Introduction to Visual Medicine: Techniques, Applications and Software

Data Acquisition and Preprocessing

Dirk Bartz

Visual Computing (ICCAS), University of Leipzig

dirk.bartz@iccas.de

Outline

- Introduction
- **Medical Imaging Techniques**
- **Data Pre-Processing**
- Visualization and Navigation Techniques
- Visual Programming
- Medical Visualization in Radiology
- Visualization in Clinical Practice - A Vendor's Perspective

Afternoon: Advanced Visual Medicine

Basics

New book on that topic

(check Morgan-Kaufmann booth in the exhibition)

Bernhard Preim/Dirk Bartz:

Visualization in Medicine

Basics

Data Acquisition
using medical imaging techniques

Pre-Processing
segmentation, classification, etc.

Exploration
using visualization and
navigation techniques

Basics

Data Acquisition

using medical imaging techniques

Pre-Processing

segmentation, classification, etc.

Exploration

using visualization and navigation techniques

Medical Imaging Techniques (1)

© Siemens Medical Solutions

X-Ray

2D projection images based on absorption and scattering

- Very high resolution
- Bone/tissue contrast by selecting hard/soft radiation
- Only 2D

Medical Imaging Techniques (1)

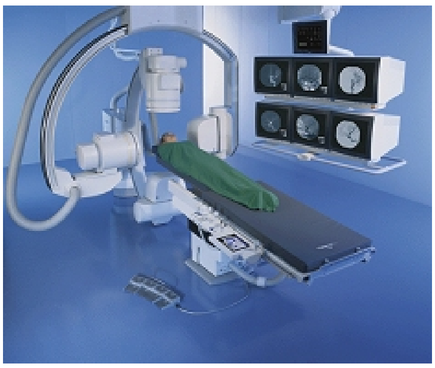
X-Ray

2D projection images based on absorption and scattering

- Very high resolution
- Bone/tissue contrast by selecting hard/soft radiation
- Only 2D

Hand of wife of C. Röntgen

Medical Imaging Techniques (2)



© Siemens Medical Solutions

Rotational Angiography

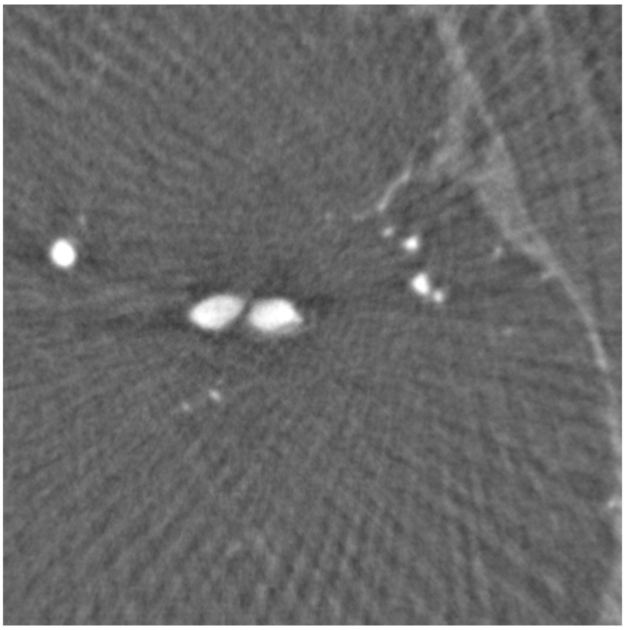
3D volume is reconstructed from **series of X-ray** scans

- Very high resolution
- Isotropic spacing (reduces artifacts)

Medical Imaging Techniques (3)

Rotational Angiography / 3D X-Ray:

- Slice of rotational angiography dataset
- Rotation over approx. 160^0



Medical Imaging Techniques (4)

Rotational Angiography / 3D X-Ray:

- 3D Rendering

Datasets at: http://www.volvis.org

Medical Imaging Techniques (5)

© Siemens Medical Solutions

Computed Tomography (CT/CAT)

