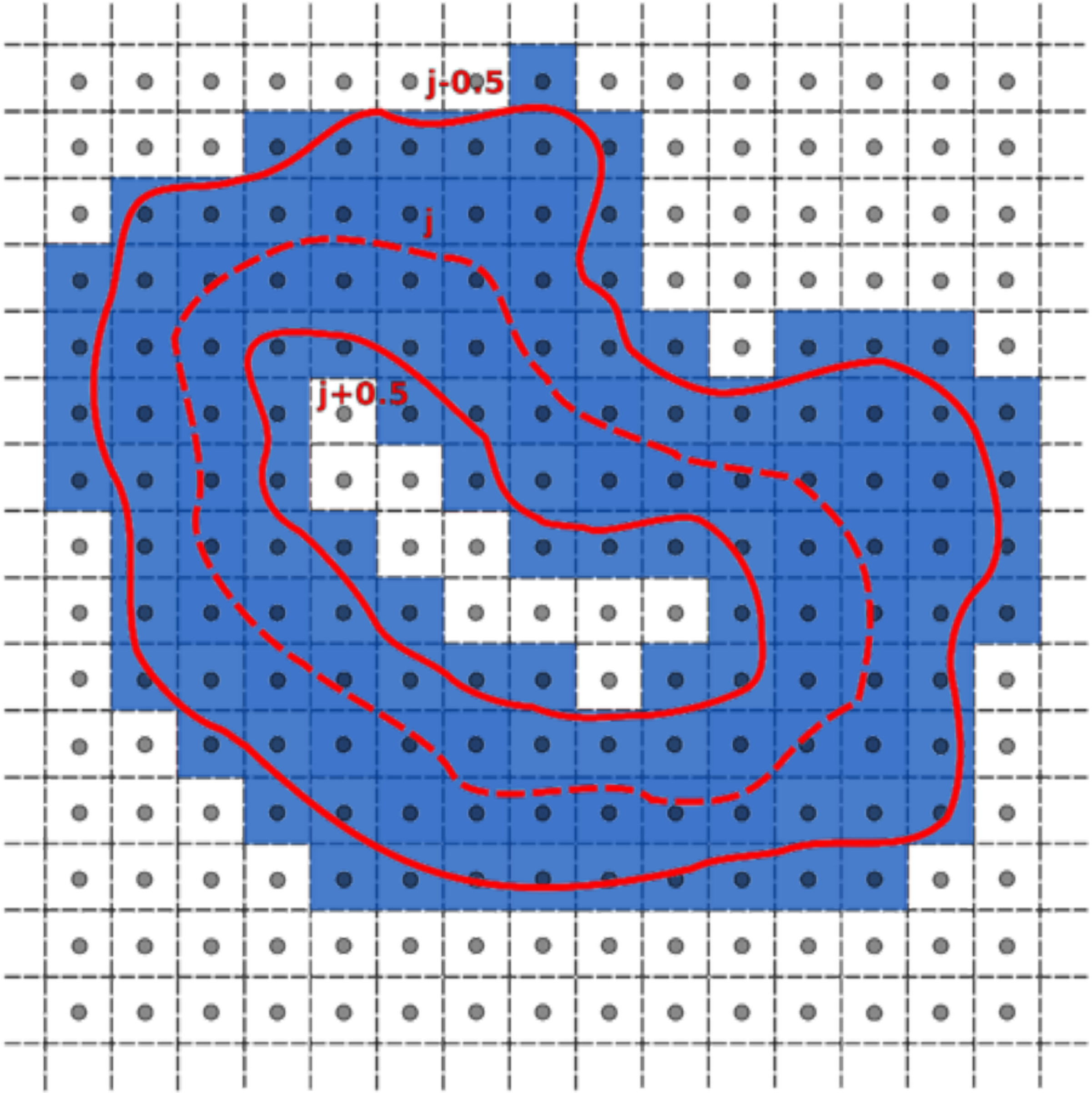


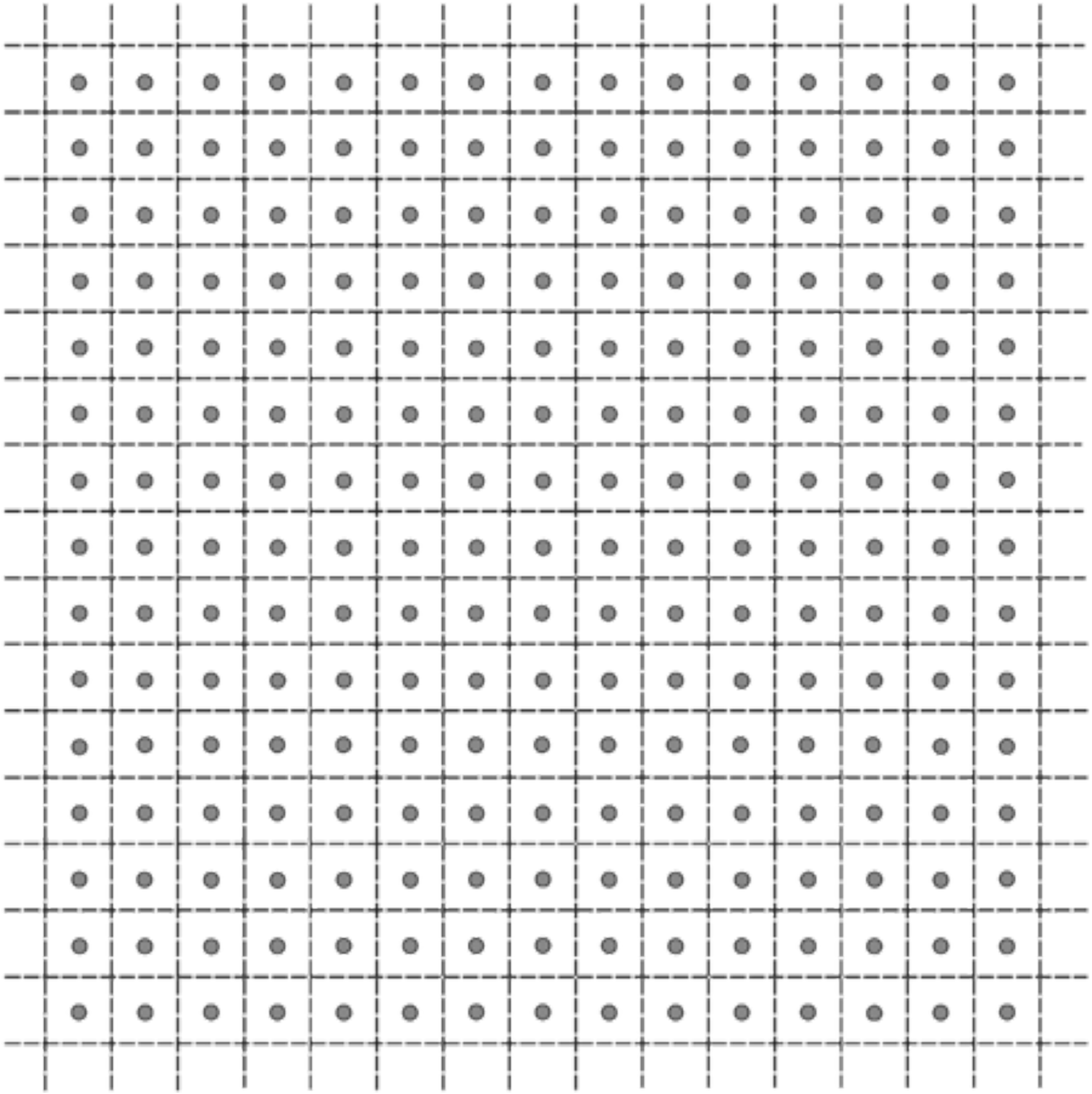

j-0.5
j
j+0.5

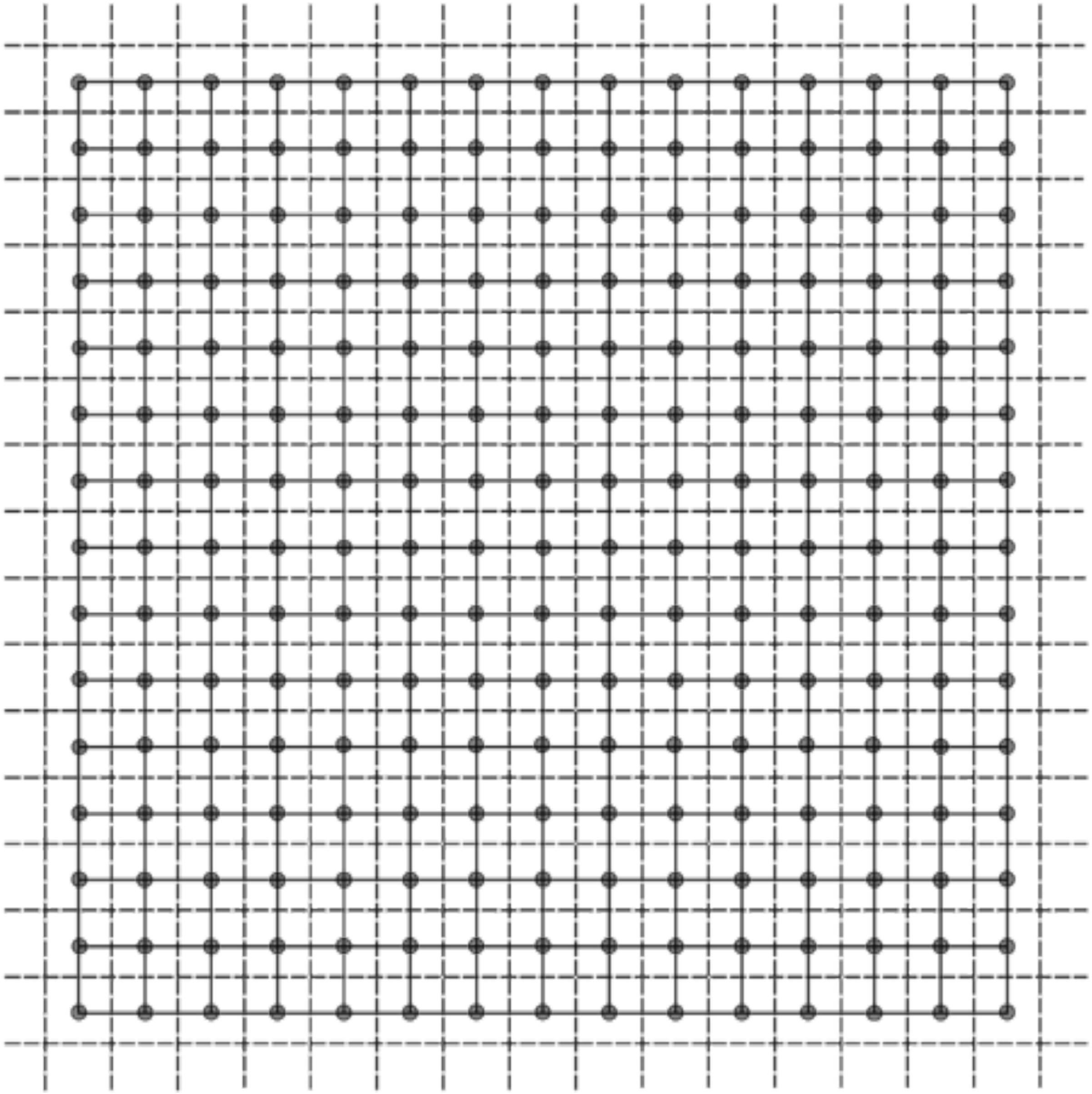


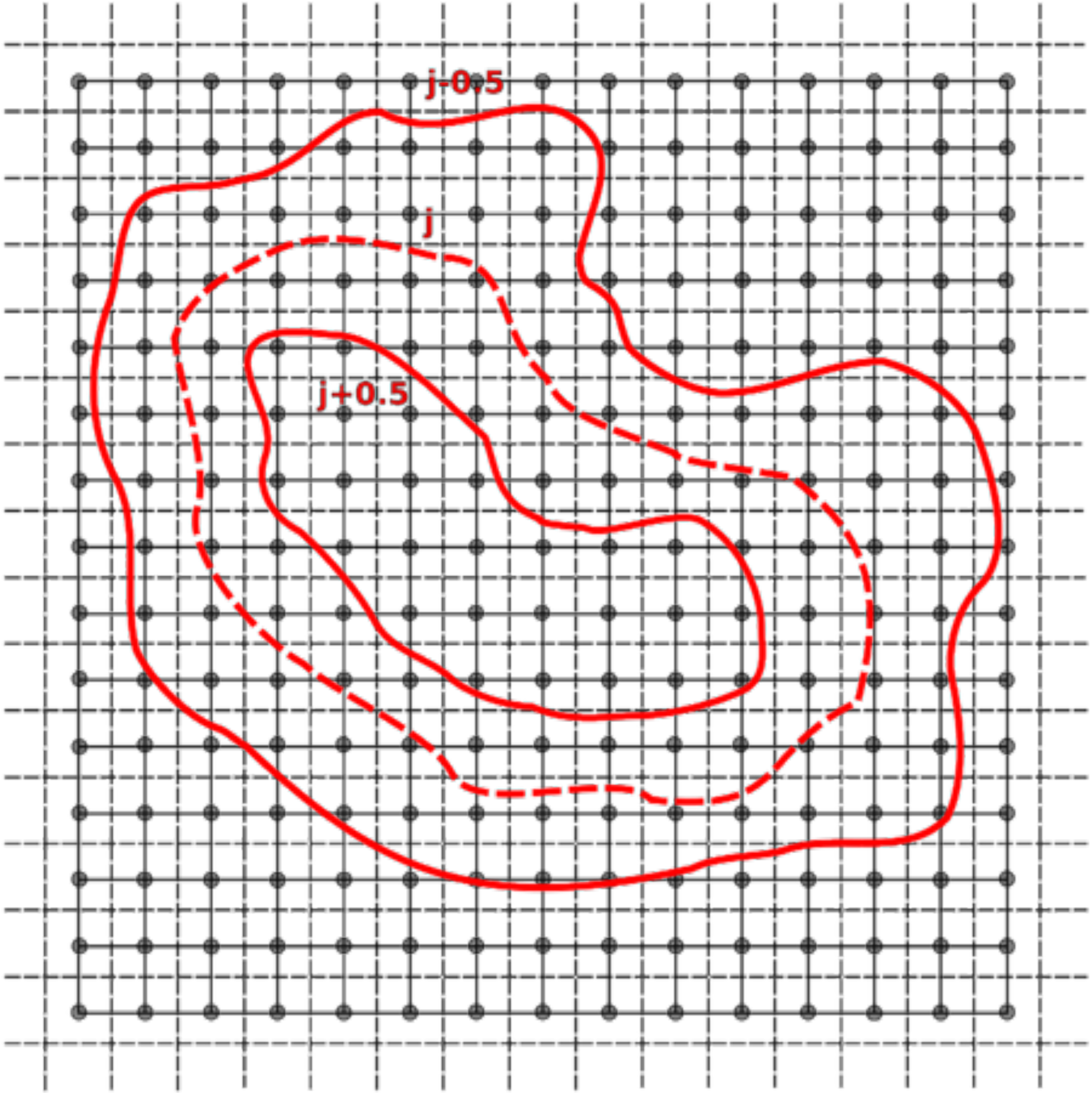
j-0.5
j
j+0.5

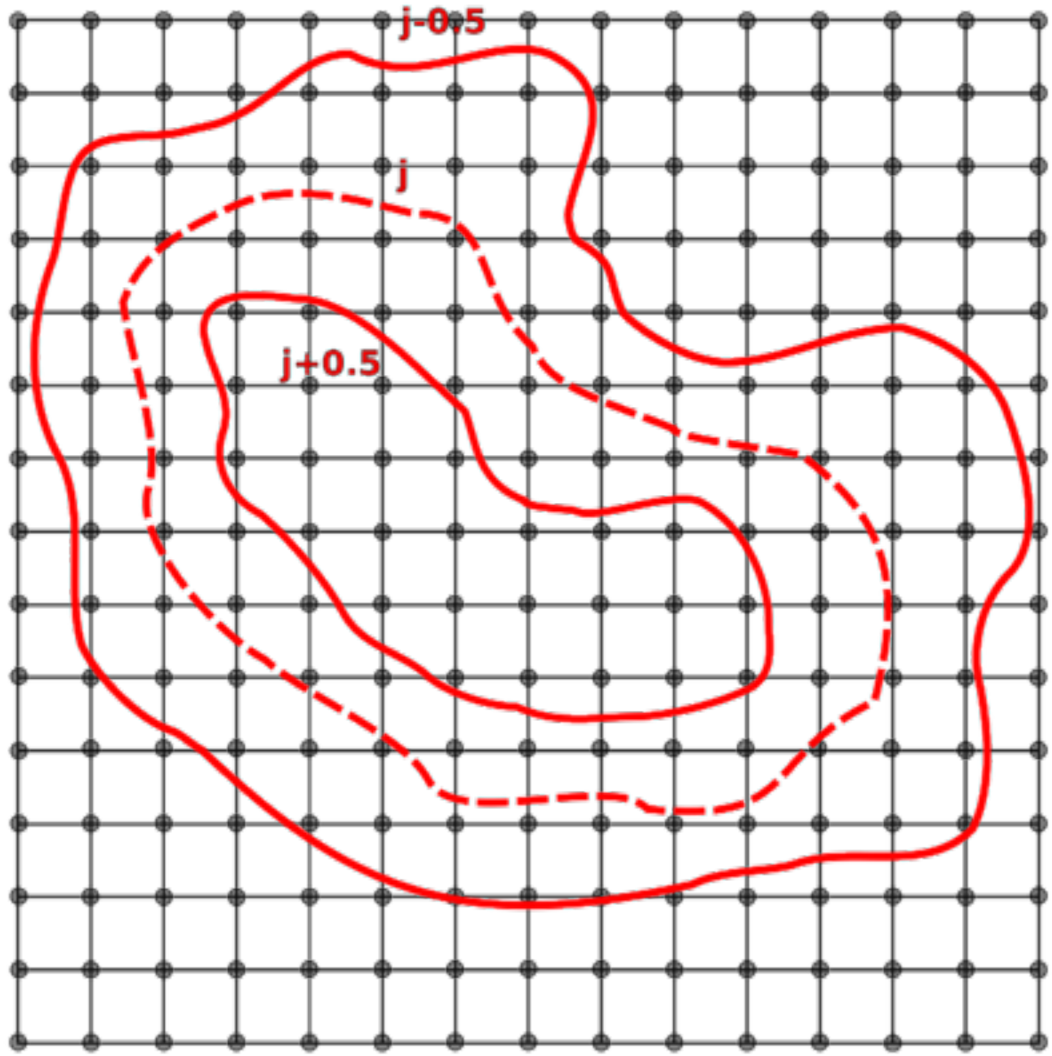

j-0.5
j
j+0.5


j-0.5
j
j+0.5

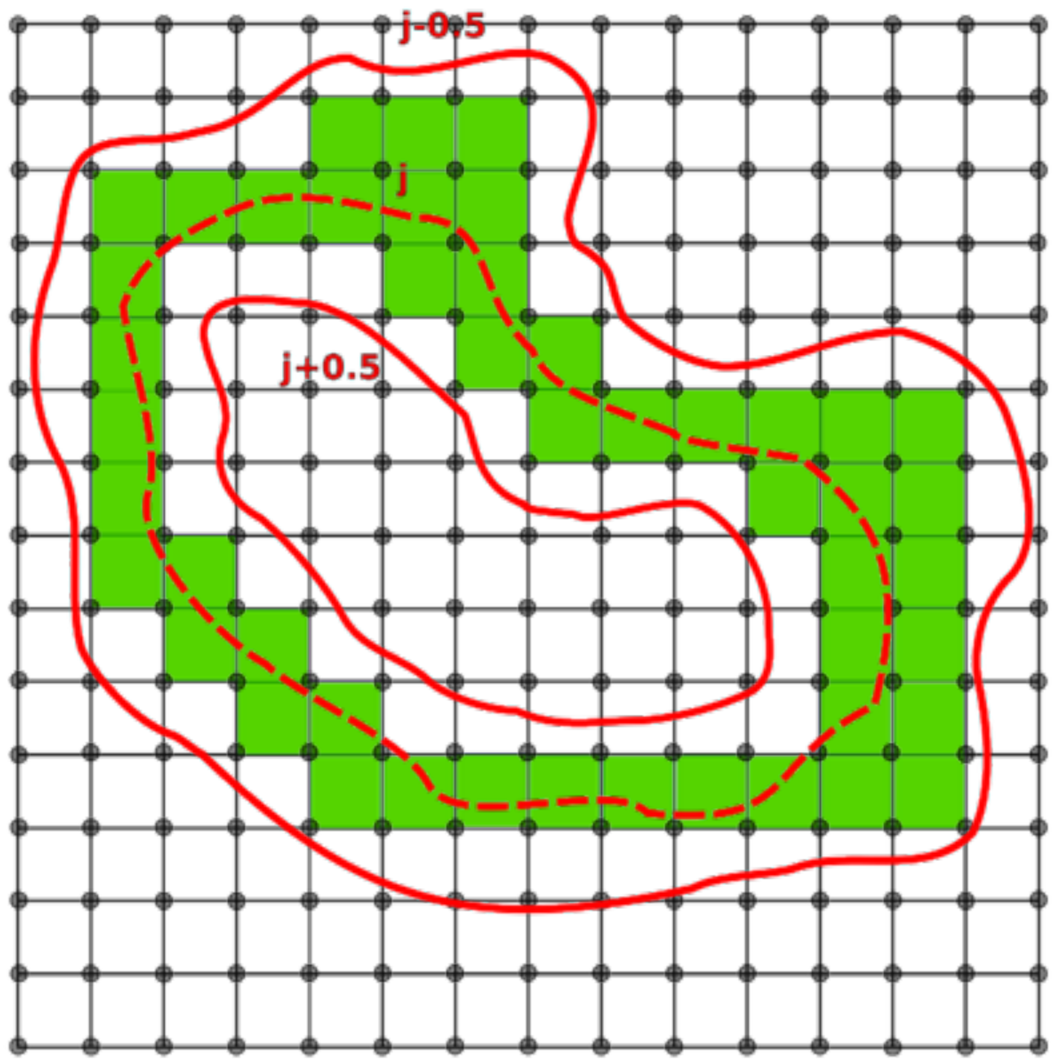





j-0.5
j
j+0.5



j-0.5
j
j+0.5


j-0.5
j
j+0.5

Overview

- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

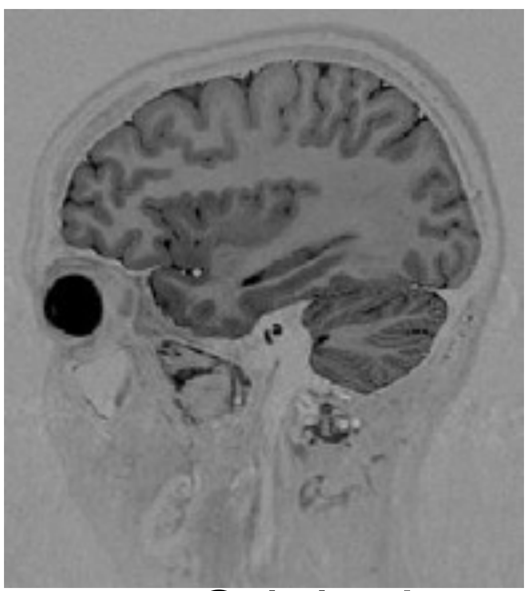
Color Coding

- Easy to apply to 1D and 2D scalar fields
  - Map color to each pixel on 1D or 2D image

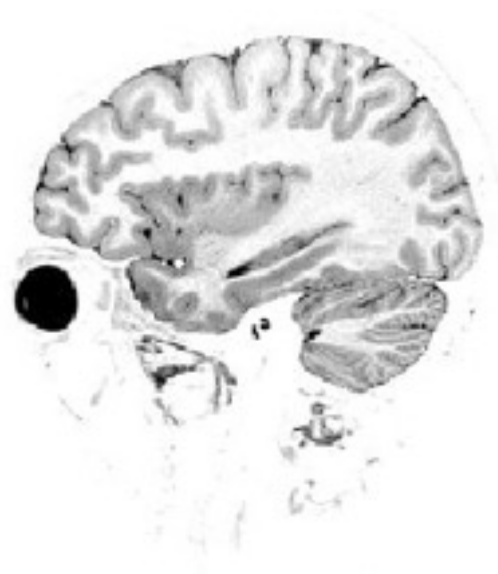


Color Coding

- Example
  - Special color table to visualize the brain tissue
