Spatial Data

(Part 2)

Cmpt 767 Visualization

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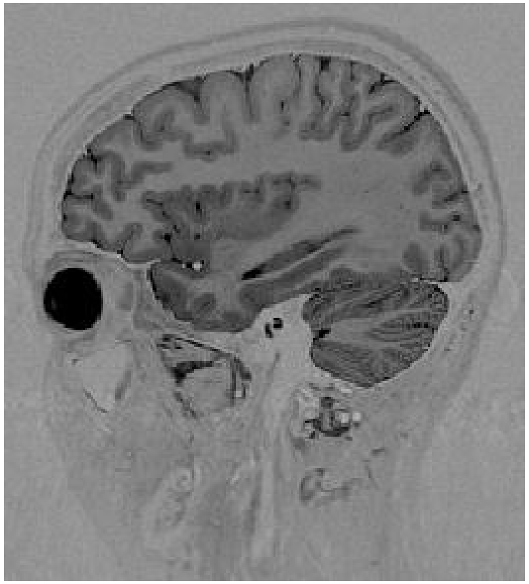
[Weiskopf/Machiraju/Möller]

Overview

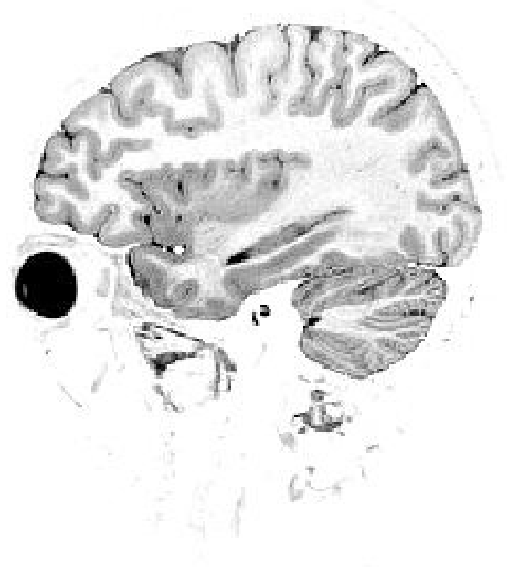
- Basic strategies
- Function plots and height fields
- Isolines
- Color coding
- Volume visualization (overview)
- Classification
- Segmentation
- Volumetric illumination
- Scalar Data in High-D