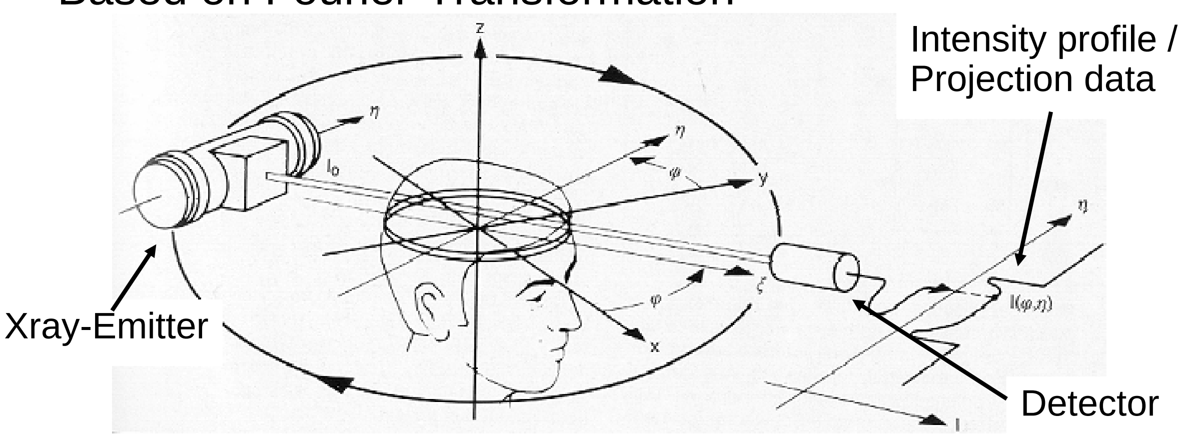
3D volume is reconstructed from X-ray projections
(Spiral CT, Multi-Slice CT 4/16, 64, FlatPanel)

- Fast image acquisition
- High resolution
- Different reconstruction approaches

Medical Imaging Techniques (6)

Computer Tomography (CT):

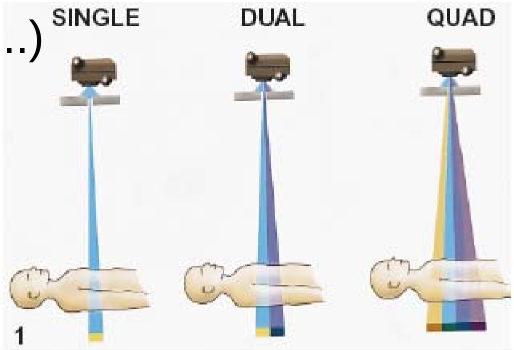
- Radon-Transformation reconstructs images from projection data/-profiles
- Based on Fourier-Transformation

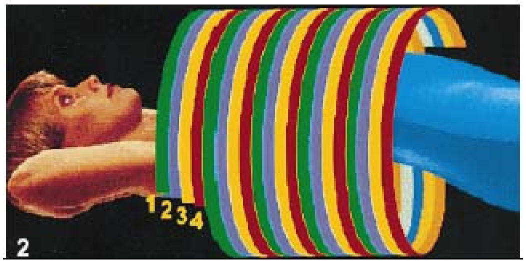


Medical Imaging Techniques (7)

Computer Tomography (CT):

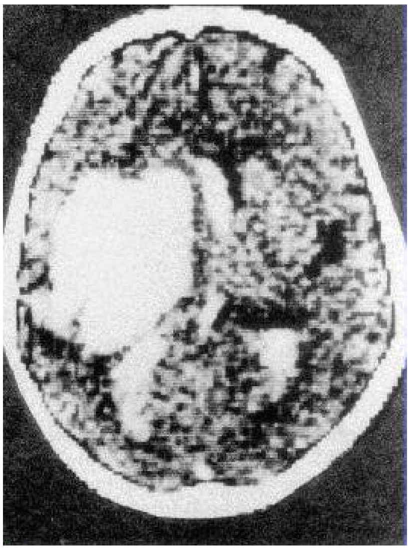
- Spiral- und Multi-Slice CT (4,16,...)
- Cone-beam reconstruction
- Flat panel detector: 256 slices
- Pros:
  - Better radiation usage
  - Faster
  - Higher resolution
- But more expensive





Medical Imaging Techniques (8)