  - Special color table to visualize the bone structure



Original



Brain

Tissue

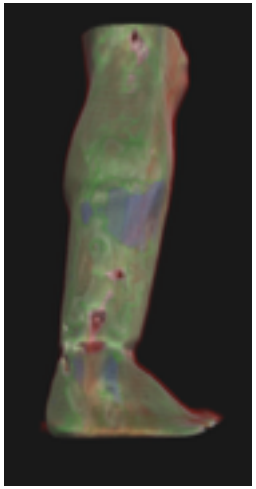
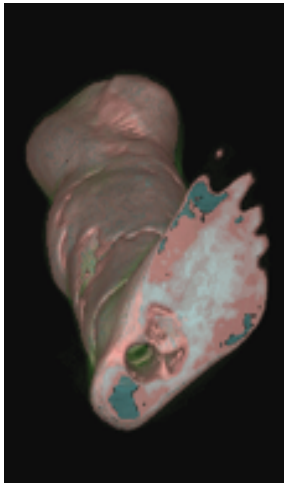
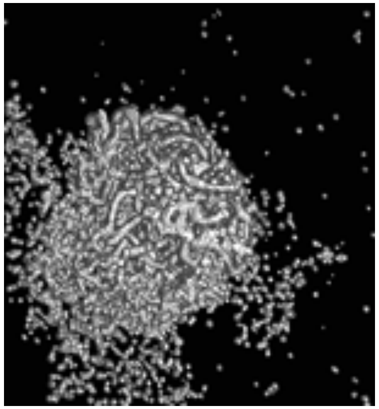
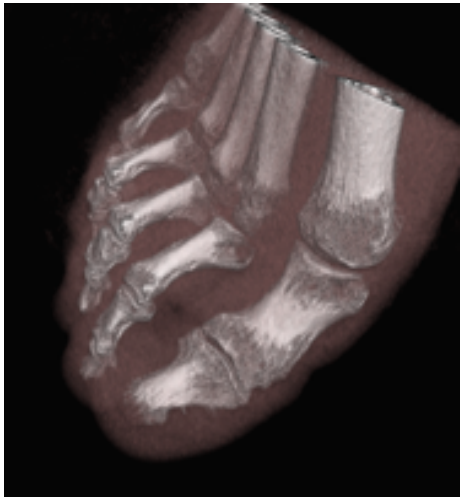
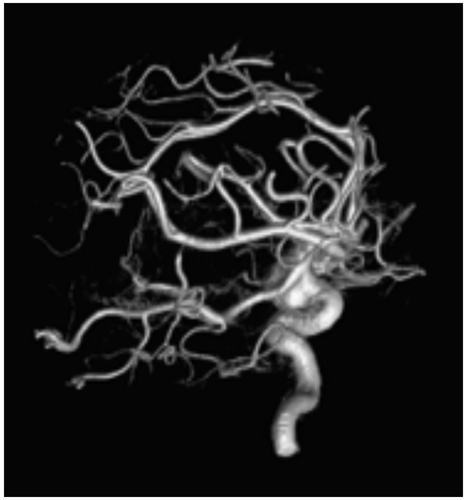
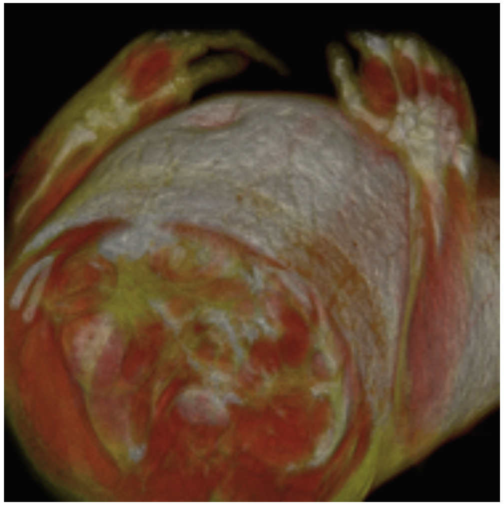
Overview

- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

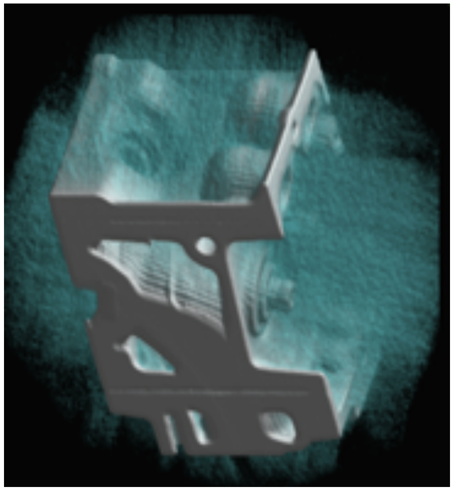
Volume Visualization

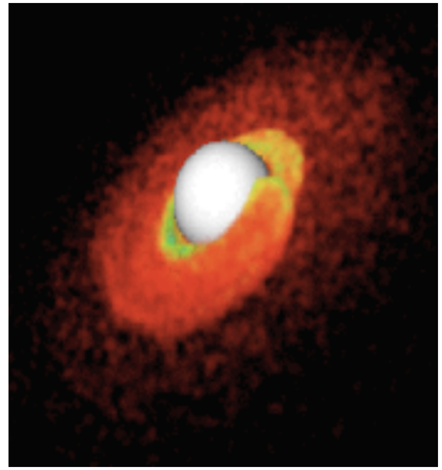
$$\Omega \in R^3 \rightarrow R$$

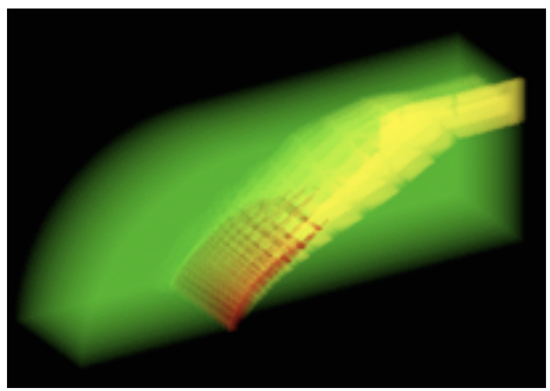
- Scalar volume data
- Medical Applications: CT, MRI, confocal microscopy, ultrasound, etc.