Color Coding

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



Original



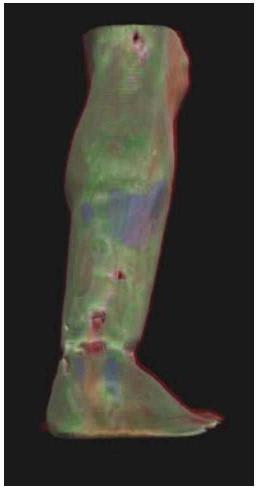
Brain

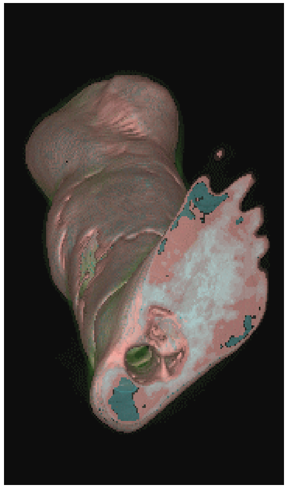
Tissue

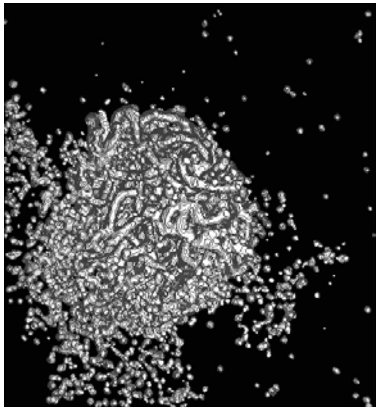
Volume Visualization

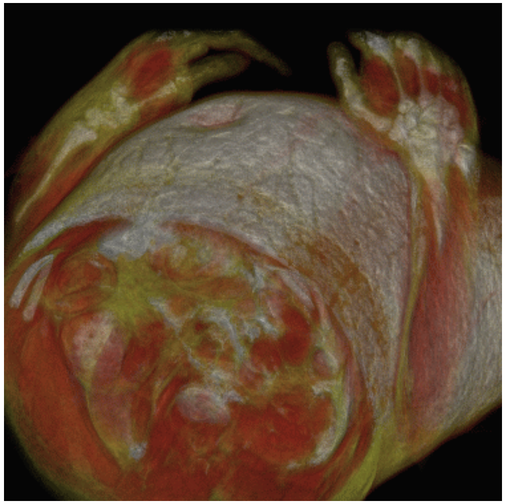
$$\Omega \in R^3 \rightarrow R$$

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

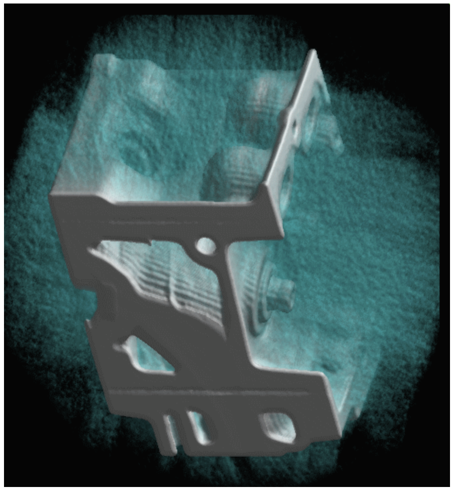


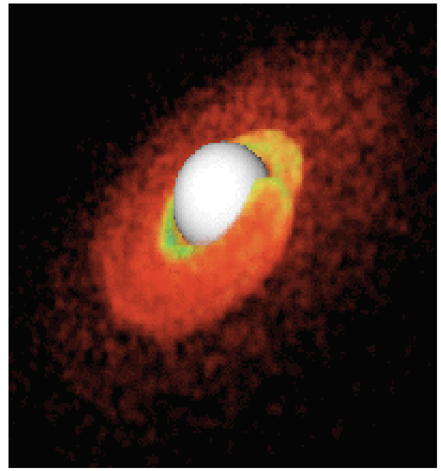


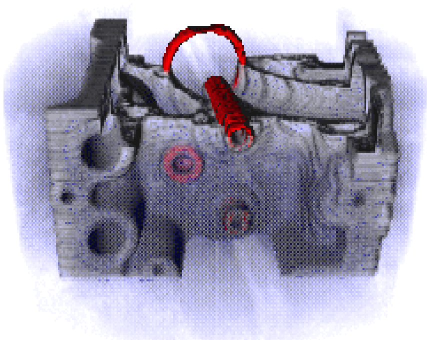


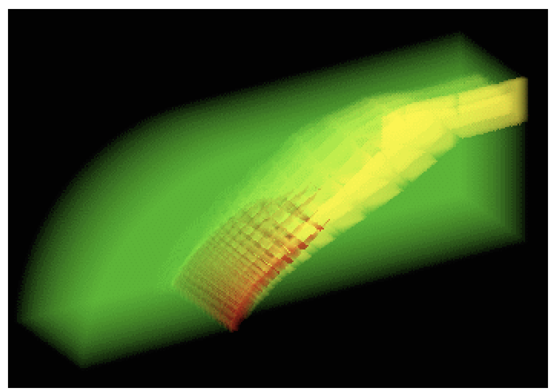


Volume Visualization

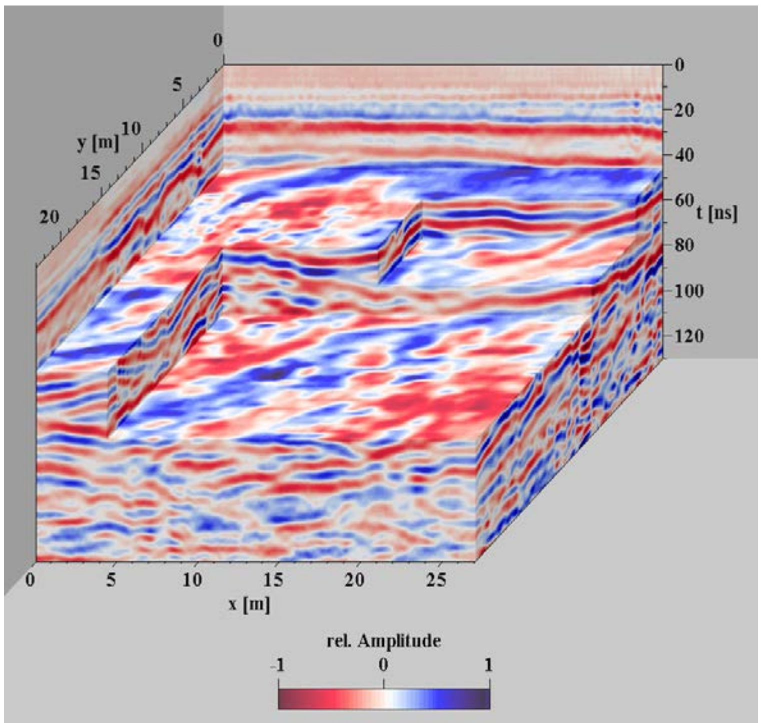


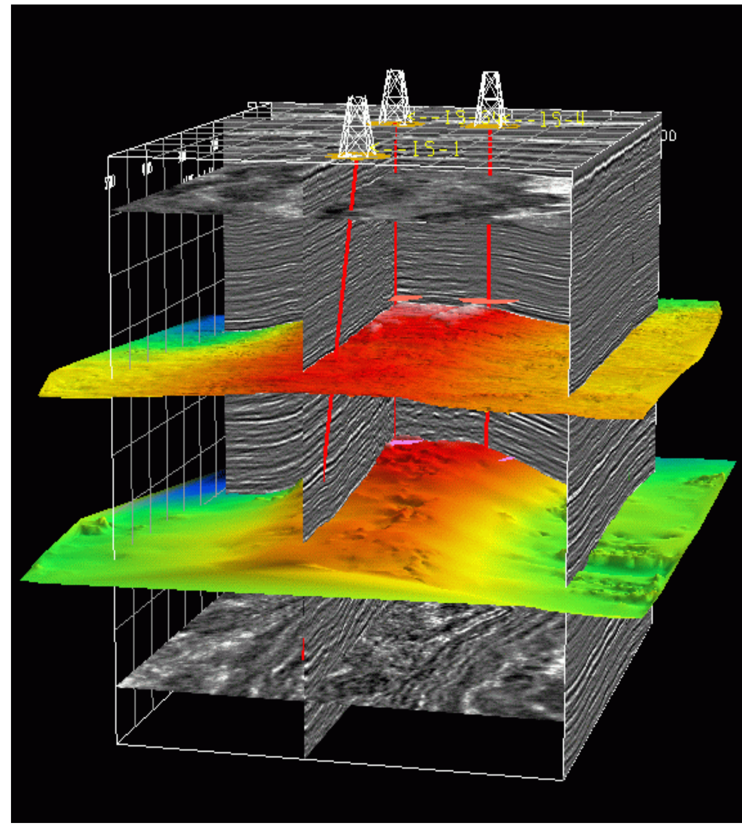




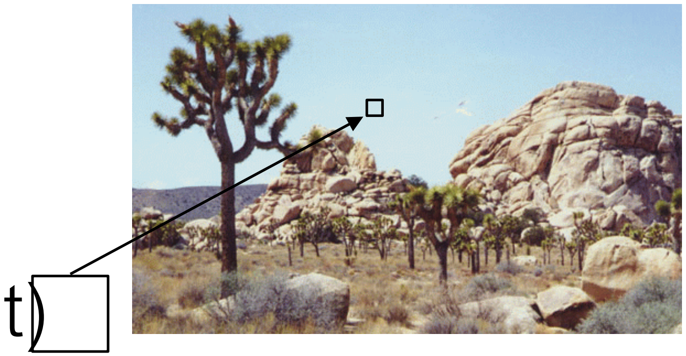


Volume Visualization

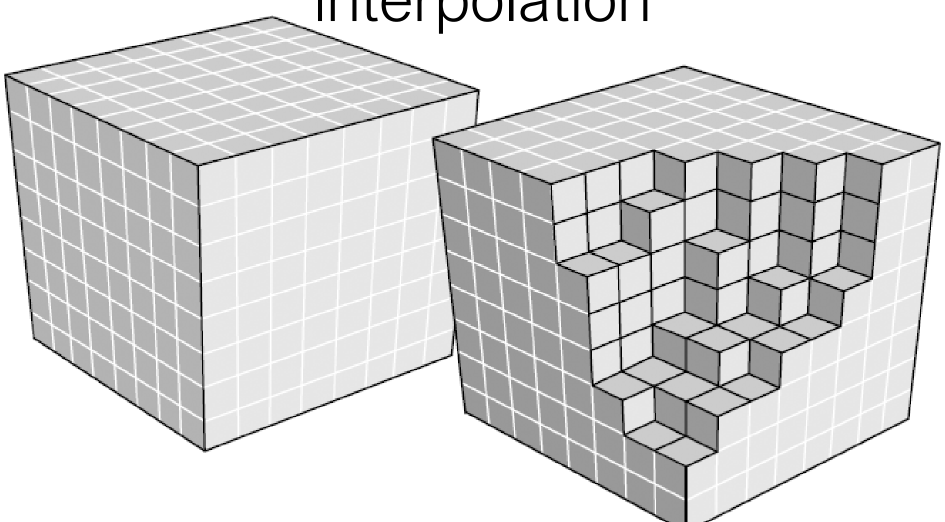


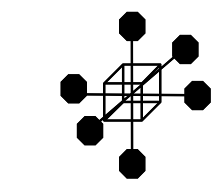


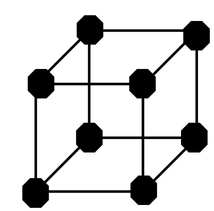
Volume Visualization