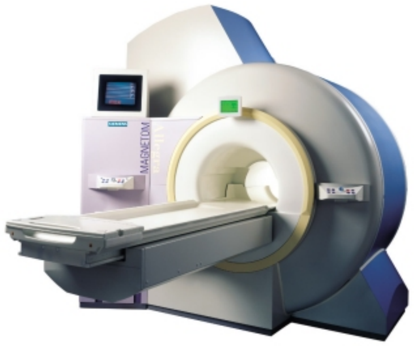
Computer Tomography (CT):



First images from Hounsfield

Abdomen CT

Medical Imaging Techniques (9)



Magnetic Resonance Imaging (MRI)

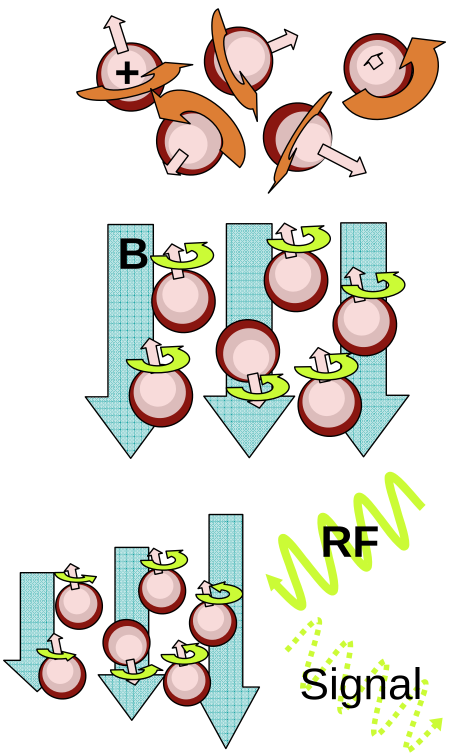
3D volume is reconstructed from measured proton (H_2-nuclei) spin (1.5T, 3T, ...)

- Relatively slow image acquisition
- No ionizing radiation
- Resolution depends on magnetic field strength
- Different protocols for a variety of tissue properties

Medical Imaging Techniques (10)

Principles of MRI

- H_2 nuclei have charge **(+)** and "spin" $\Rightarrow$ magnetic dipole moment
- Fixed external magnetic (**B**) field (1.5T, 3T, ...) causes dipole alignment and precession (like little tops)
- External radio-frequency (**RF**) pulse **resonates** with dipole precession
- Resulting rotating transverse magnetization received by coils
- Magnetic gradients vary Larmor frequency to encode position
- Slice images reconstructed via Fourier Transform



Medical Imaging Techniques (11)

Magnetic Resonance Imaging/Tomography

T2-weighted MRI-Image
(3D-CISS)

T1-weighted MRI-Image
(MR-Flash)

Sagittal Orientation

Medical Imaging Techniques (12)

Functional MRI (fMRI)

- Blood flow increases to active regions of the brain – saturates it with oxygen.
- Deoxyhemoglobin is paramagnetic (no O_2) and can be imaged with fMRI.
- While in scanner, subject exercises mental functions.
- This is useful in neurosurgical planning.

Medical Imaging Techniques (13)

Functional MRI (fMRI)

- Reconstructed scanning dataset includes volumes of
  - Anatomy of brain
  - Vasculature (blood vessels)
  - Each volume for an activation area

Medical Imaging Techniques (14)

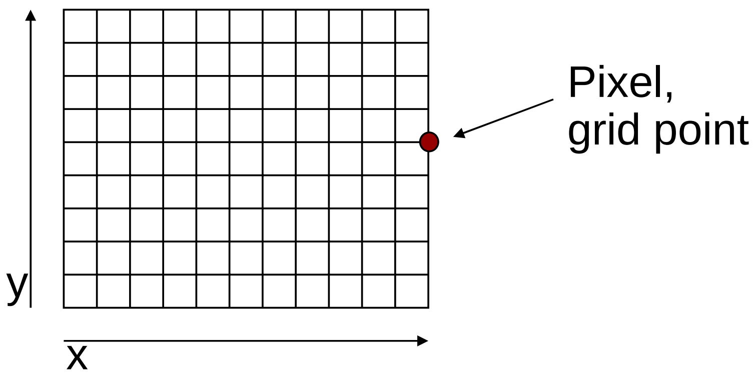
Many other imaging techniques:

- DTI – Diffusion Tensor Imaging (this afternoon)
- MRS – MR Spectroscopy
- MEG – **M**agneto**E**ncephalo**G**raphy
- (3D) Ultrasound
- Positron Emission Tomography (PET)
- SPECT
- …

Medical Imaging Techniques (15)

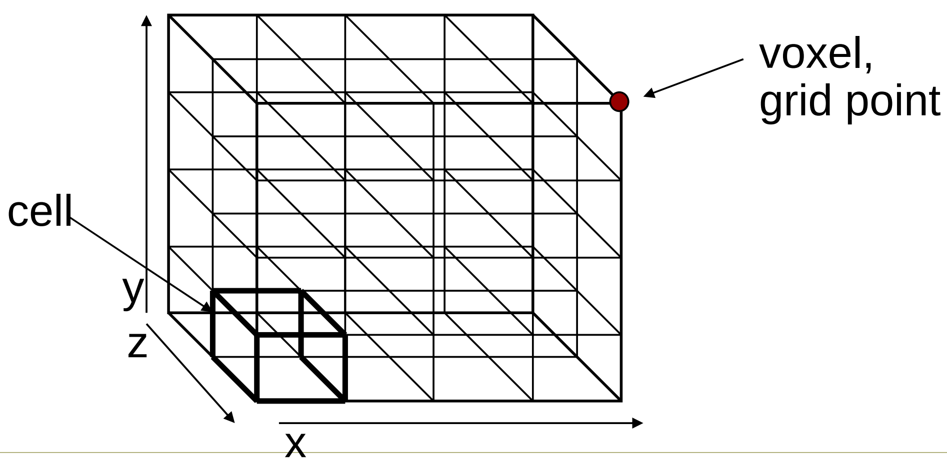
Volume data / stack of images:

- Images are composed of image elements
  → **pixel** (picture element)

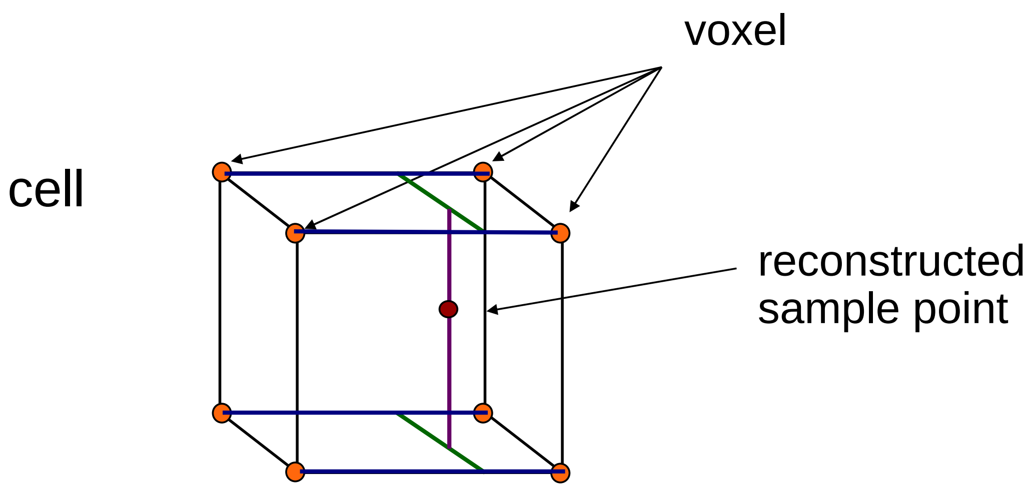


Medical Imaging Techniques (16)

- Volumes are composed of a stack of images (image stack).
  Volume elements are called voxels.