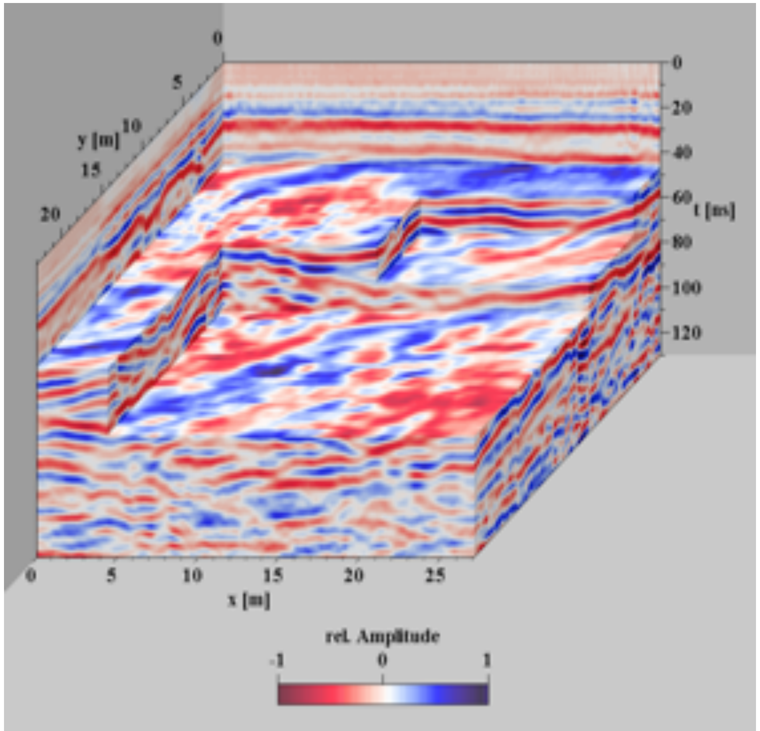
Volume Visualization

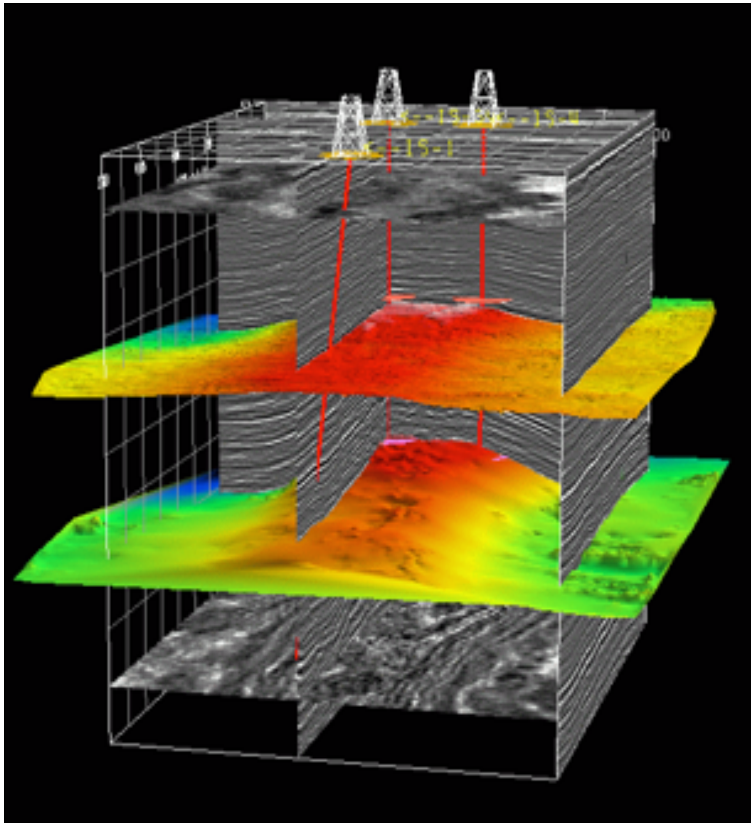






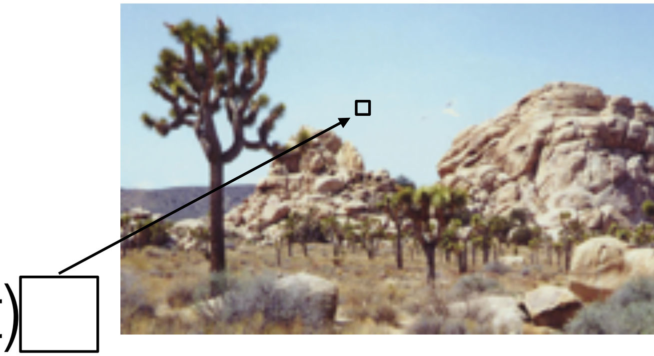
Volume Visualization



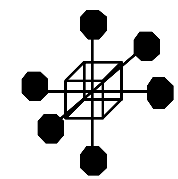


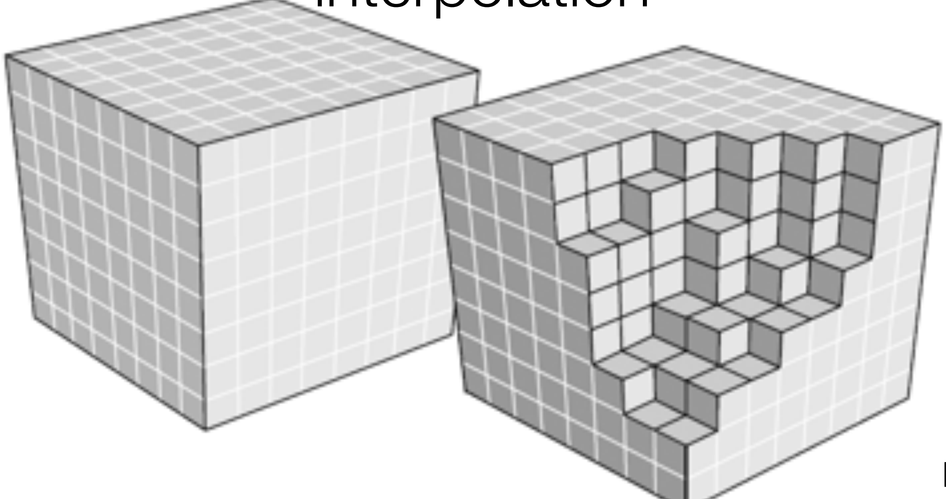
Volume Visualization

- Representation of scalar 3D data set $\Omega \in R^3 \rightarrow R$
- Analogy: pixel (picture element)

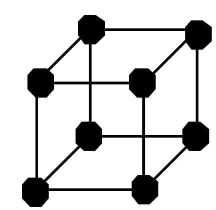


- Voxel (volume element), with two interpretations:
  - Values between grid points are resampled by interpolation



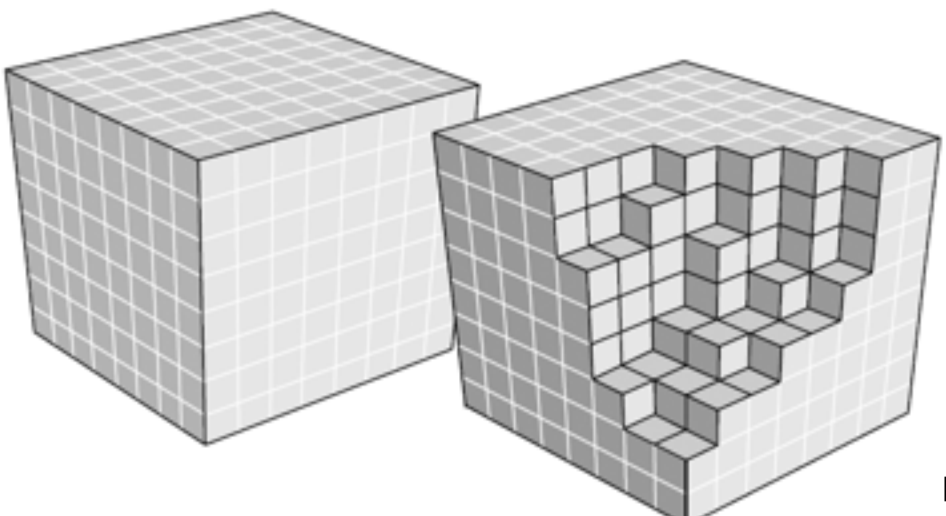


- Collection of voxels
- Uniform grid



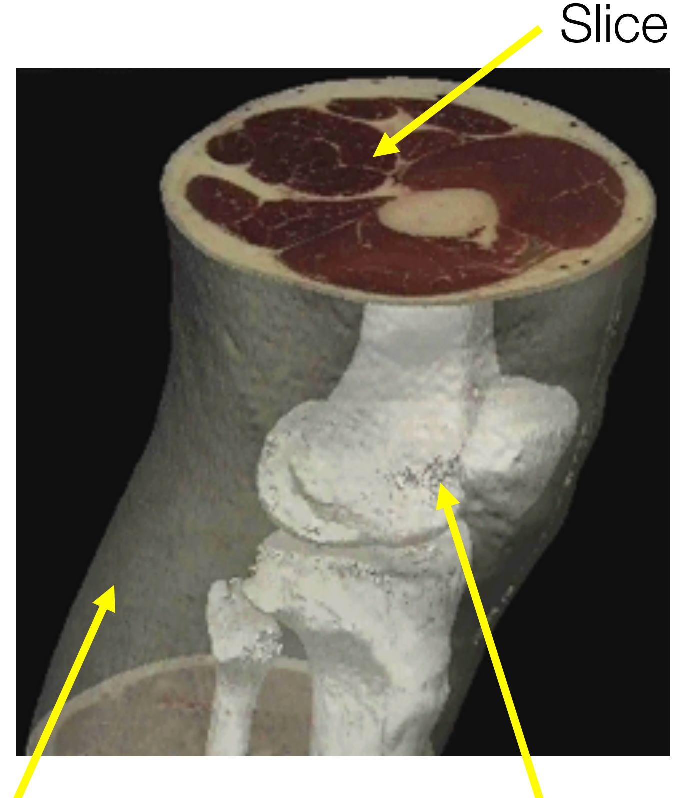
Volume Visualization

- Challenges
  - Essential information in the interior
  - Occlusion?
  - Often data sets cannot be described by geometric representation
    (fire, clouds, gaseous phenomena)

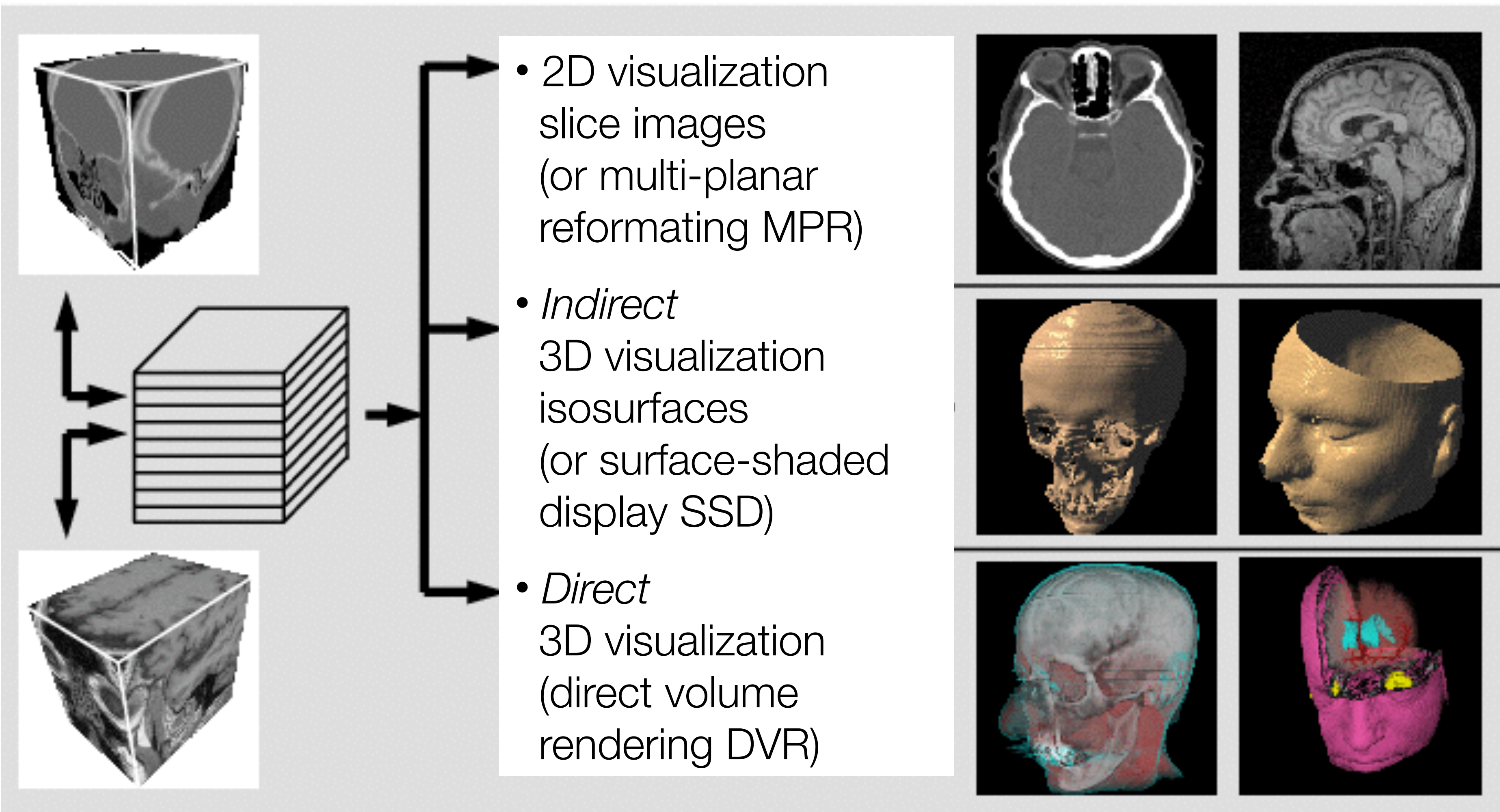


Volume Visualization

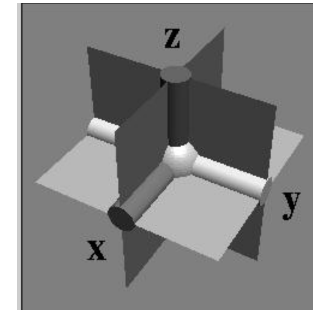
- Slicing:
  Display the volume data, mapped to colors, on a slice plane
- Isosurfacing:
  Generate opaque/semi-opaque surfaces
- Transparency effects:
  Volume material attenuates reflected or emitted light