- 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



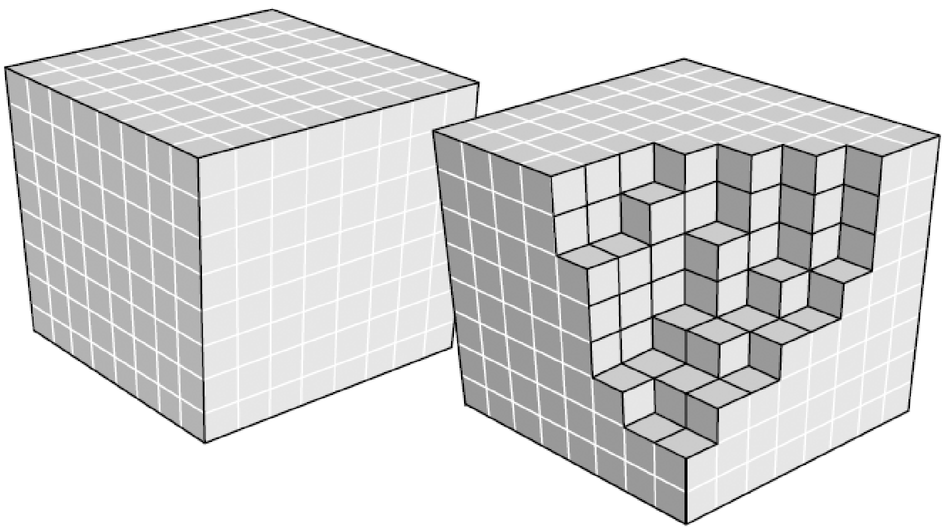




- Collection of voxels
- Uniform grid

Volume Visualization

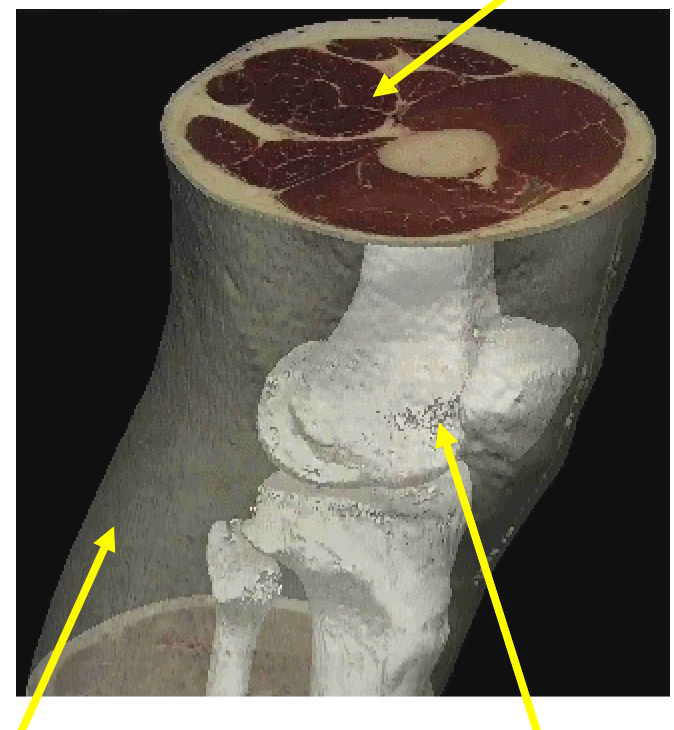
- Challenges
  - Essential information in the interior
  - Occlusion?
  - Often data sets cannot be described by geometric representation (fire, clouds, gaseous phenomena)



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

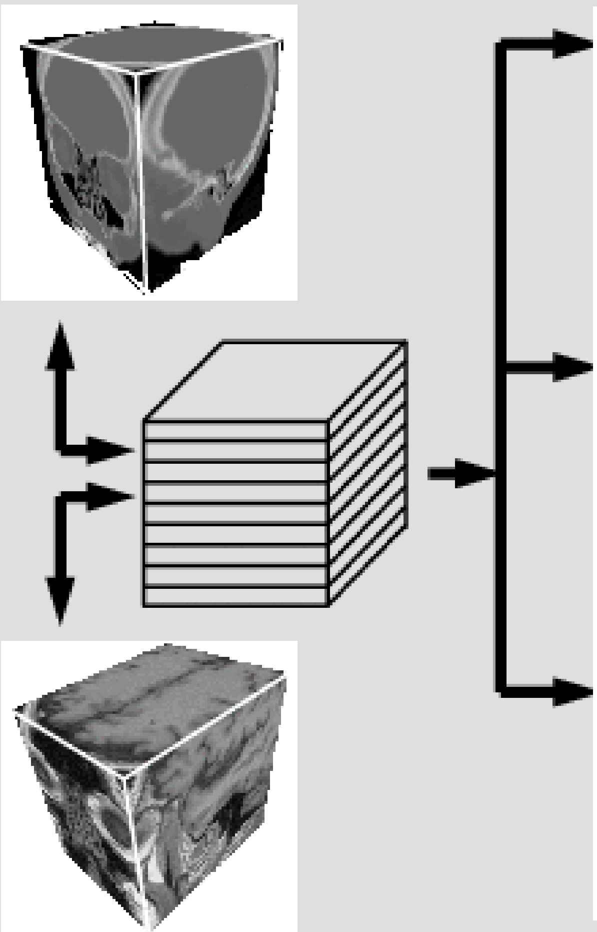
Slice



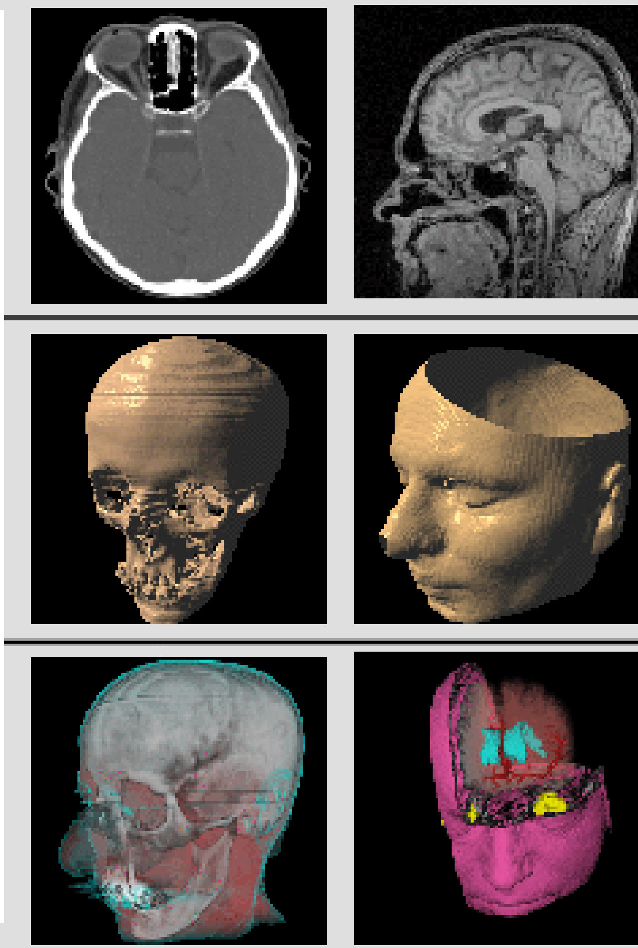
Semi-transparent material

Isosurface

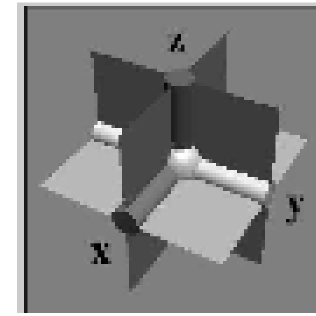
Volume Visualization



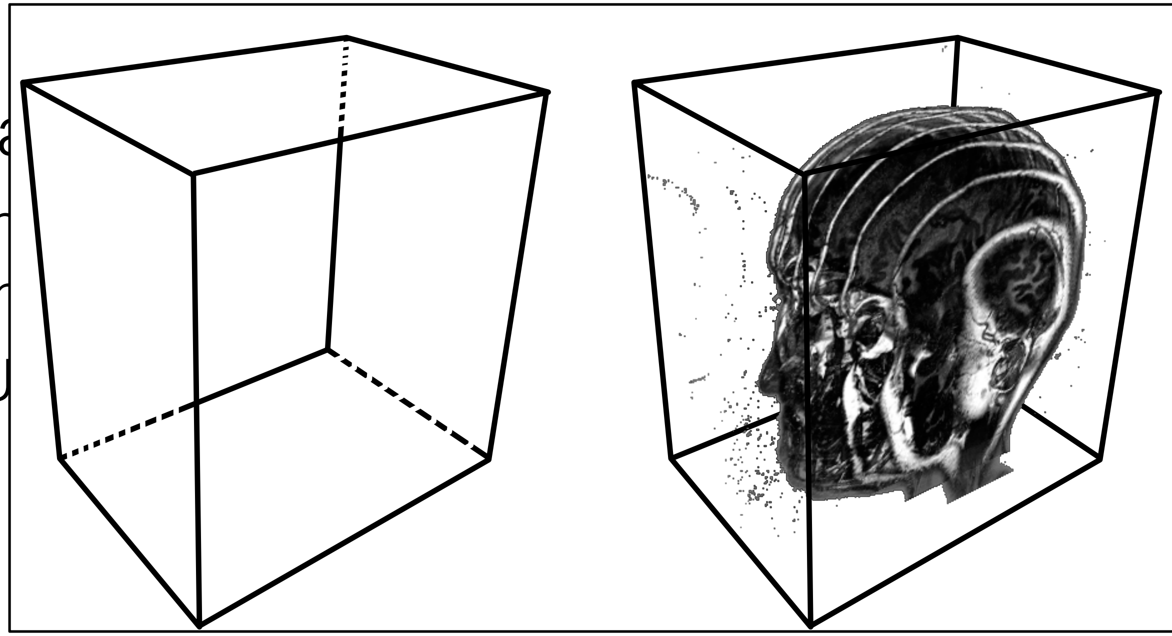
- 2D visualization
  slice images
  (or multi-planar
  reformating MPR)
- *Indirect*
  3D visualization
  isosurfaces
  (or surface-shaded
  display SSD)
- *Direct*
  3D visualization
  (direct volume
  rendering DVR)