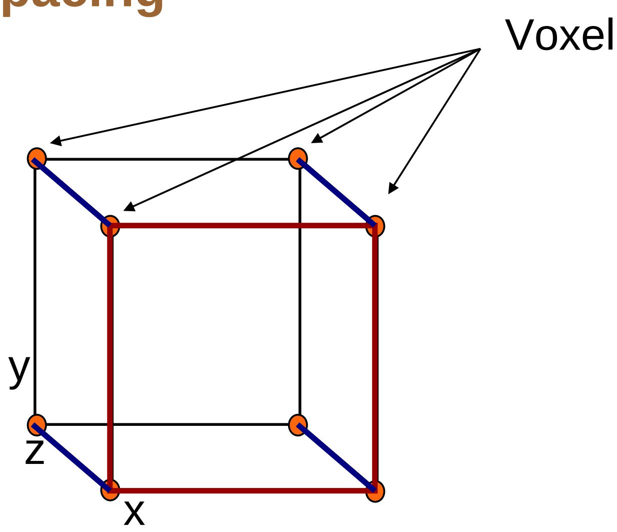


Trilinear volume interpolation:



Keywords in this context:

- **Volume cell** or simply cell
- Voxel distance or **voxel spacing**
  - **Pixel distance** (x/y) - Distances within a slice
  - **Slice distance** (z) – Distance between slices



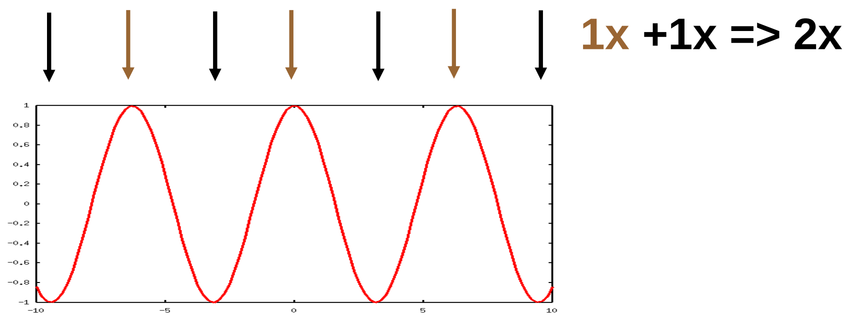
Limitations of volume data
- Aliasing problems

Most image/volume artifacts can be traced back to

- violating the **sampling theorem**, or
- **partial volume effects**
- **interpolation artifacts**

Sampling Theorem (Nyquist, Shannon):

The proper reconstruction of a signal requires a sampling of **at least two times** as fast (frequency) as the signal (**Nyquist - Rate**)



Medical Imaging Techniques (21)

Sampling Theorem:

- Sampling rate at least twice as high
- Better three times higher

Medical Imaging Techniques (22)

Partial Volume Effects:

- Basically also due to **undersampling** (at volume reconstruction)
- Large **intensity difference** between neighboring materials
- Sampling does not reflect high frequencies

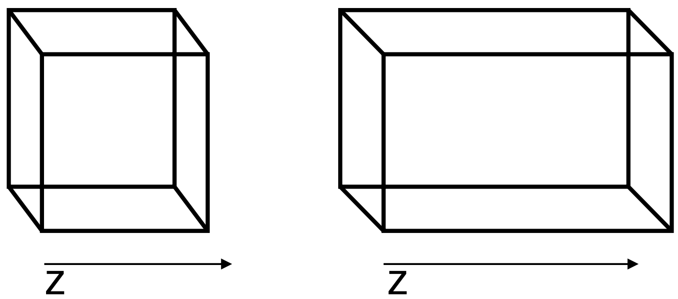
➔ **Material interface artifacts** (ie., holes, false connections) due to inherent **smoothing**

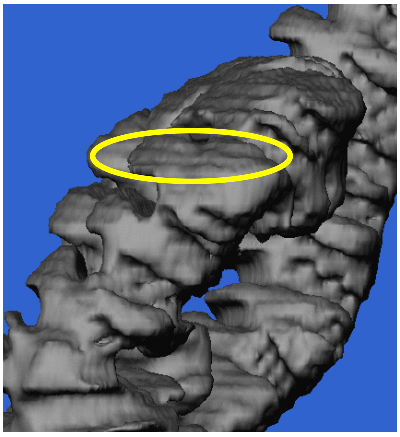
Medical Imaging Techniques (23)

Stair case artifacts

- Normal ($\vec{n}$) problem in anisotropic datasets

isotropic anisotropic





Foundations

Data Acquisition
using medical imaging techniques

Pre-Processing
segmentation, classification, etc.