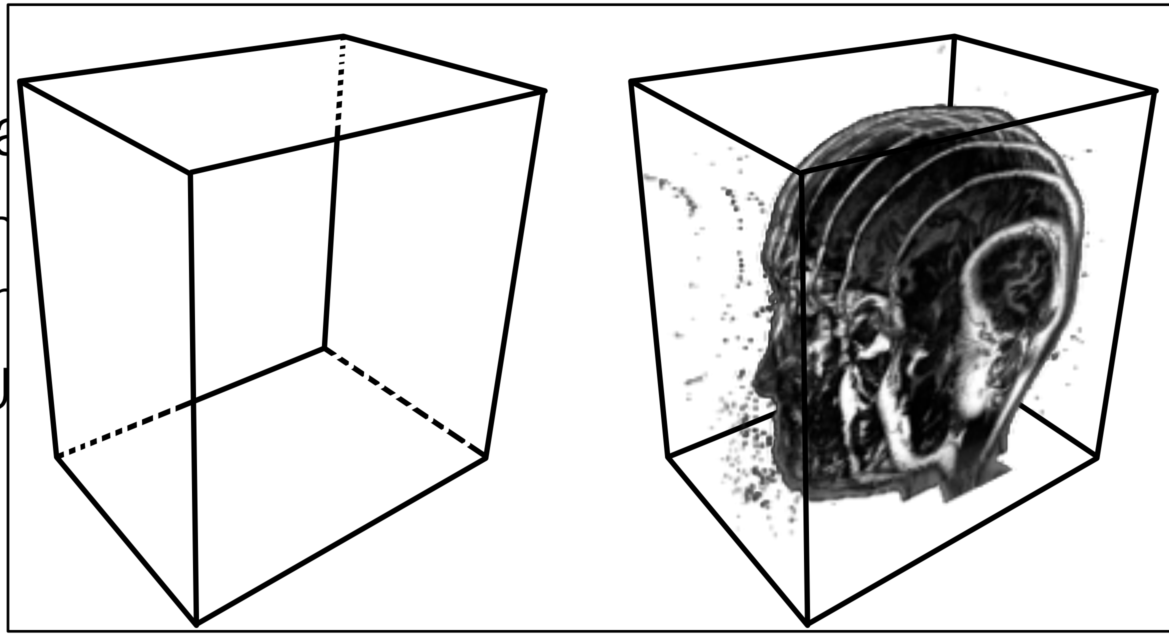
Volume Visualization

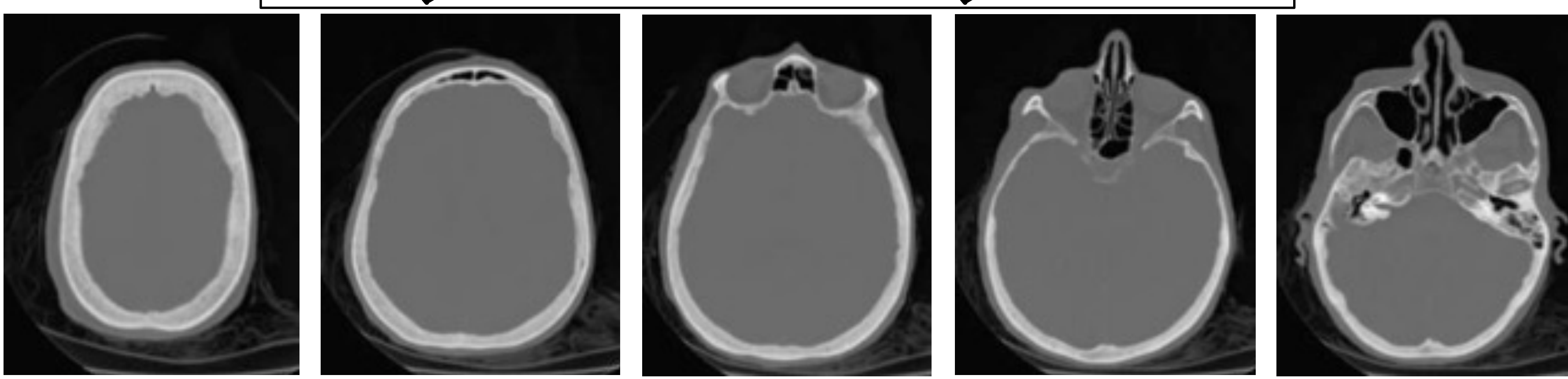


Volume Visualization



- 2D a…
  - In… …dicular to th…
  - U…



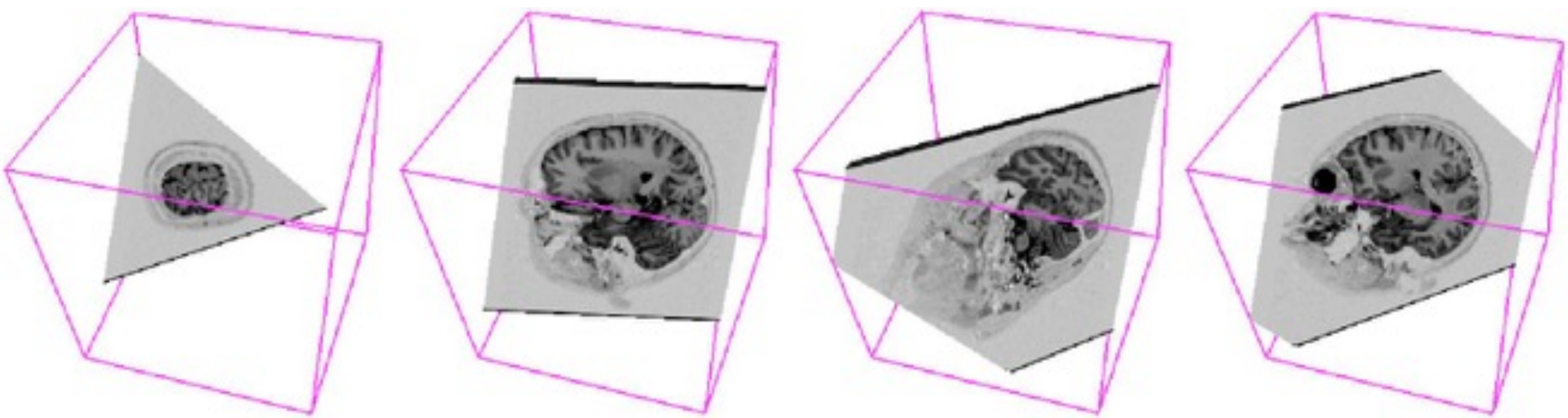


Slice 20 30 40 50 60

CT data set

Volume Visualization

- Alternative: Oblique slicing (MPR multiplanar reformating)
  - Resample the data on arbitrarily oriented slices
    - Resampling on CPU or on graphics hardware (trilinear interpolation)
    - Exploit 3D texture mapping functionality
      - Store volume in 3D texture
      - Compute sectional polygon (clip plane with volume bounding box)
      - Render textured polygon



Overview

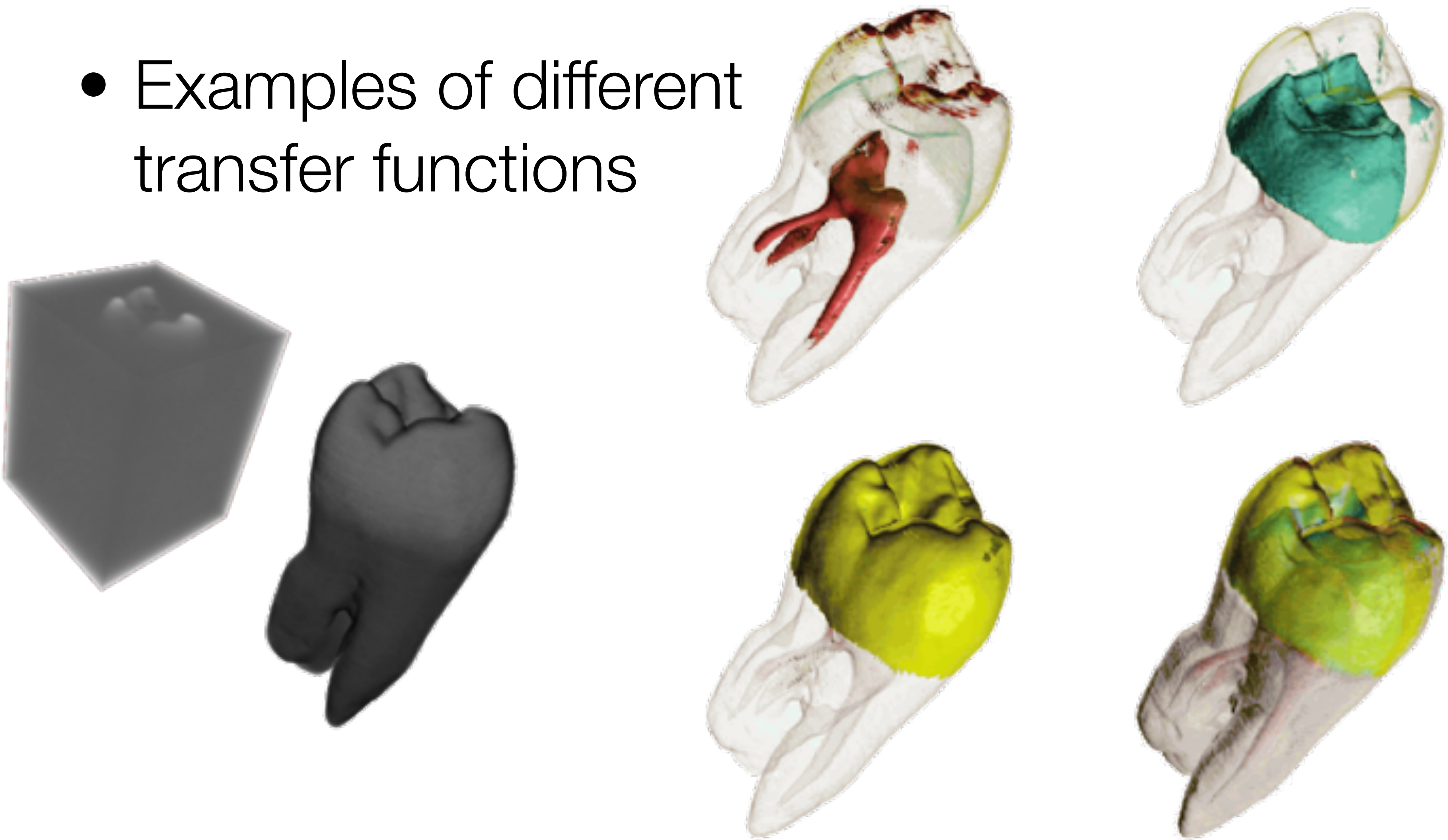
- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Classification

- Goals and issues:
  - Empowers user to select “structures”
  - Extract important features of the data set
  - Classification is non trivial
  - Histogram can be a useful hint
  - Often interactive manipulation of transfer functions needed
- Usually needed for volume visualization
- Standard approach: Transfer function
  - Color table for volume visualization
  - Maps raw voxel value into presentable entities: color, intensity, opacity, etc.

Classification

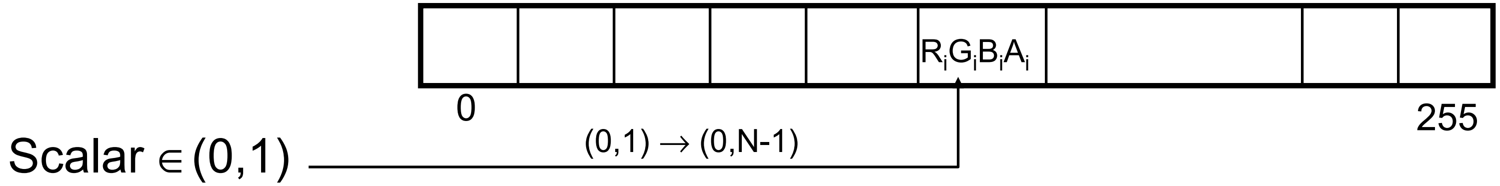
- Examples of different transfer functions



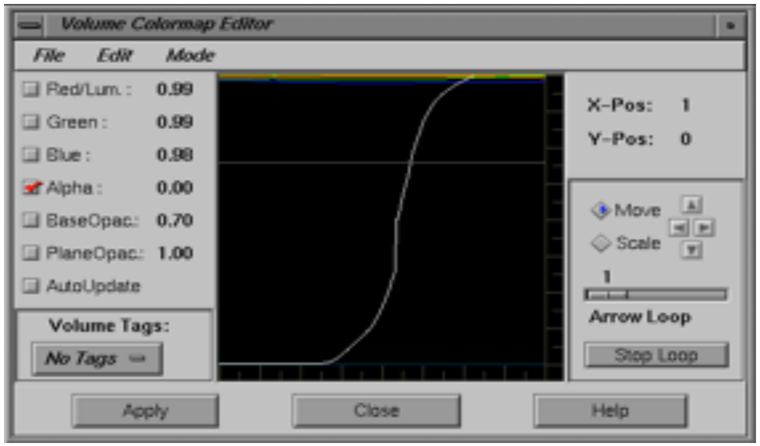
Classification

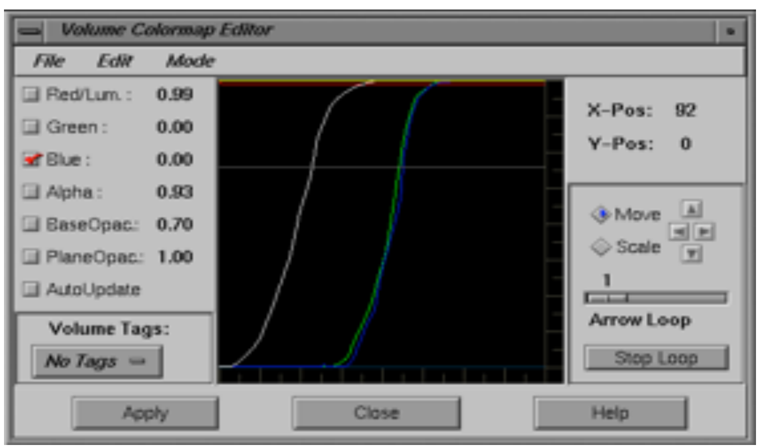
- Most widely used approach for transfer functions:
  - Assign each scalar value a different color value
  - Assignment via transfer function *T*