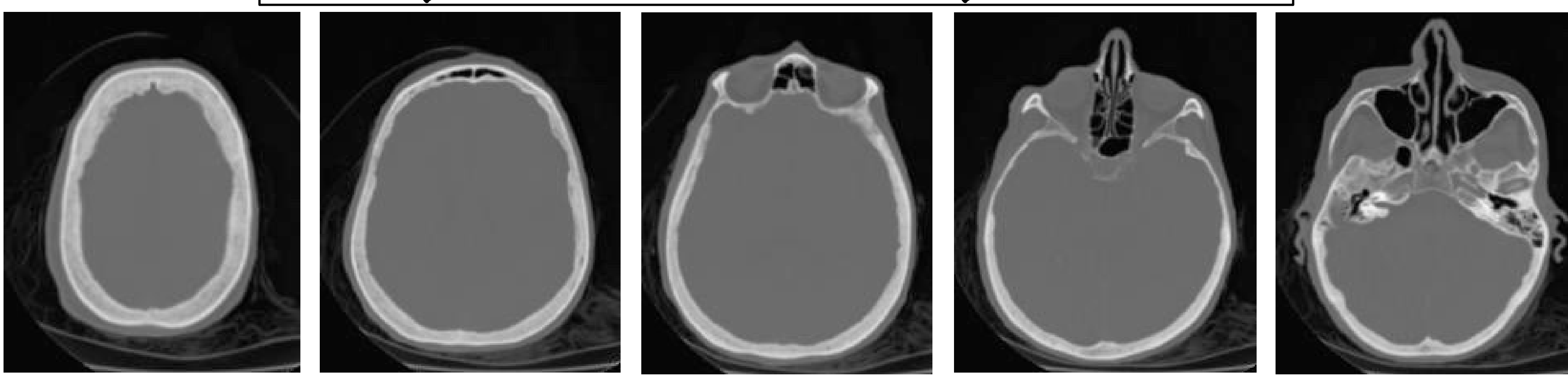


Volume Visualization



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

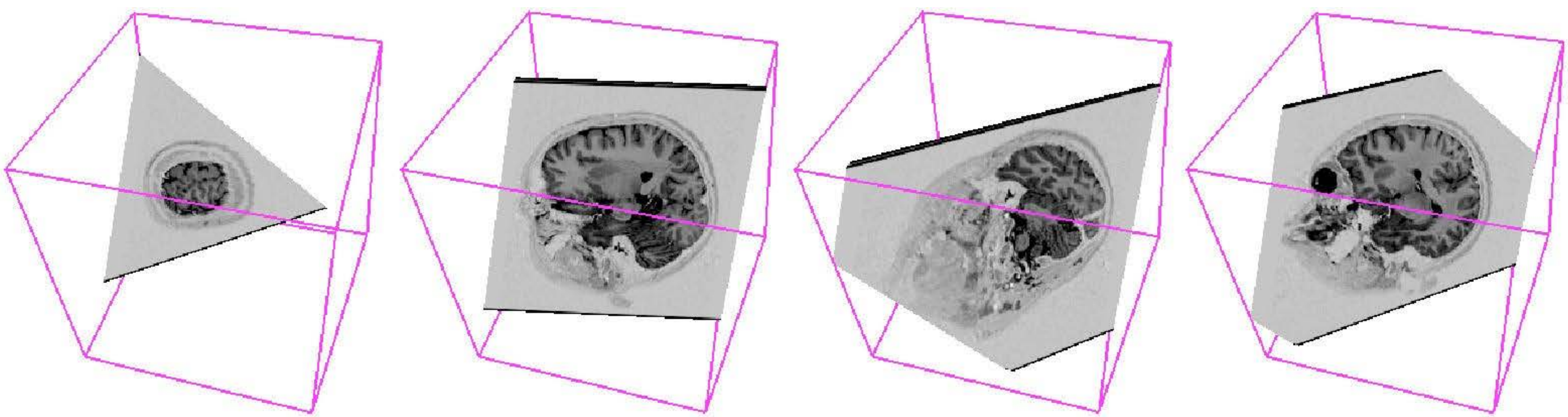




Slice 20 30 40 50 60
CT data set

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

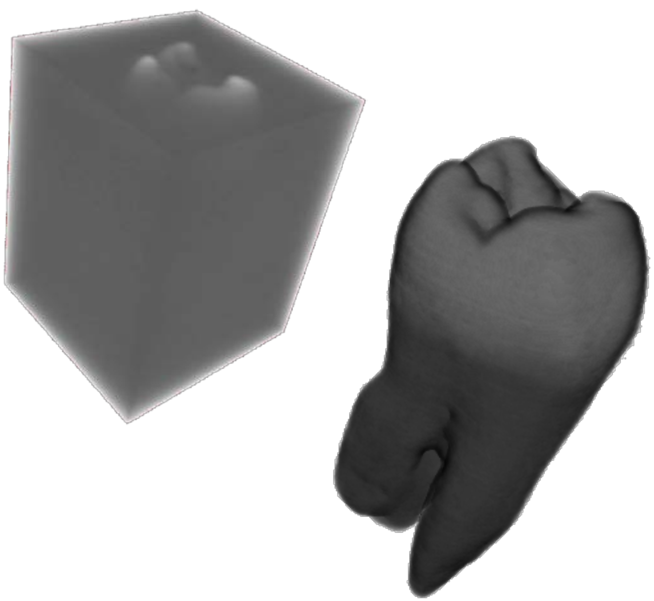


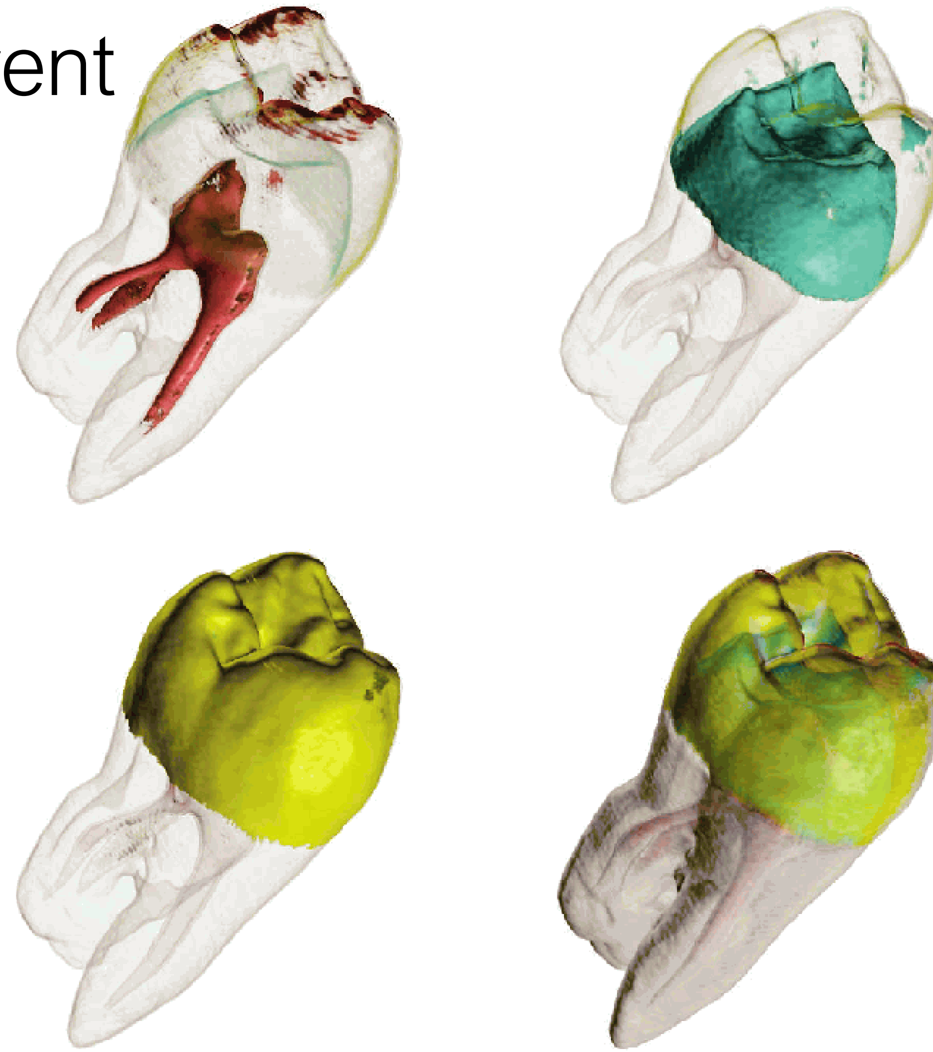
Classification

- 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



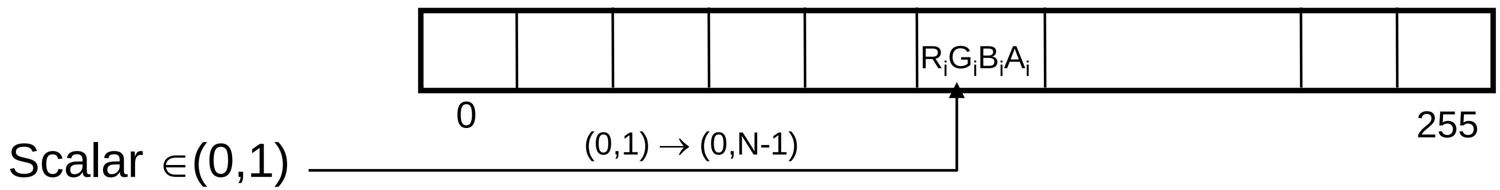


Classification

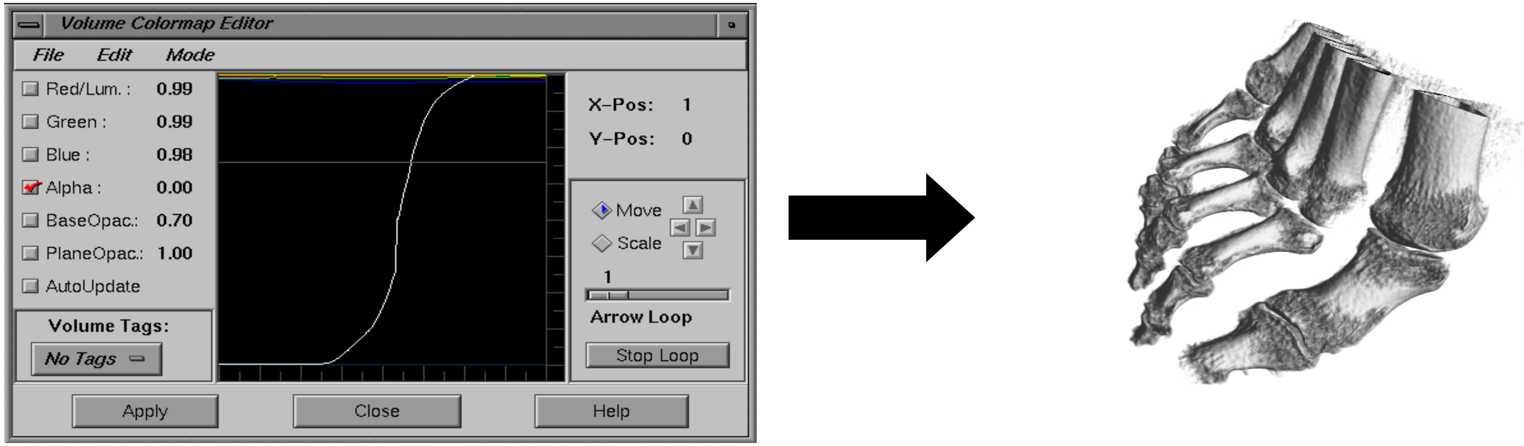
- Most widely used approach for transfer functions:
  - Assign each scalar value a different color value
  - Assignment via transfer function ***T***

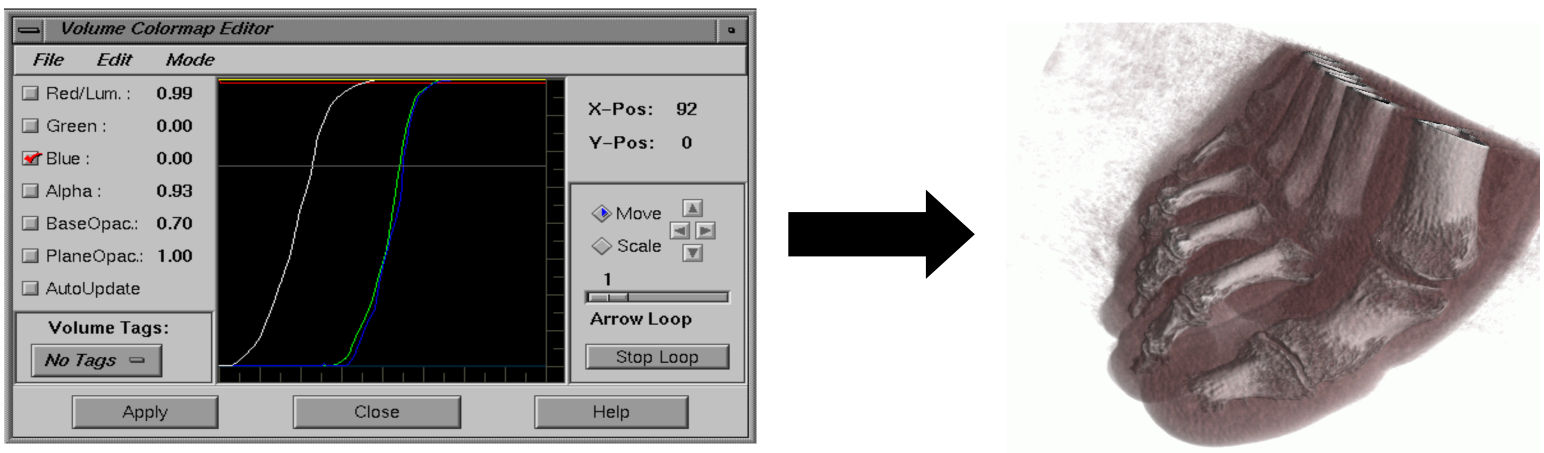
    $$T : scalarvalue \rightarrow colorvalue$$