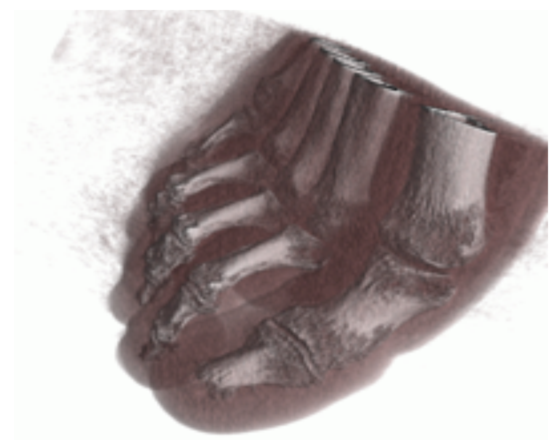
    $T : scalarvalue \rightarrow colorvalue$
  - Common choice for color representation: RGBA
  - Alpha value is very important, describes opacity
  - Code color values into a color lookup table
  - On-the-fly update of color LUT



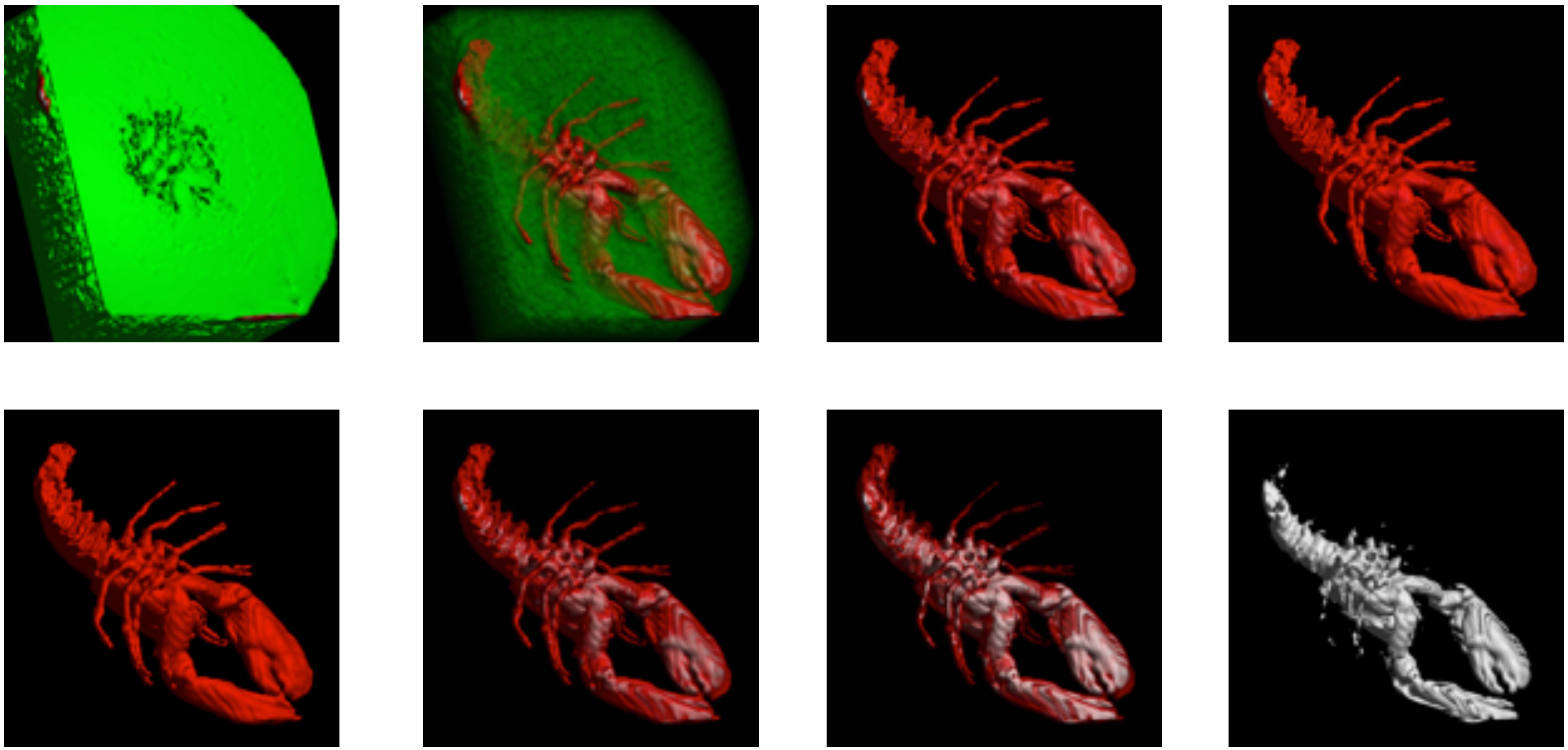
Classification





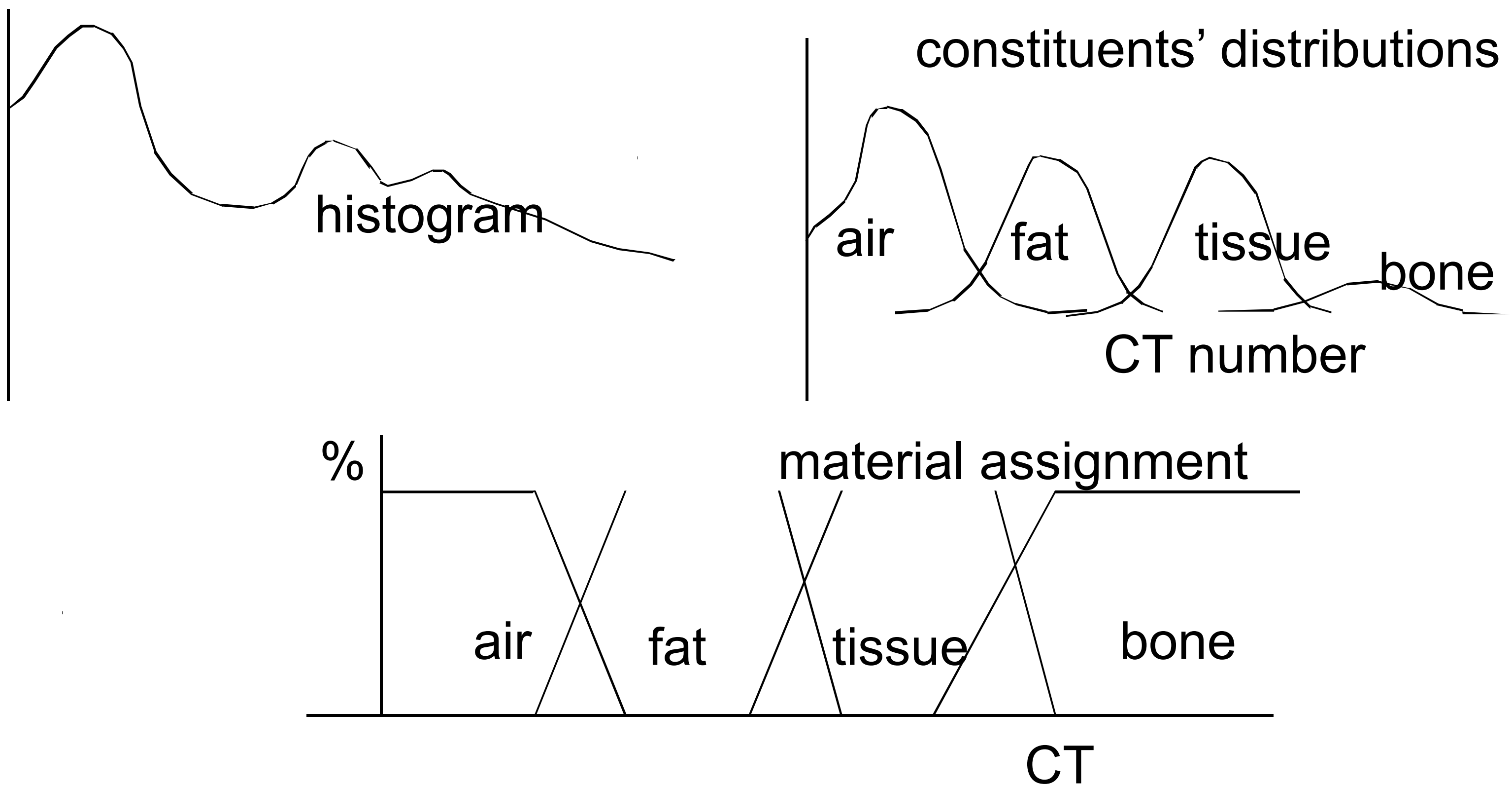


Classification



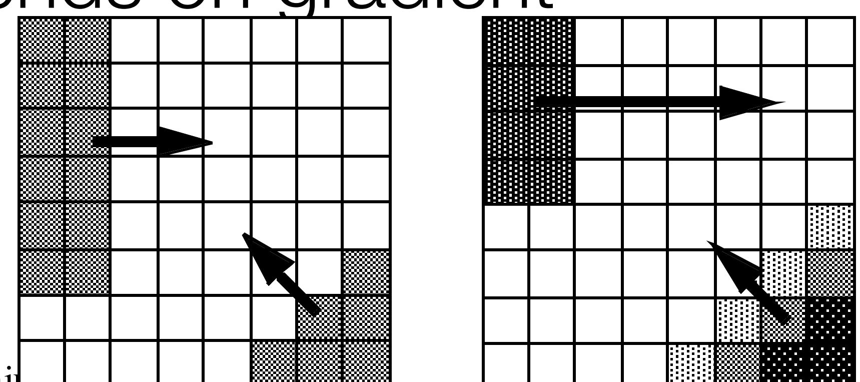
Classification

- Heuristic approach, based on measurements of many data sets



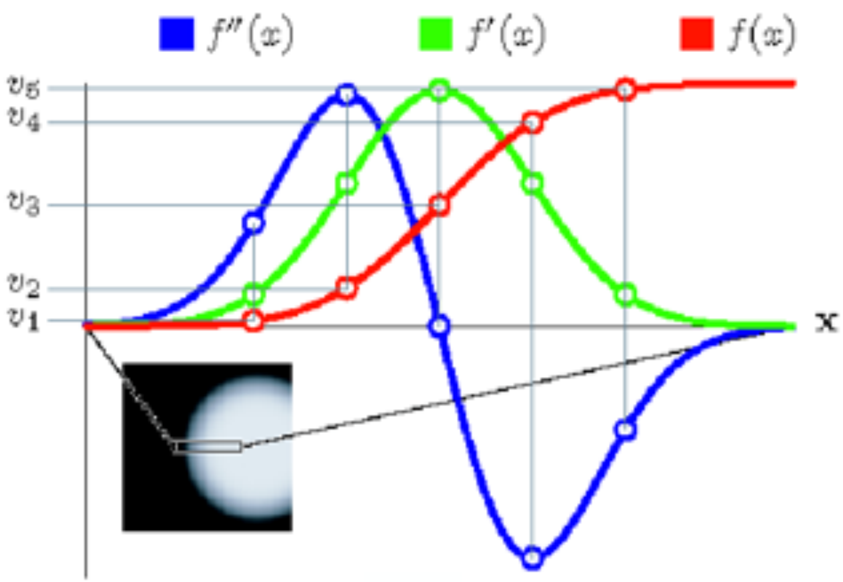
Classification

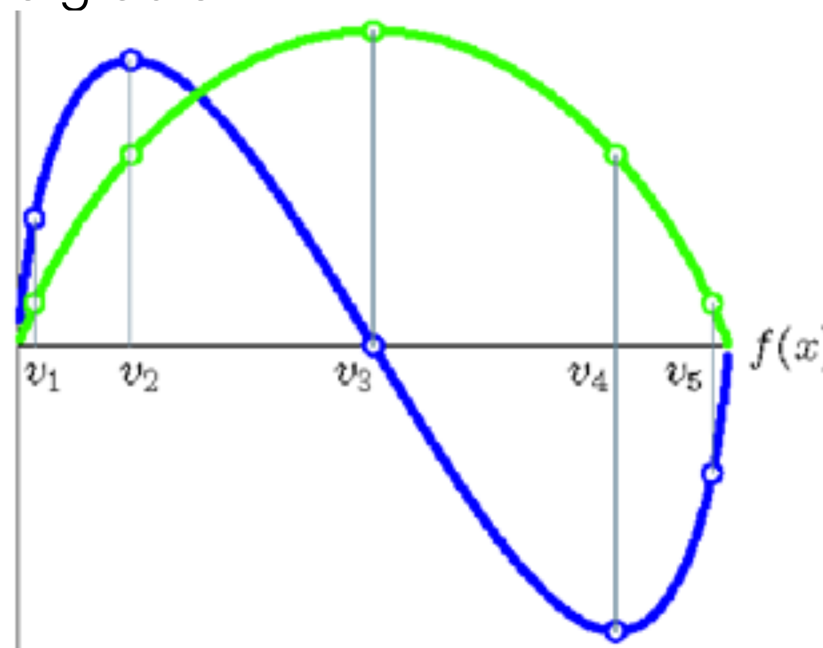
- Usually not only interested in a particular isosurface but also in regions of “change”
- Feature extraction - High value of opacity in regions of change
  - Homogeneous regions less interesting - transparent
- Surface “strength” depends on gradient
- Gradient of the scalar field is taken into account