  - 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

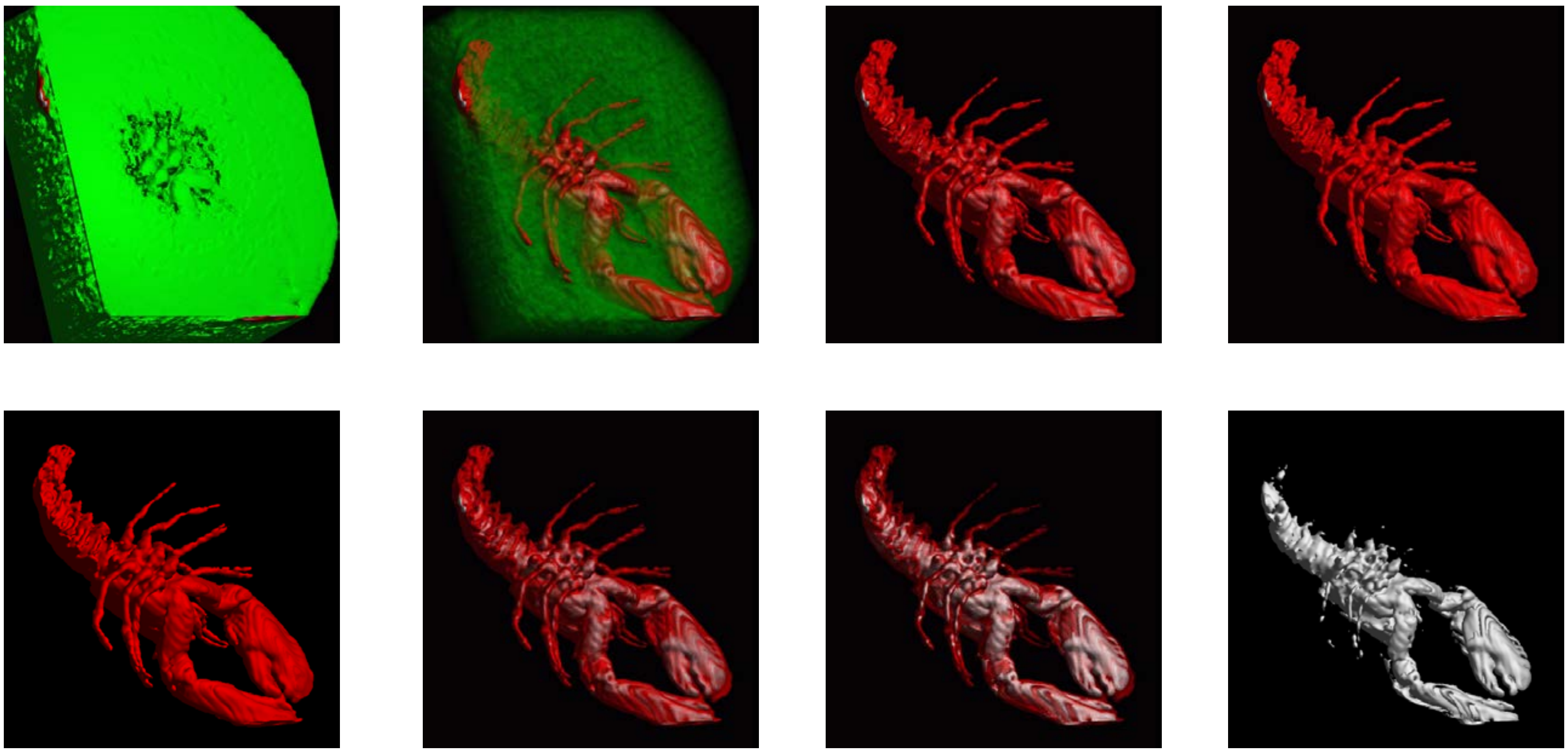


Classification



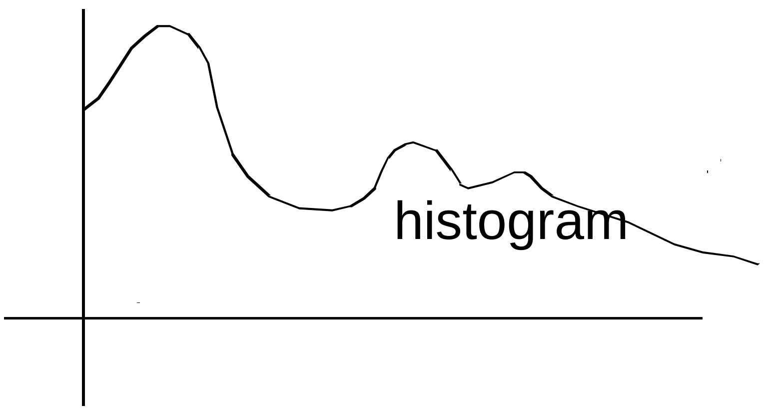


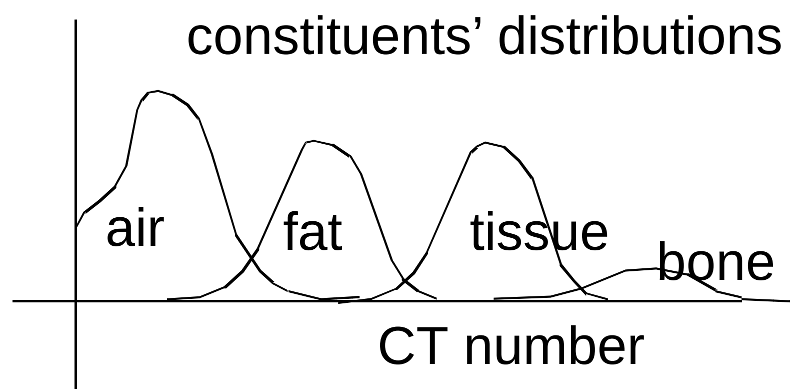
Classification

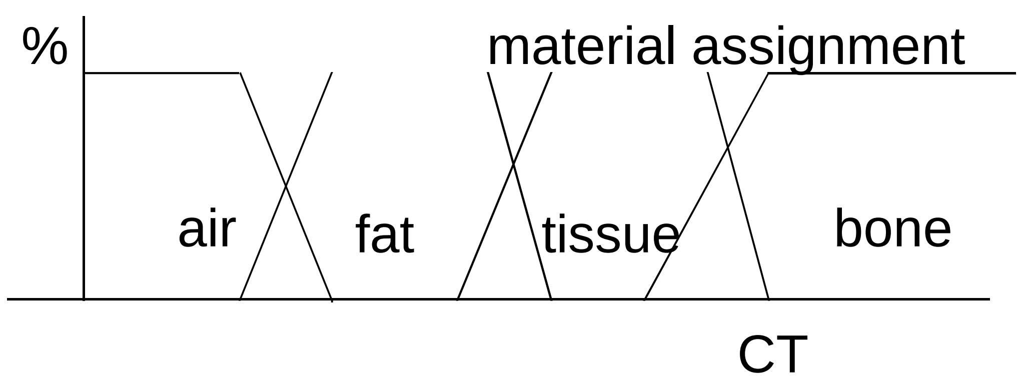


Classification

- Heuristic approach, based on measurements of many data sets





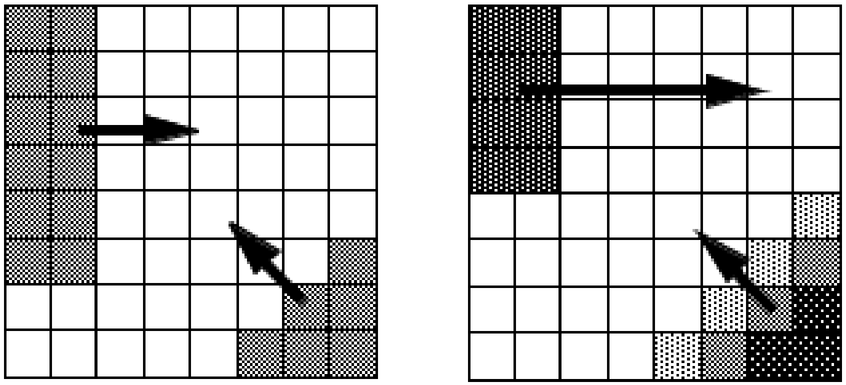


Classification

- Hounsfield units (HU) for CT data sets
  - Describes x-ray attenuation, i.e., density of material
  - 12-bit CT-measurements
  - Range of values from -1024 to +3071 HU
  - Typical values:
    - Air: -1024
    - Fat: -100 to -20
    - Water: 0
    - Soft tissue such as muscle: +20 to +80
    - Bone: > +500
  - For visualization, 12 bits are often reduced to 8 bits by windowing (loss of dynamic range)

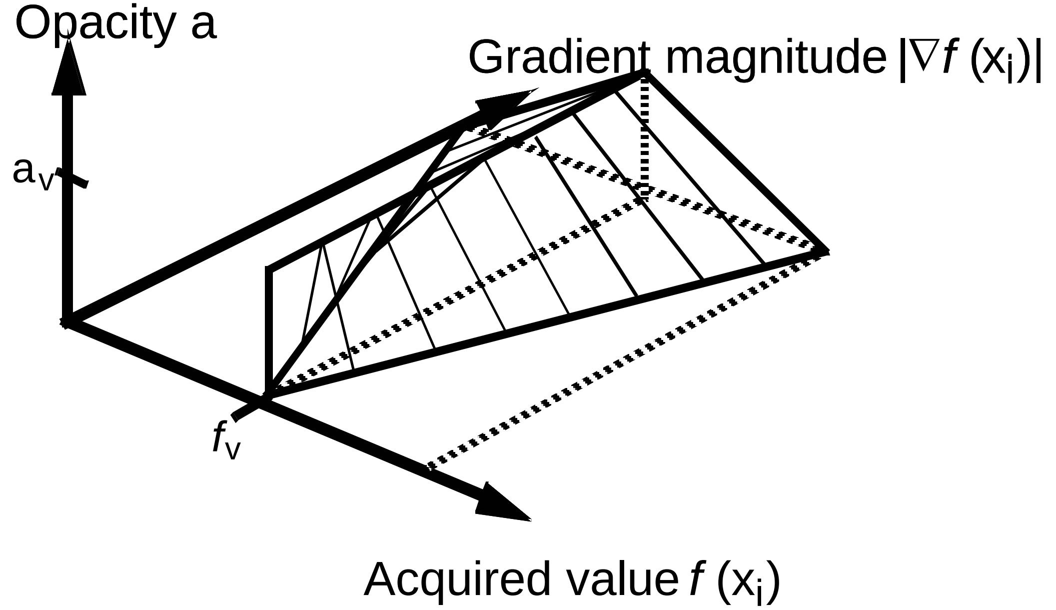
Classification

- 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



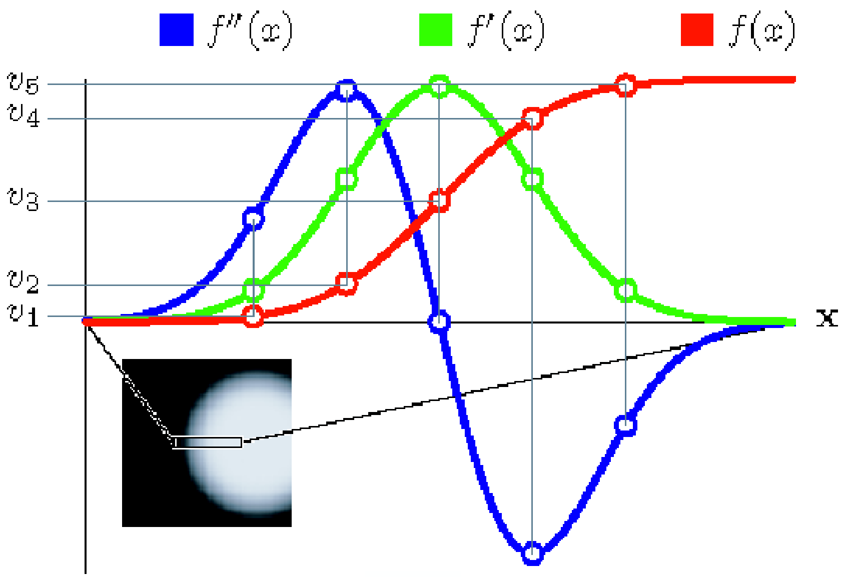
Classification

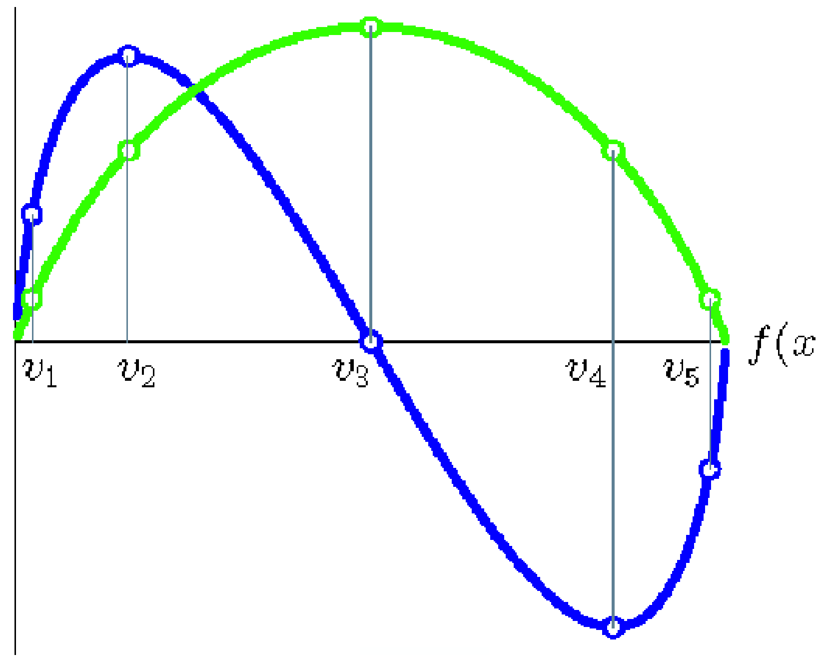
- Scalar value and gradient of the scalar field in a transfer function to emphasize isosurfaces [Levoy 1988]