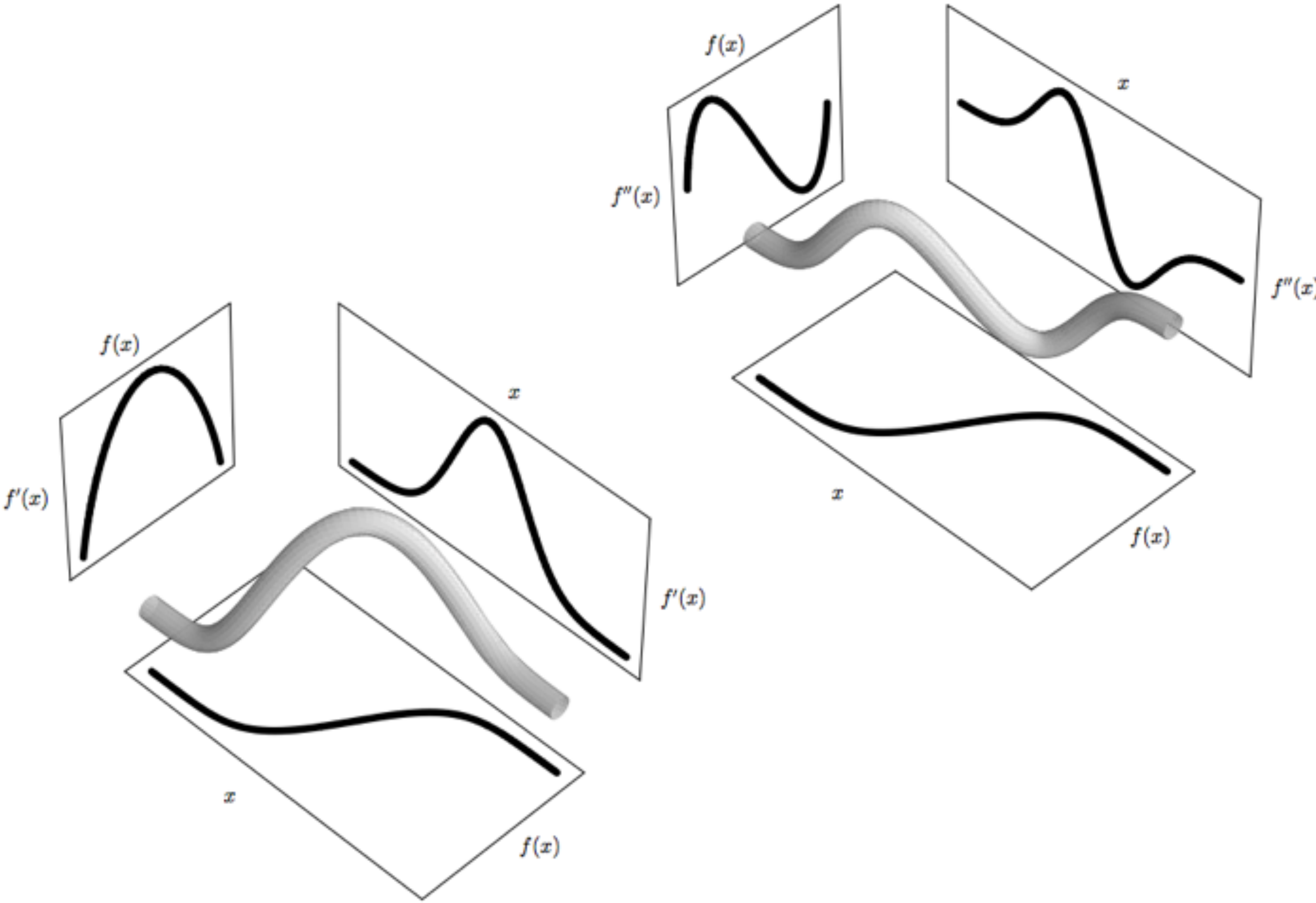


Classification

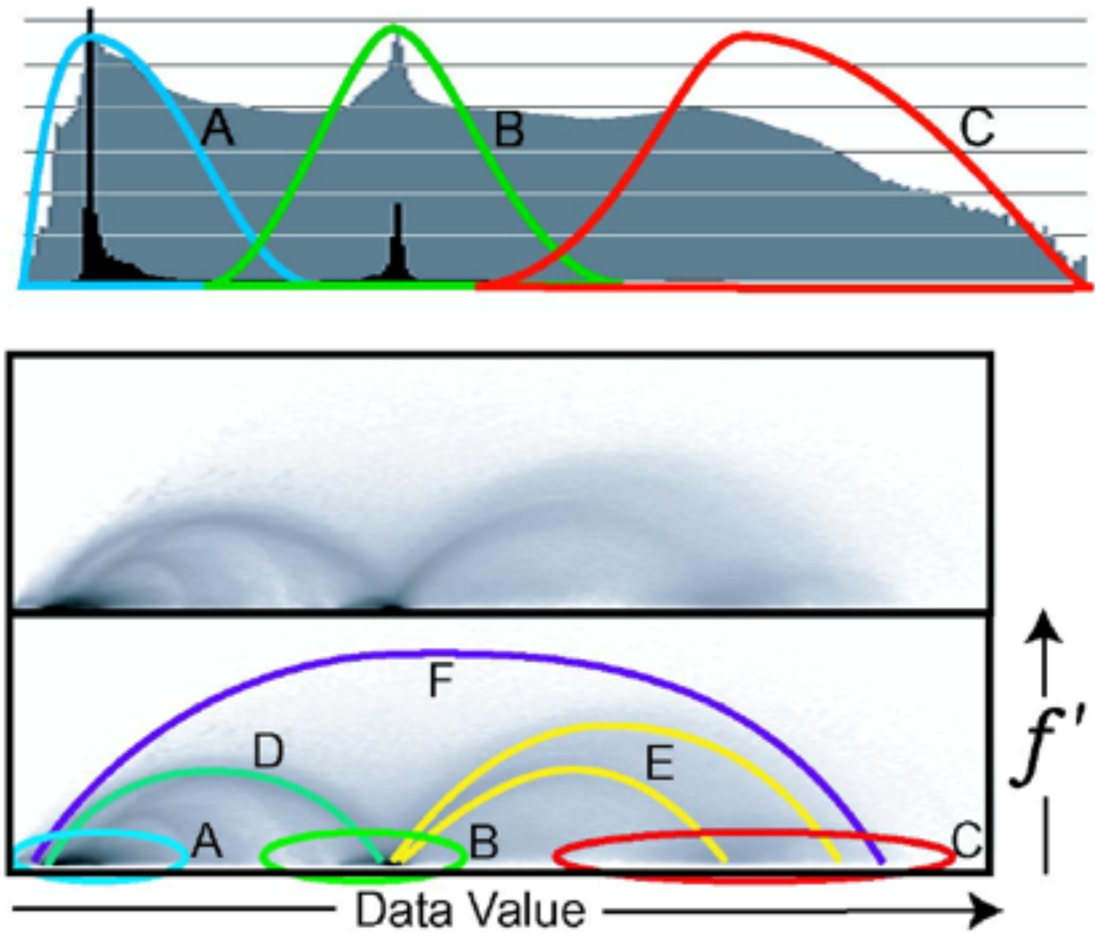
- Multidimensional transfer functions
  [Kindlmann & Durkin 98, Kniss, Kindlmann, Hansen 01]
- Problem: How to identify boundary regions/ surfaces
- Approach: 2D/3D transfer functions, depending on
  - Scalar value, magnitude of the gradient

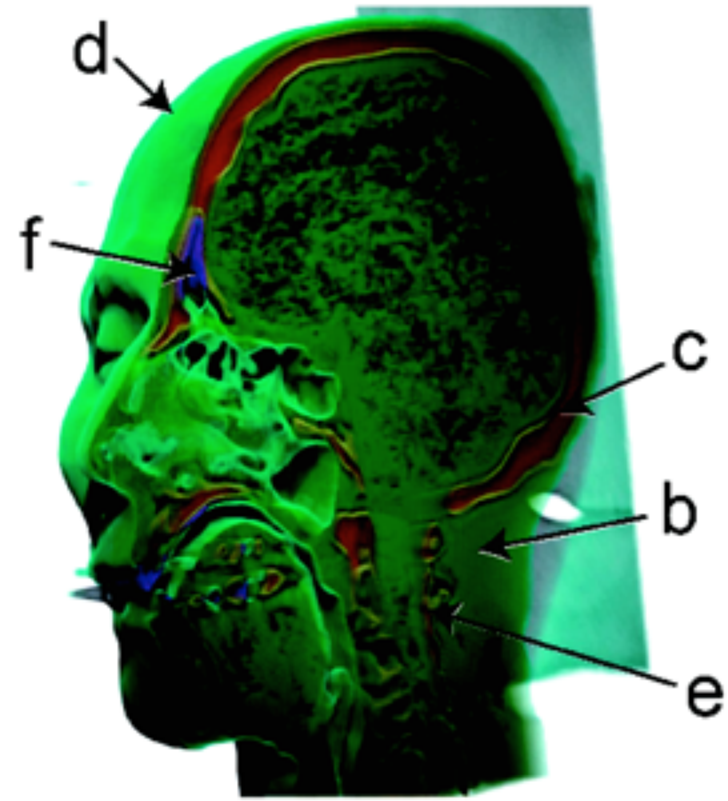





f(x)
f''(x)
x
f''(x)
x
f(x)
f(x)
f'(x)
x
f'(x)
x
f(x)

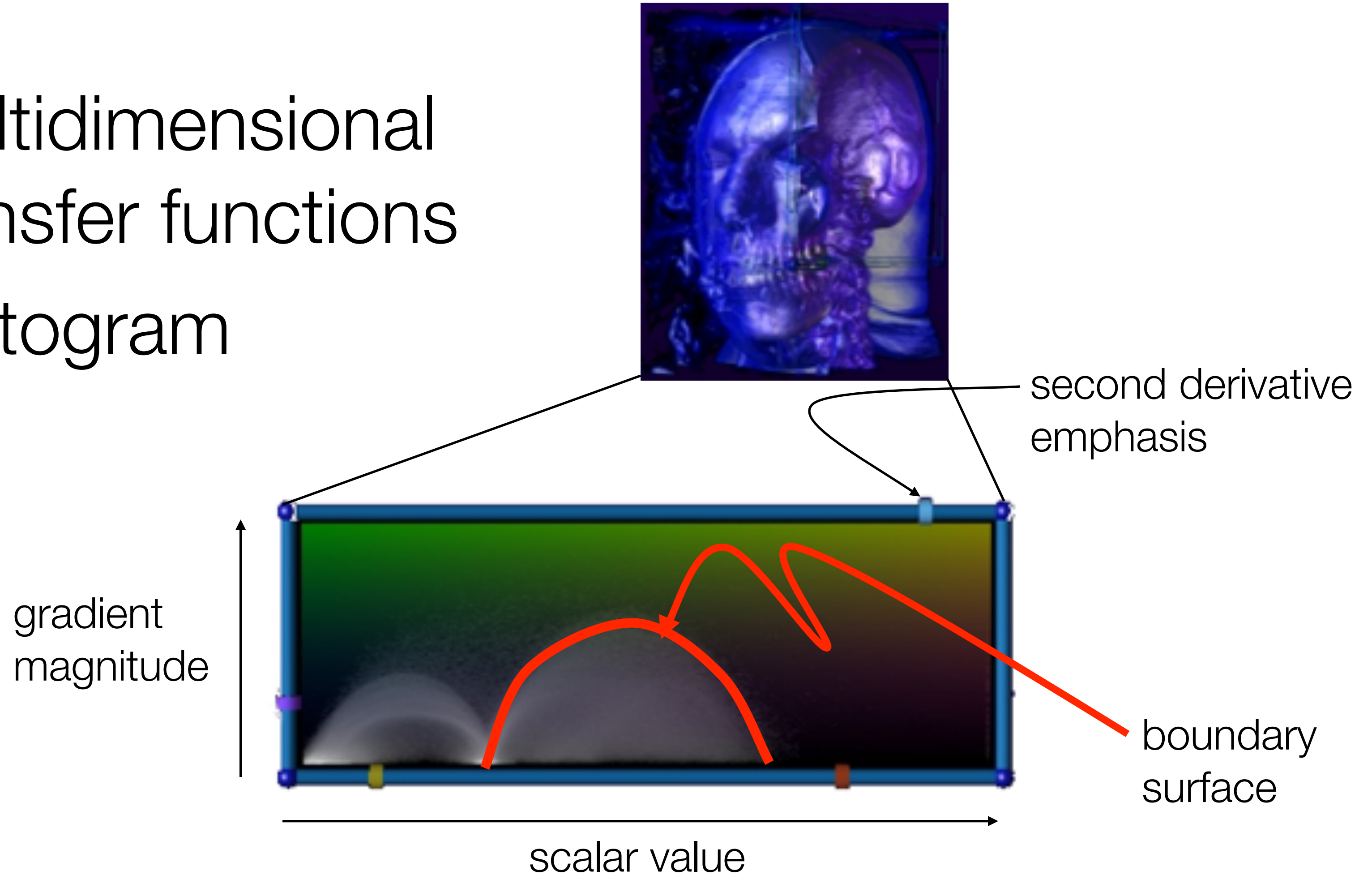
Classification





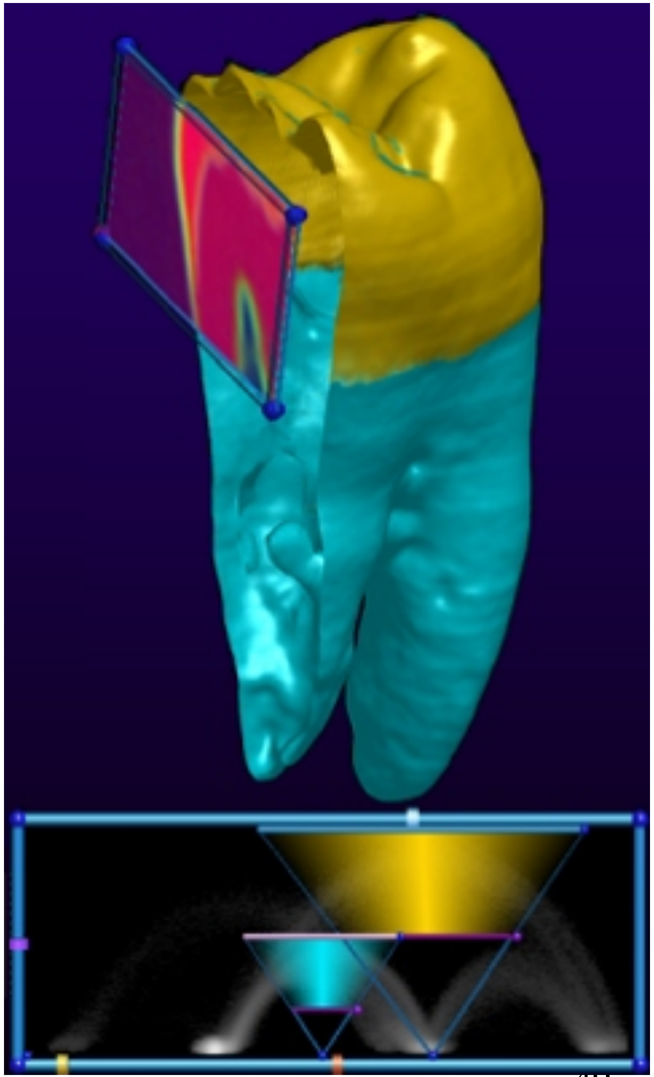
Classification

- Multidimensional transfer functions
- Histogram



Classification

- Multidimensional transfer functions
- Extraction of two boundaries
- Triangle function in histogram

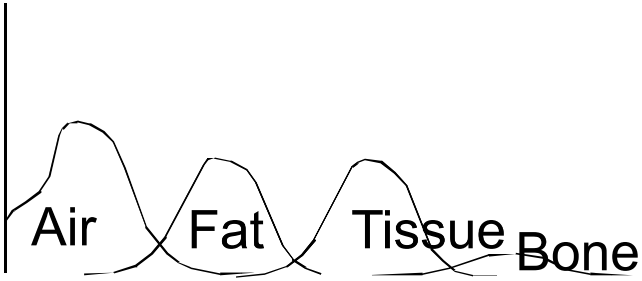


Overview

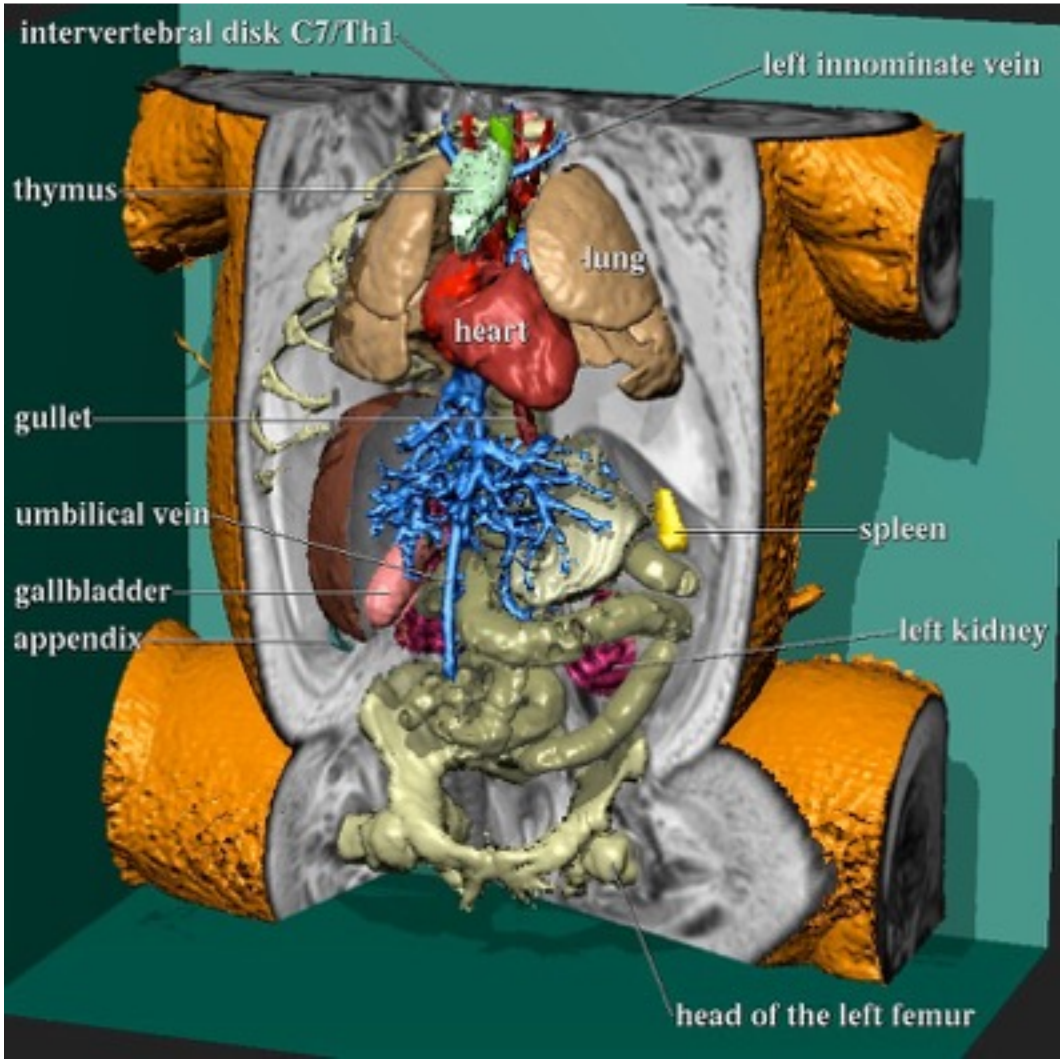
- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Segmentation

- Different features with same value
  - Example CT: different organs have similar X-ray absorption
  - Classification cannot be distinguished
- Label voxels indicating a type
- Segmentation = pre-processing
- Semi-automatic process



Segmentation



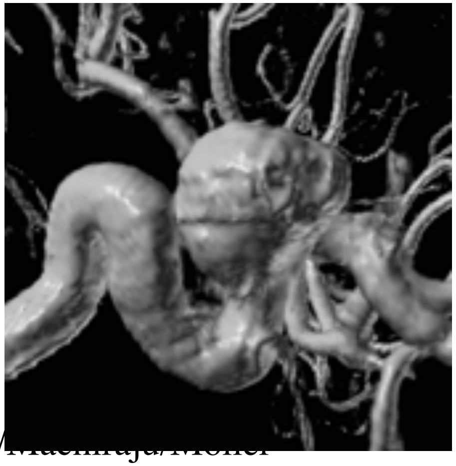
Anatomic atlas

Overview

- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

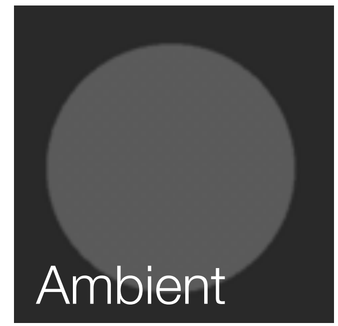
Volumetric Illumination

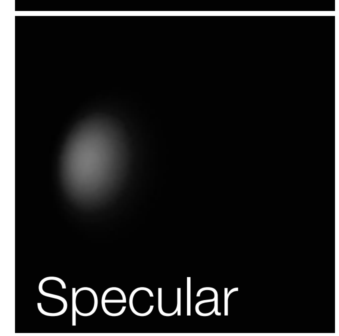
- Illumination:
  - Simulate reflection of light
  - Simulate effect on color
- We want to make use of the human visual system’s ability to efficiently deal with illuminated objects



Volumetric Illumination

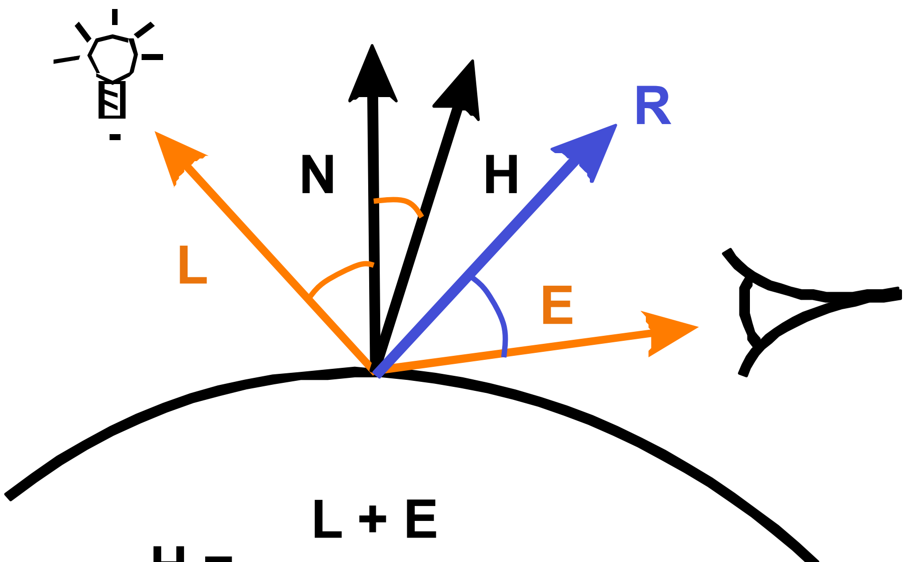
- Review of the Phong illumination model
  - Ambient light + diffuse light + specular light
- Ambient light: $C = k_a C_a O_d$
  - k_a is ambient contribution
  - C_a is color of ambient light
  - O_d is diffuse color of object
- Diffuse light: $C = k_d C_p O_d \cos(\theta)$
  - k_d is diffuse contribution
  - C_p is color of point light
  - O_d is diffuse color of object
  - $\cos(\theta)$ is angle of incoming light
- Specular light: $C = k_s C_p O_s \cos^n(\sigma)$
  - k_s is specular contribution
  - C_p is color of point light
  - $\cos(\sigma)$ is angle of reflected light and eye
  - n is the specular exponent



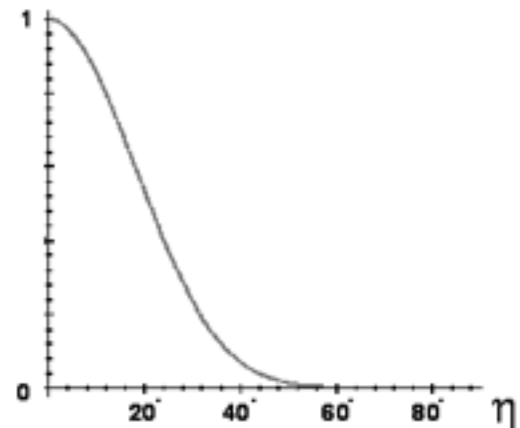


Volumetric Illumination

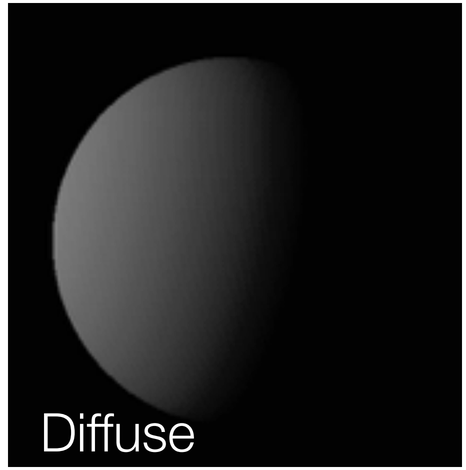
- $\cos(\theta) = \mathbf{R} \bullet \mathbf{E}$
- $\cos(\theta_1) = \mathbf{N} \bullet \mathbf{H}$ (Blinn-Phong)

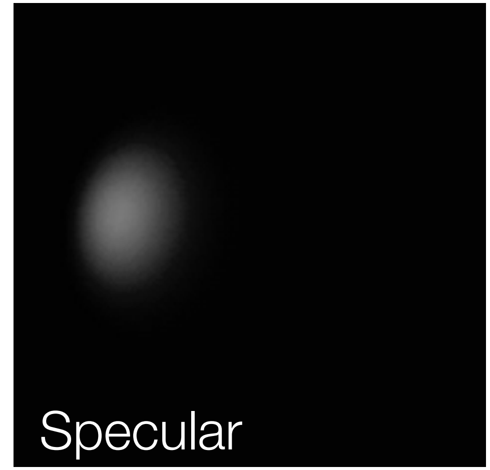


$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{E}}{\|\mathbf{L} + \mathbf{E}\|}$$



Volumetric Illumination

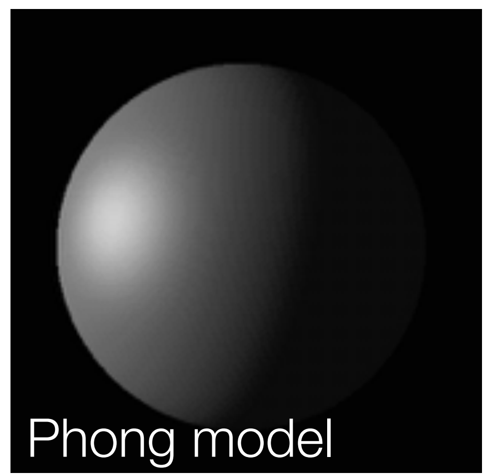




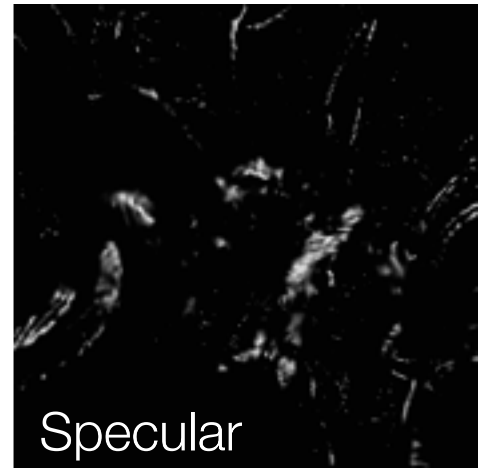
$k_a = 0.1$

$k_d = 0.5$

$k_s = 0.4$



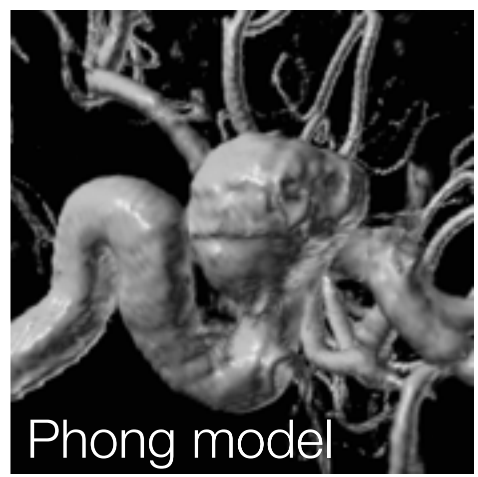
Volumetric Illumination



$k_a = 0.1$

$k_d = 0.5$

$k_s = 0.4$

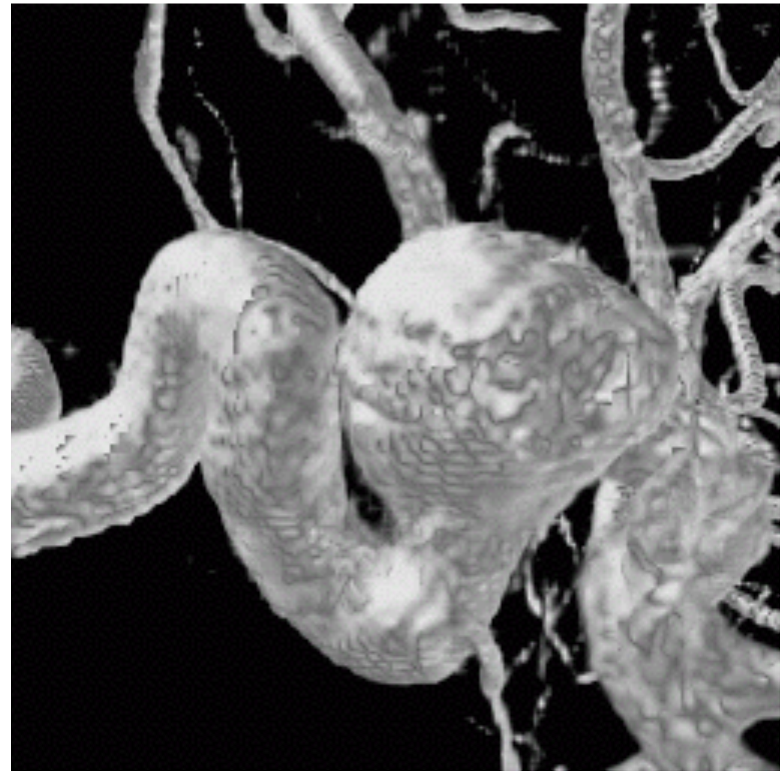


Volumetric Illumination

- What is the normal vector in a scalar field?
- Use the gradient!
- Gradient is perpendicular to isosurface (direction of largest change)
- Numerical computation of the gradient:
  - Central difference
  - Intermediate difference (forward/backward difference)
  - Sobel operator (3×3 kernel for each partial derivative)