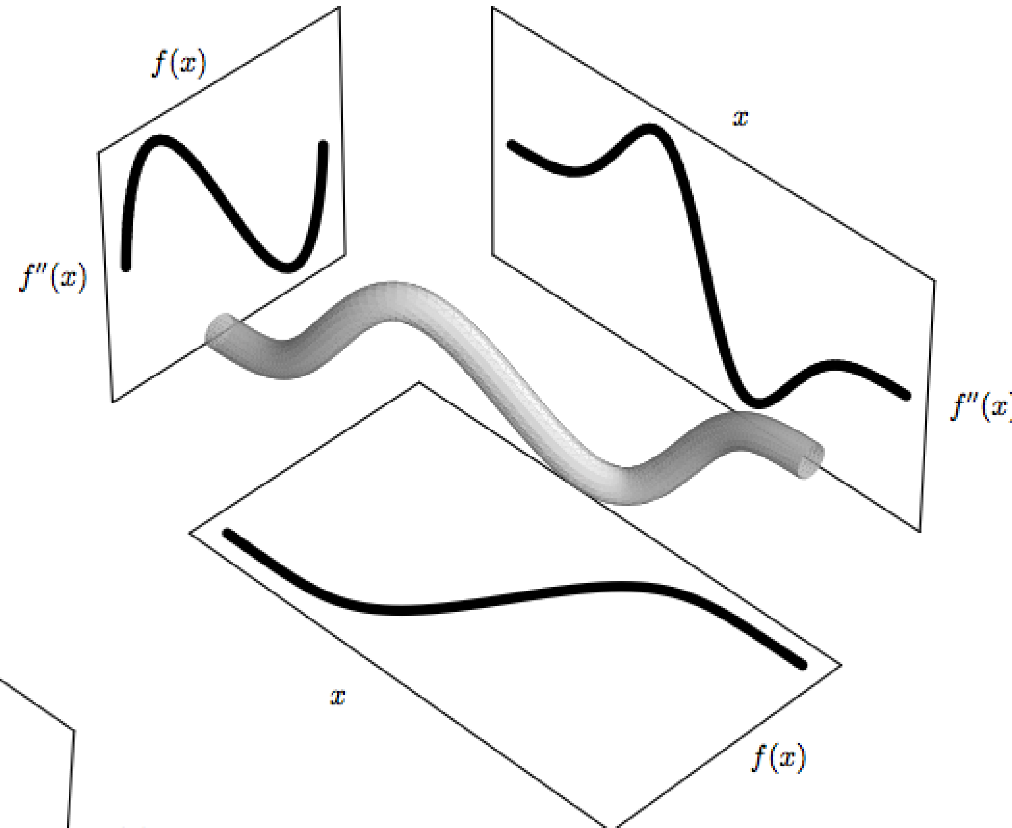


Classification

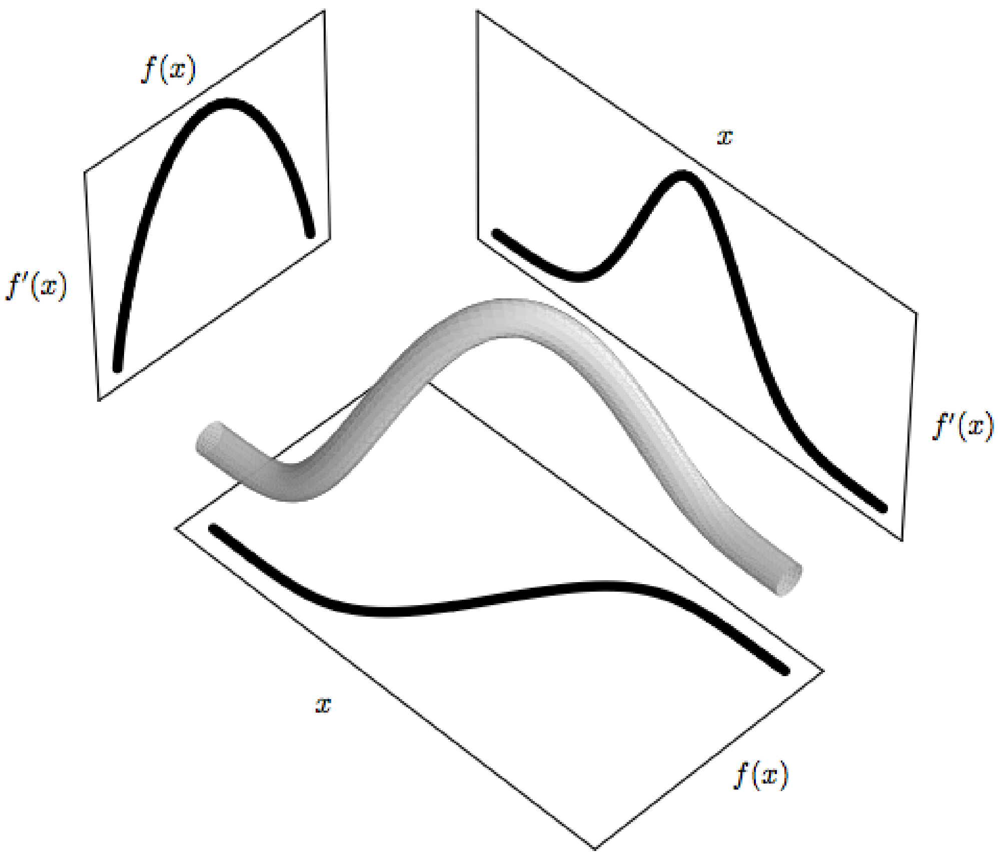
- Multidimensional transfer functions
  [Kindlmann & Durkin 98, Kniss, Kindlmann, Hansen 01]
- Problem: How to identify boundary regions/surfaces
- Approach: 2D/3D transfer functions, depending on
  - Scalar value, magnitude of the gradient





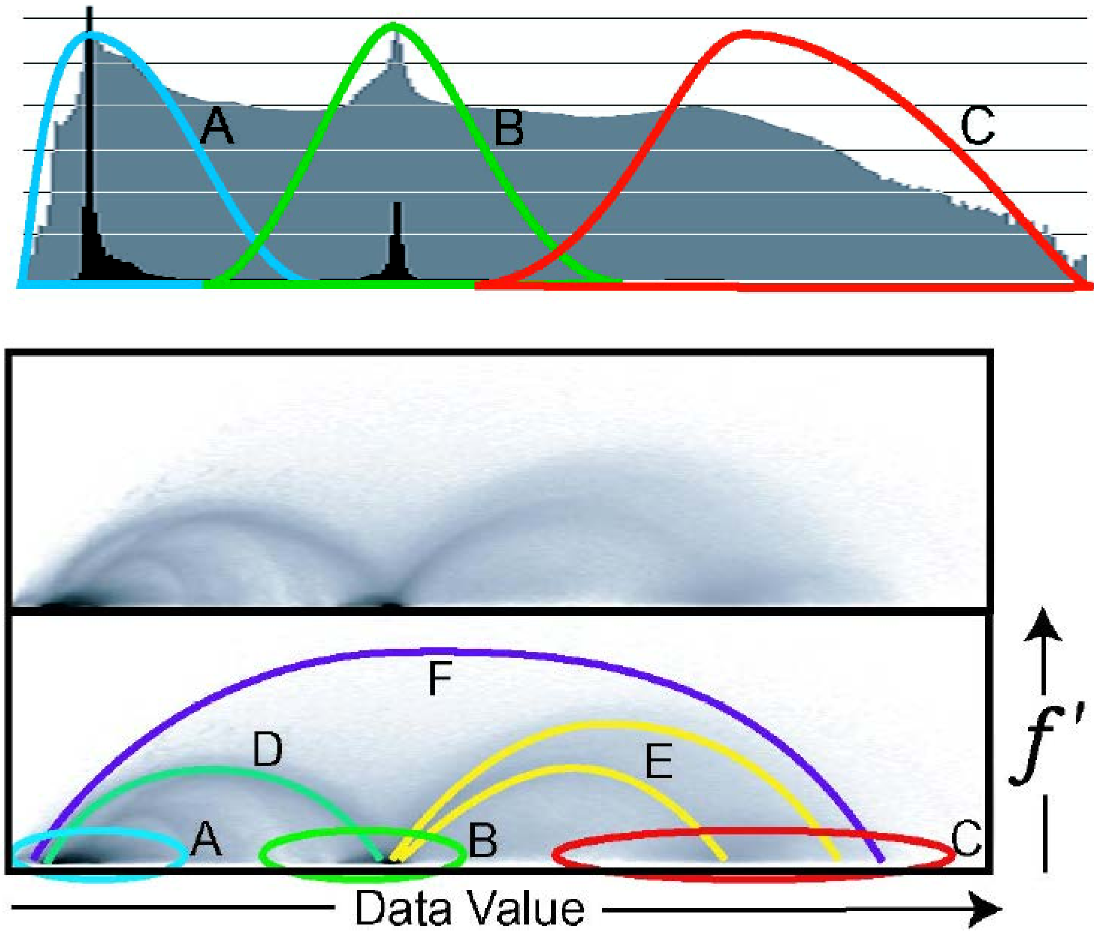


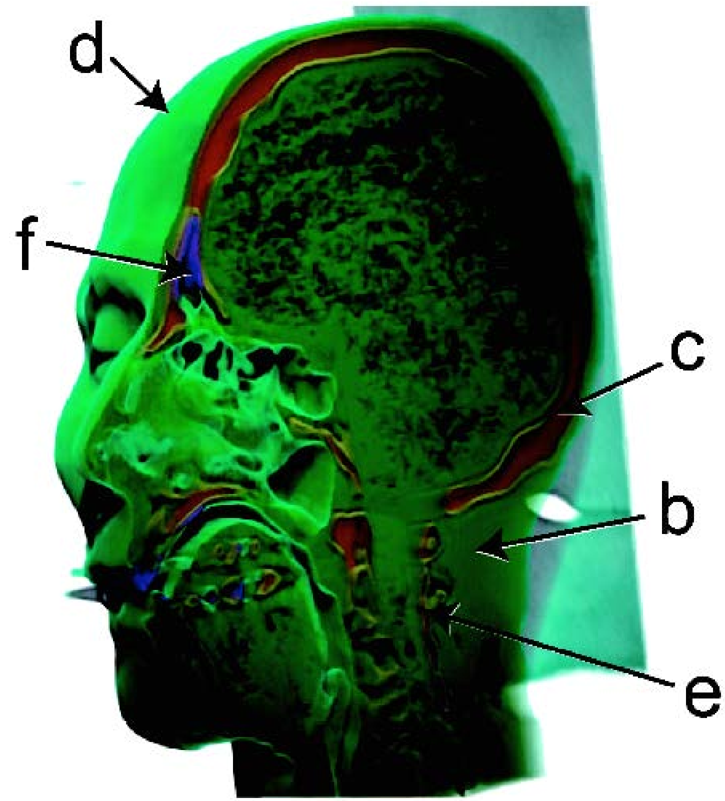
$f(x)$
$f''(x)$
x
$f''(x)$
x
$f(x)$



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

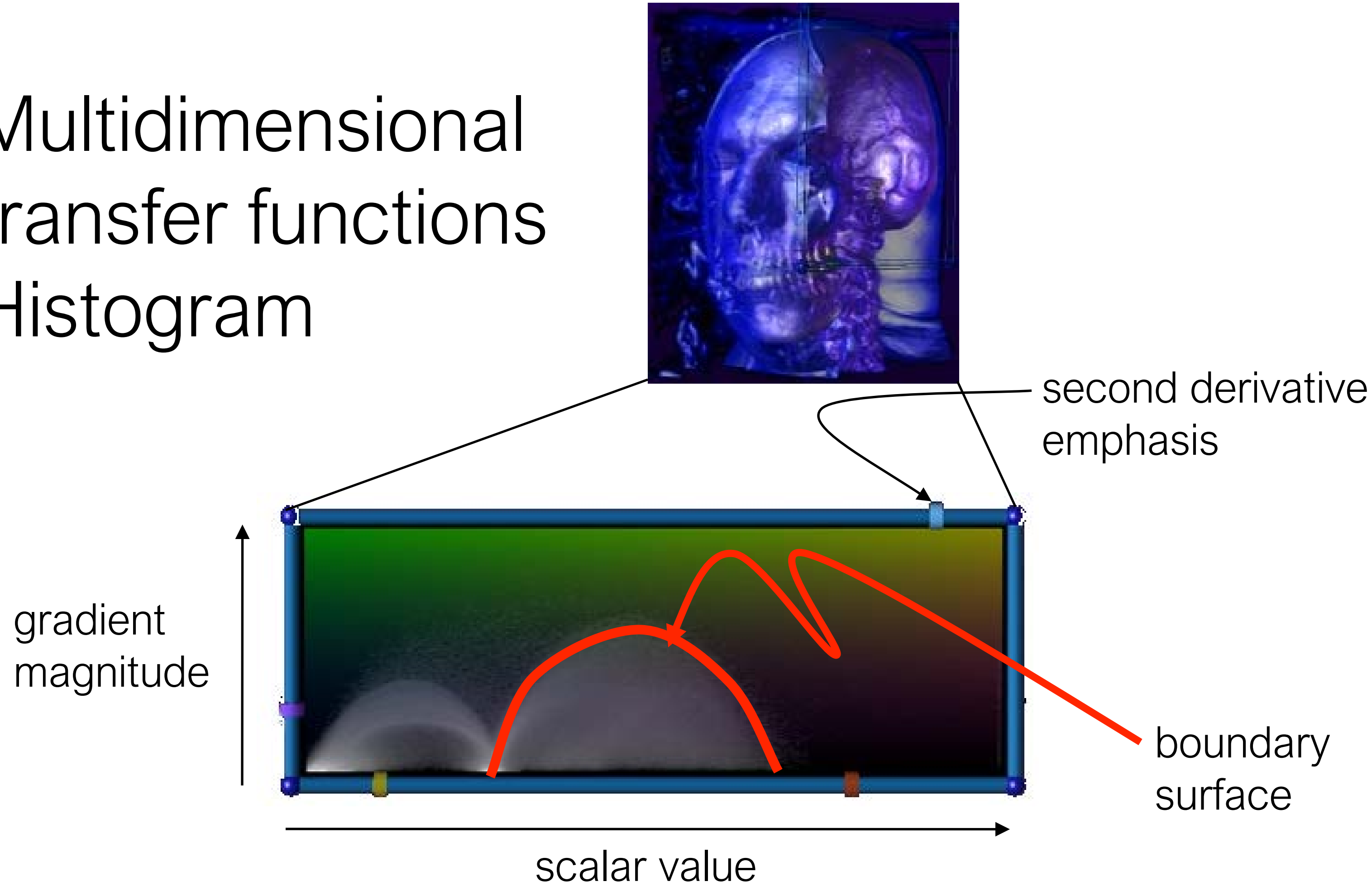
Classification





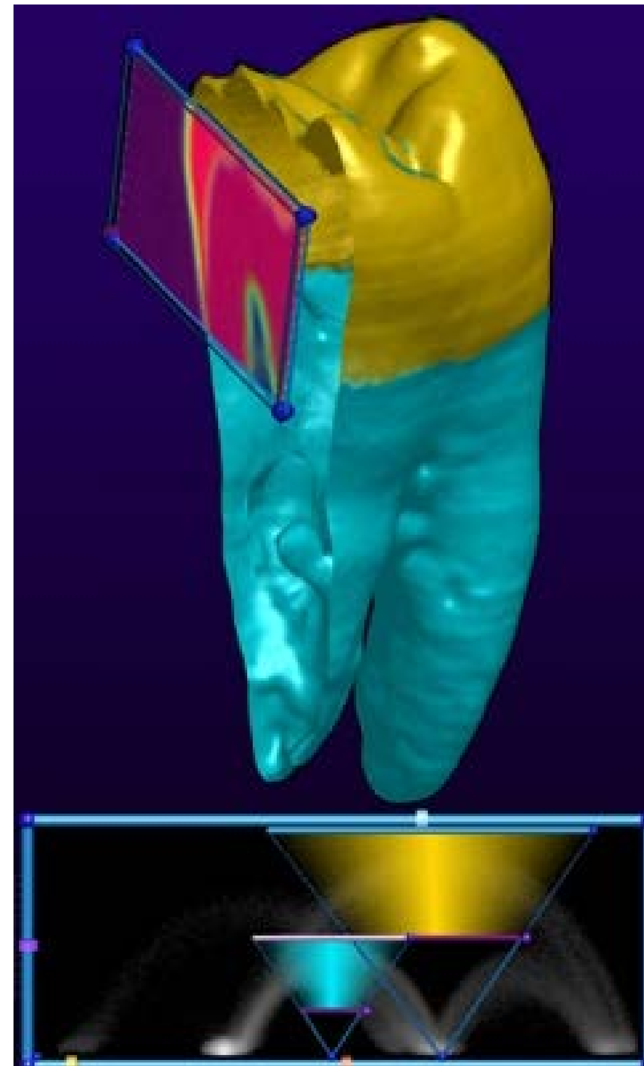
Classification

- Multidimensional transfer functions
- Histogram



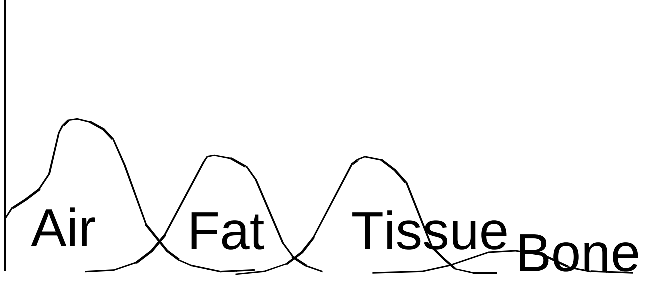
Classification

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

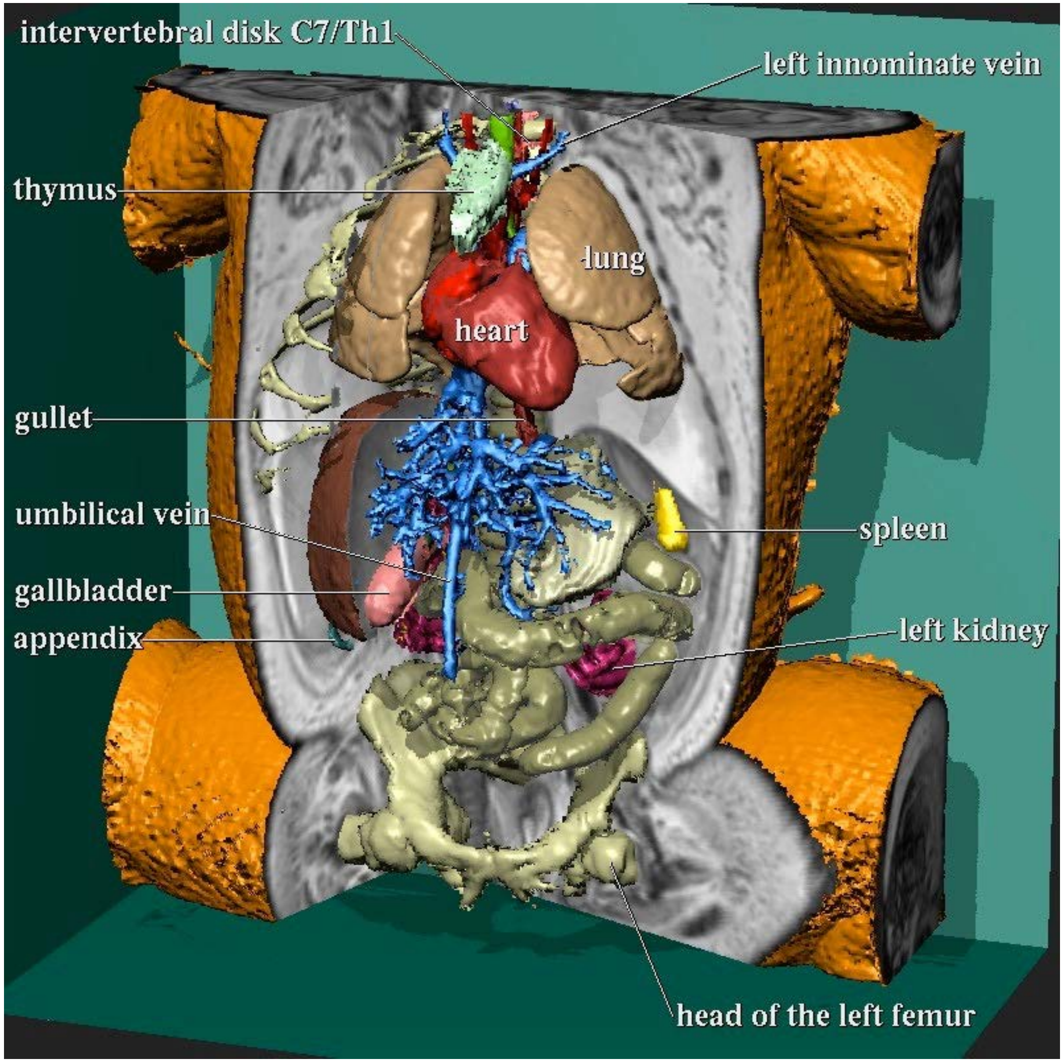


Segmentation

- 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



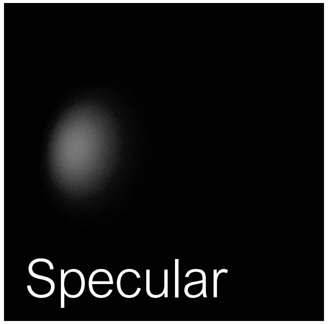
Anatomic atlas

Volumetric Illumination

- Illumination:
  - Simulate reflection of light
  - Simulate effect on color
- Use human visual system ability to interpret surface illumination

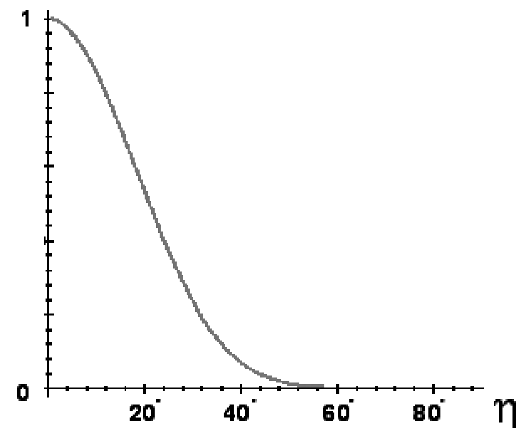
Volumetric Illumination

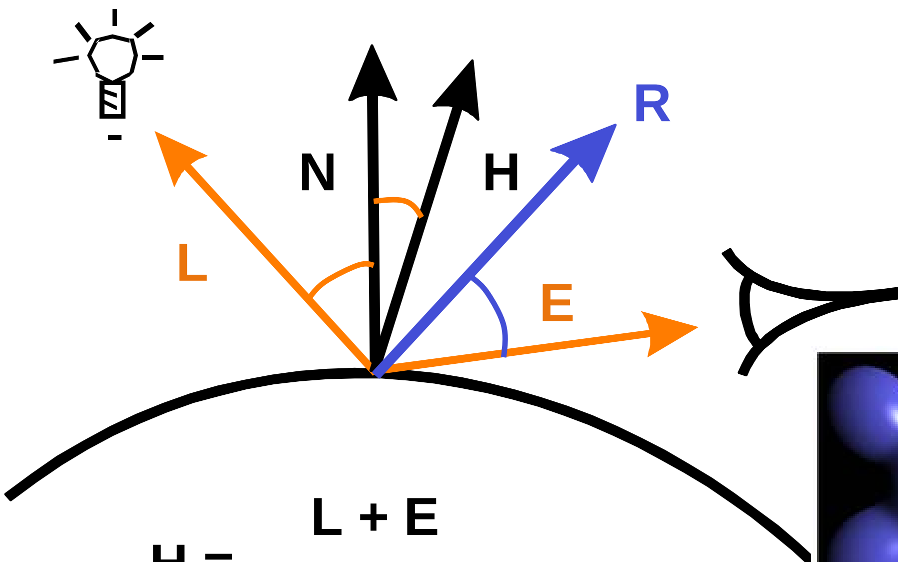
- Review of the **Phong illumination model**
  - Ambient light + diffuse light + specular light
- **Ambient** light: $C = k_a C_a O_d$
  - k_a is ambient contribution
  - C_a is color of ambient light
  - O_d is diffuse color of object
- **Diffuse** light: $C = k_d C_p O_d \cos(\theta)$
  - k_d is diffuse 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



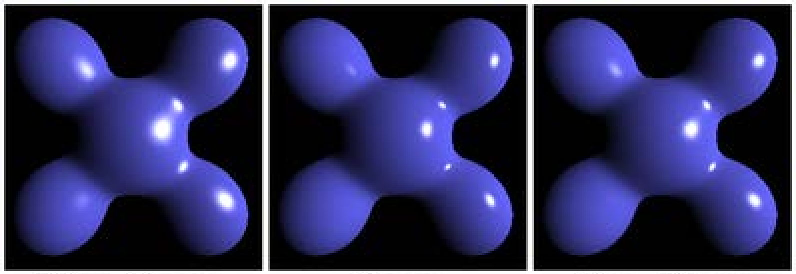
Volumetric Illumination

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



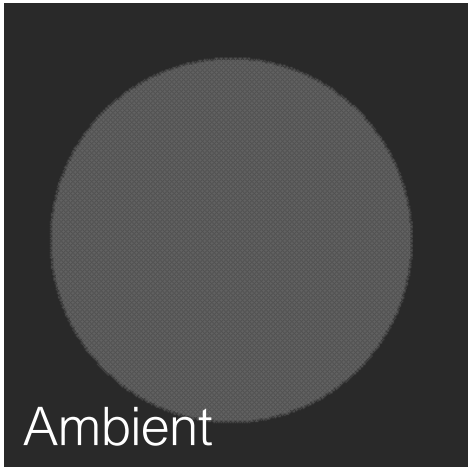


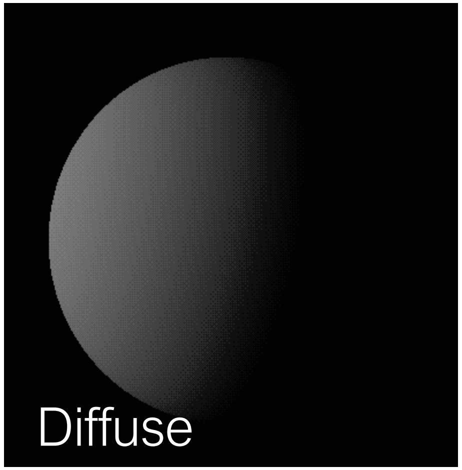
$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{E}}{\left\| \mathbf{L} + \mathbf{E} \right\|}$$