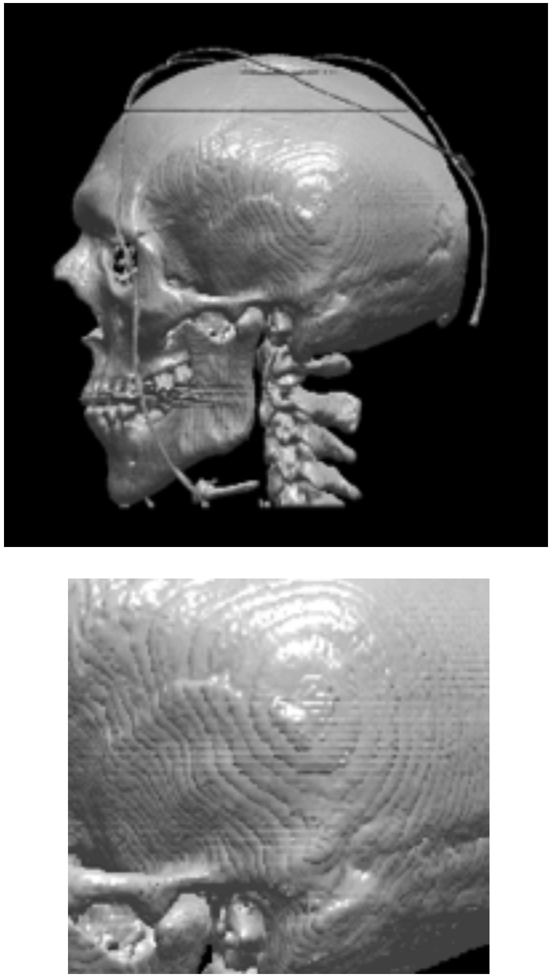
Volumetric Illumination

Central differences

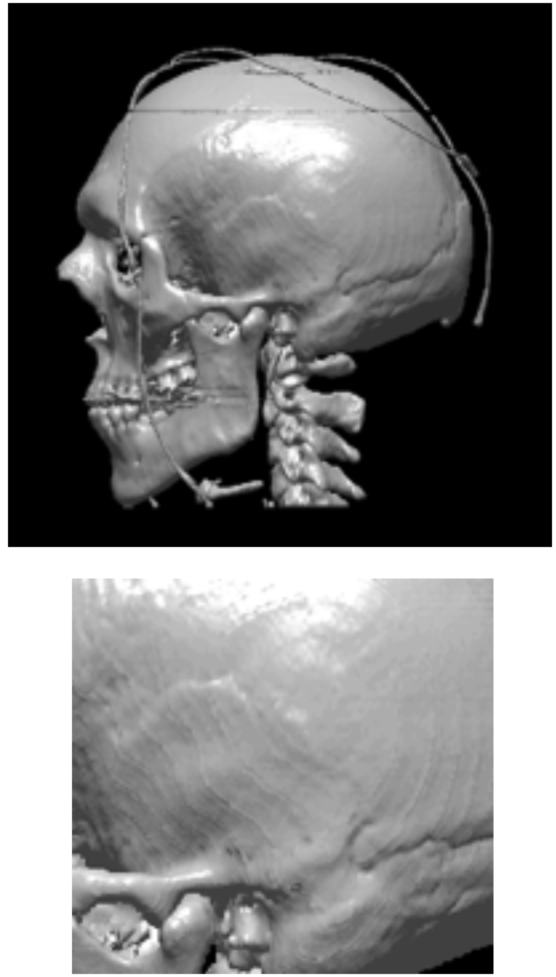


Intermediate differences

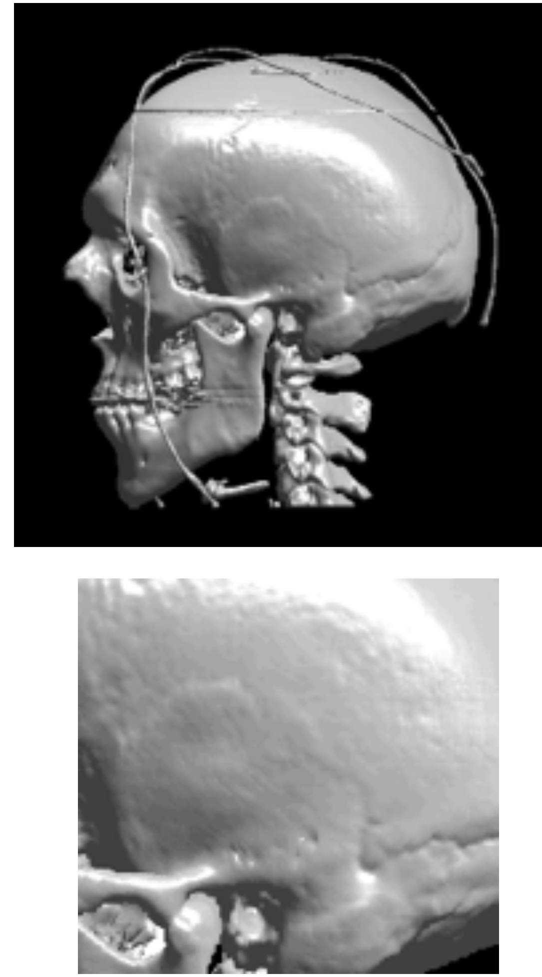
Volumetric Illumination



Intermediate differences



Central differences

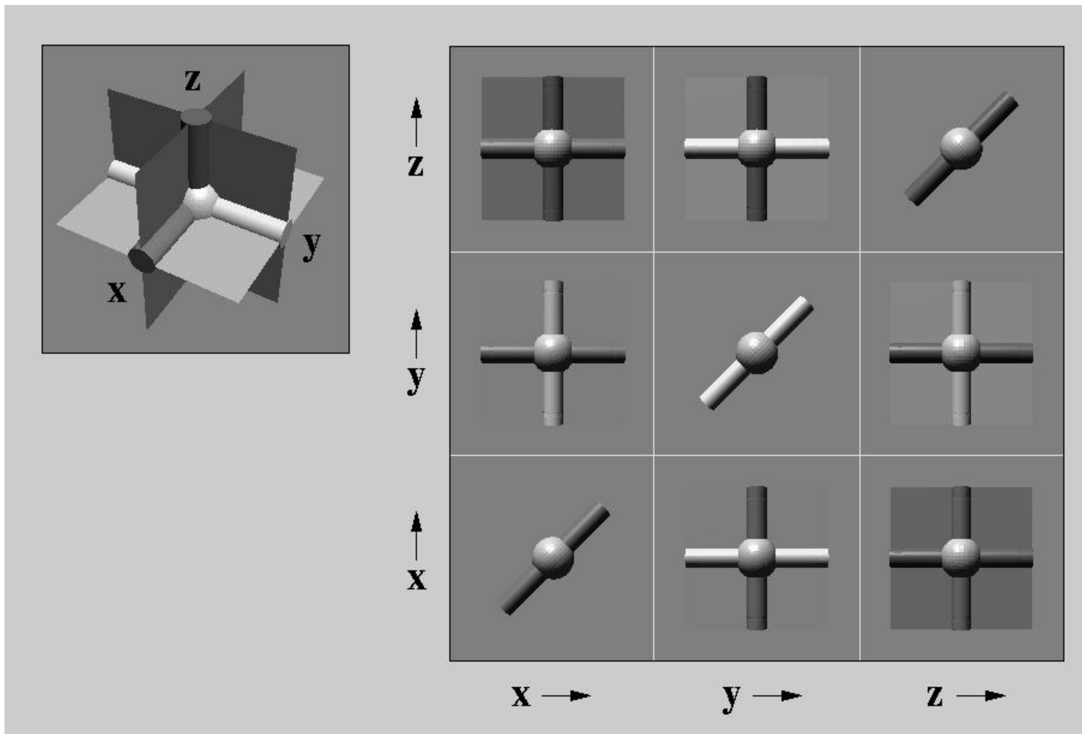


Sobel operator

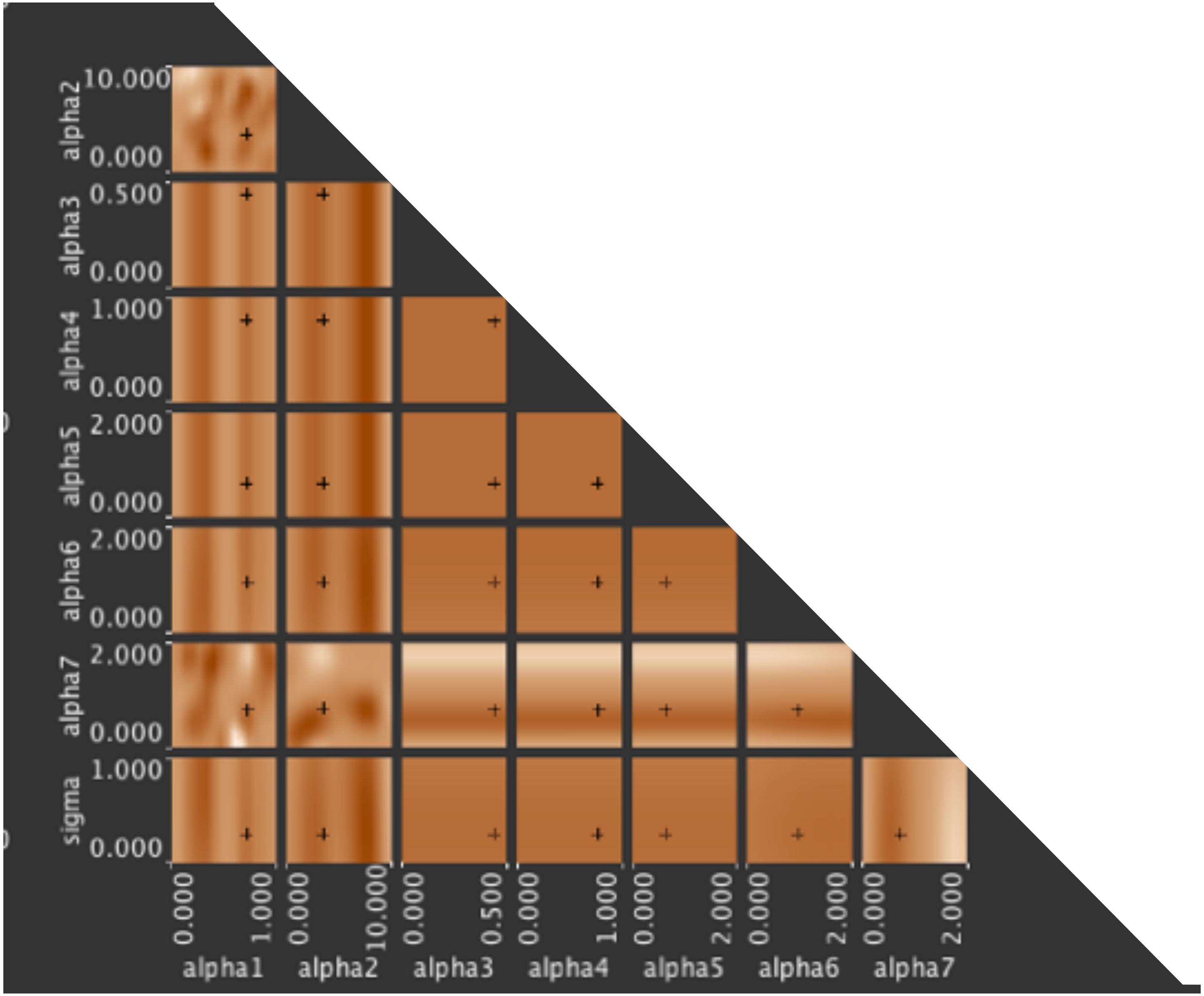
Overview

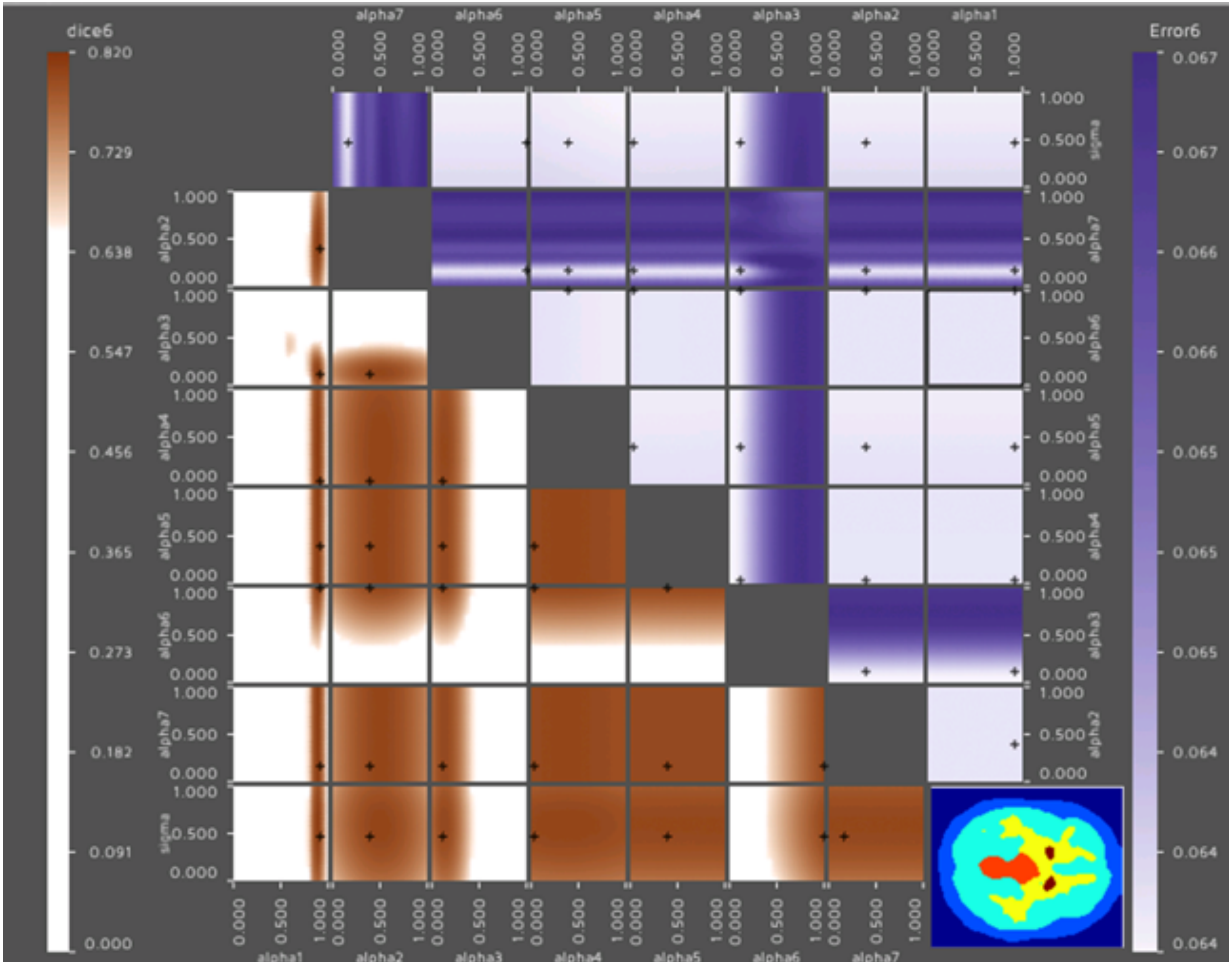
- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Scalar Data in High-D



van Wijk and van Liere 1993


alpha2
10.000
0.000
alpha3
0.500
0.000
alpha4
1.000
0.000
alpha5
2.000
0.000
alpha6
2.000
0.000
alpha7
2.000
0.000
sigma
1.000
0.000
0.000
1.000
alpha1
0.000
10.000
alpha2
0.000
0.500
alpha3
0.000
1.000
alpha4
0.000
2.000
alpha5
0.000
2.000
alpha6
0.000
2.000
alpha7


dice6
Error6
alpha7
alpha6
alpha5
alpha4
alpha3
alpha2
alpha1
sigma
0.000
0.500
1.000
0.820
0.729
0.638
0.547
0.456
0.365
0.273
0.182
0.091
0.000
0.067
0.066
0.065
0.064