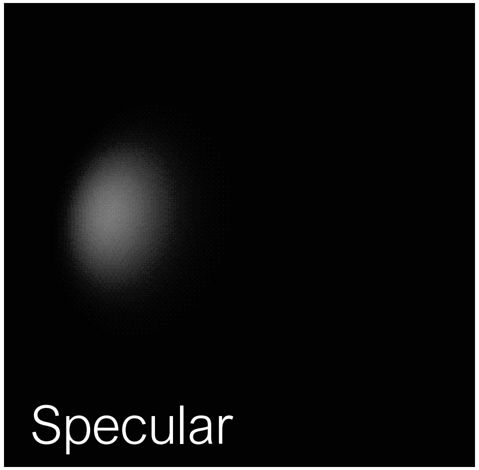


Blinn–Phong | Phong | Blinn–Phong (higher exponent)

Volumetric Illumination



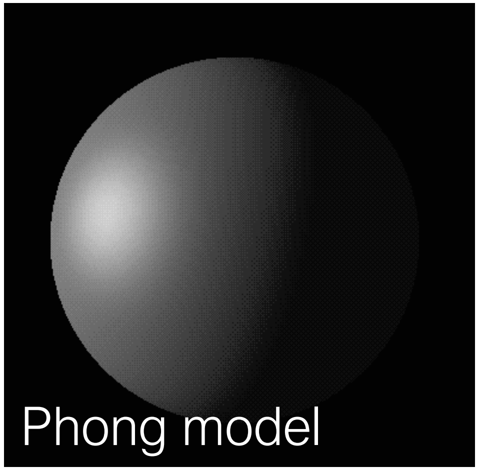




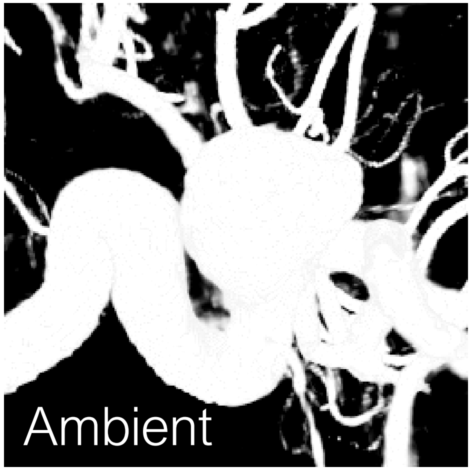
$k_a = 0.1$

$k_d = 0.5$

$k_s = 0.4$



Volumetric Illumination



$k_a = 0.1$
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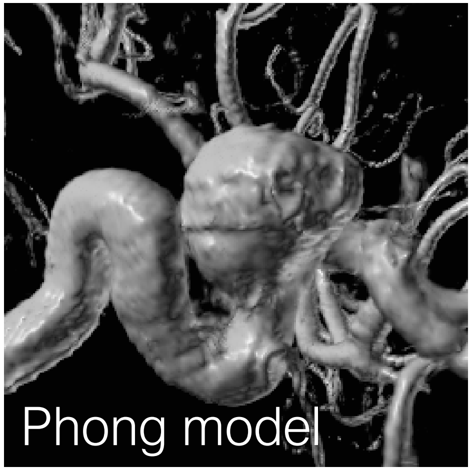
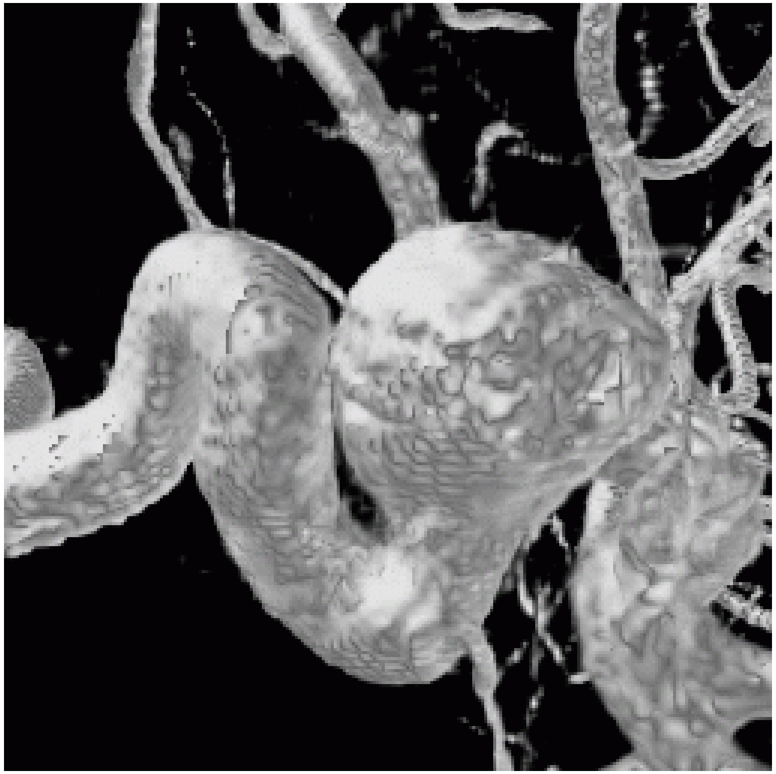


Volumetric Illumination

- 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)

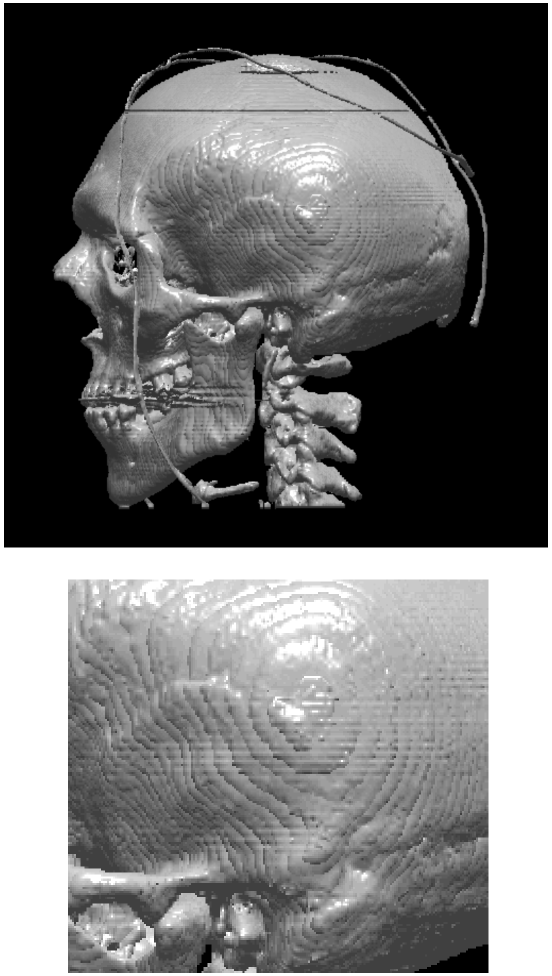
Volumetric Illumination

Central differences

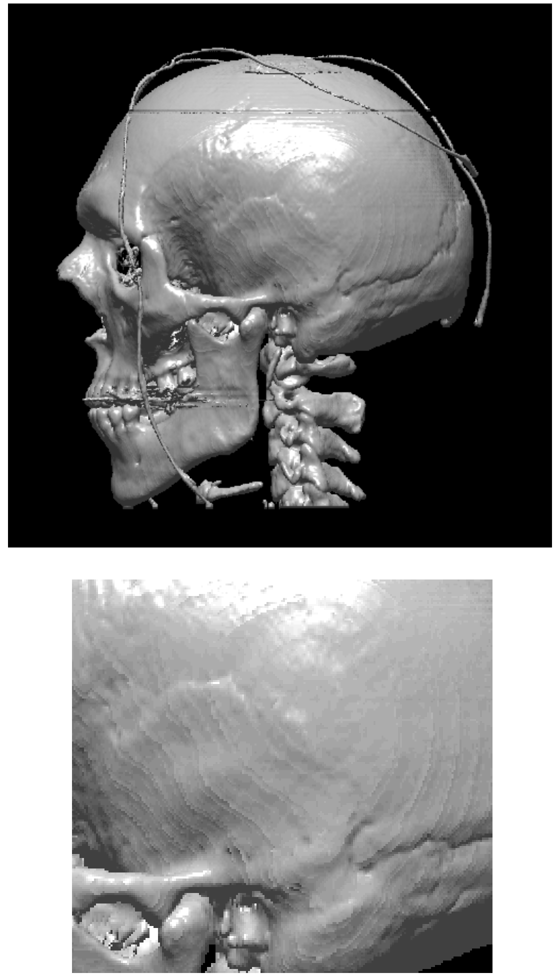


Intermediate differences

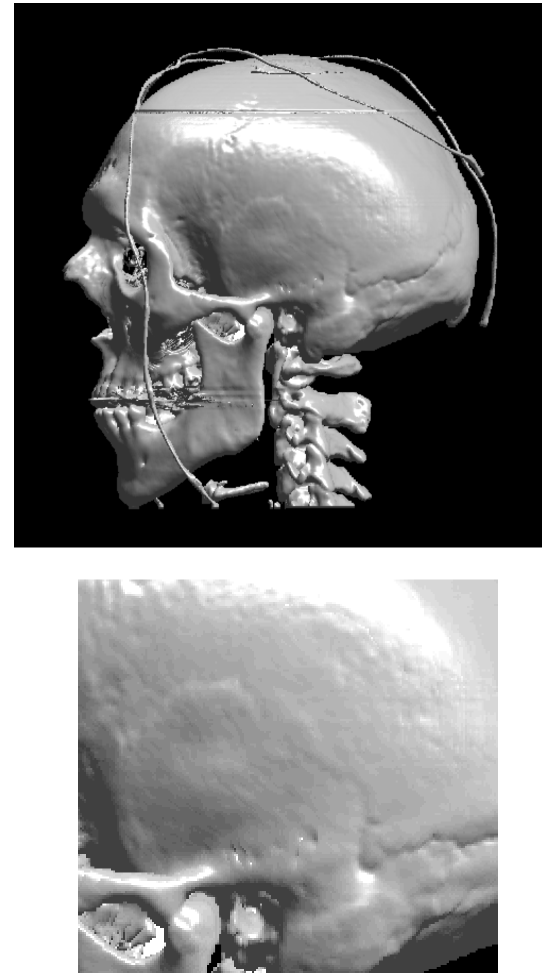
Volumetric Illumination



Intermediate differences



Central differences



Sobel operator