Exploration
using visualization and navigation techniques

Data Pre-Processing

Several pre-processing operations:

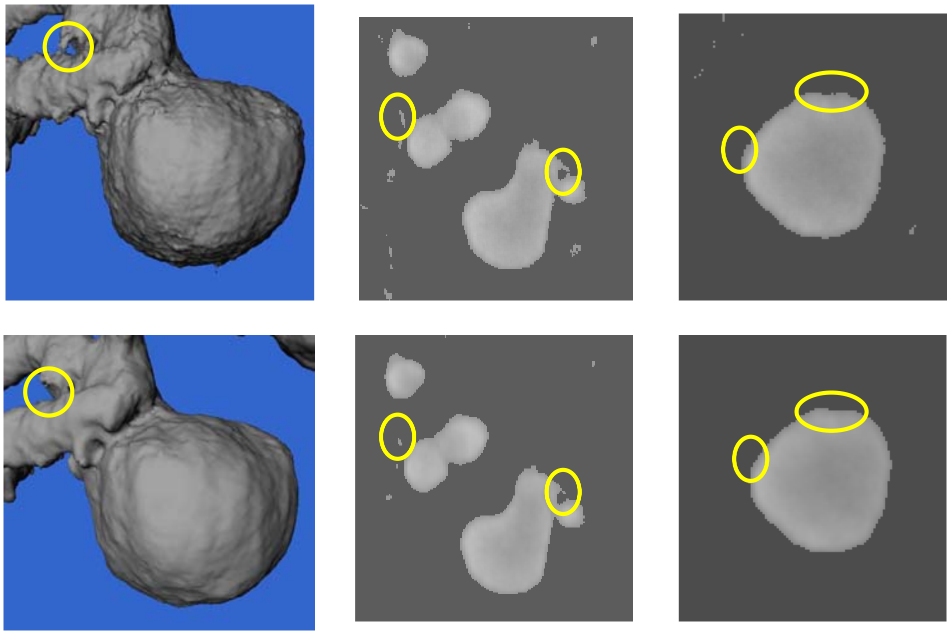
- Filtering/smoothing of data
- Segmentation of structures of interest (ie., organs)
- Classification - rendering parameters
- Registration of dataset with environment
- Fusion of multiple datasets of different origins (multi-modal representations)

Filtering (1)

- Volume data can be noisy

  ➔ low-pass filter to remove/reduce noise
- Data looses accuracy
- Small features which disappear might be below Nyquist rate
- Careful filter design
- Alternatives: Umbrella Operators

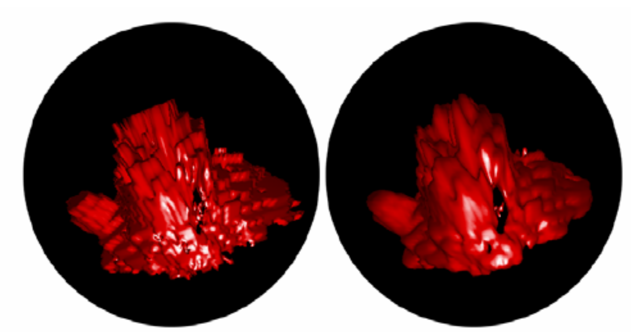
Filtering (2)



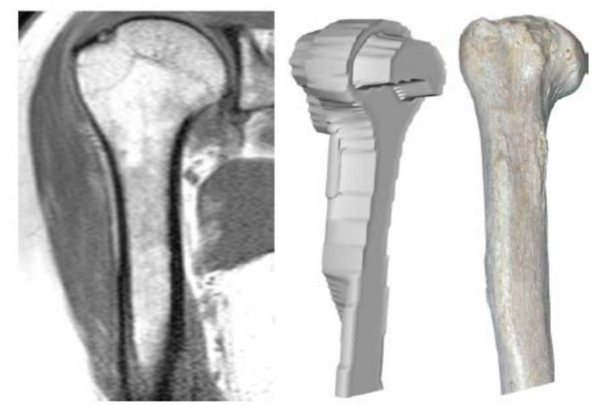
Filtered

Filtering (3)

Smoothing



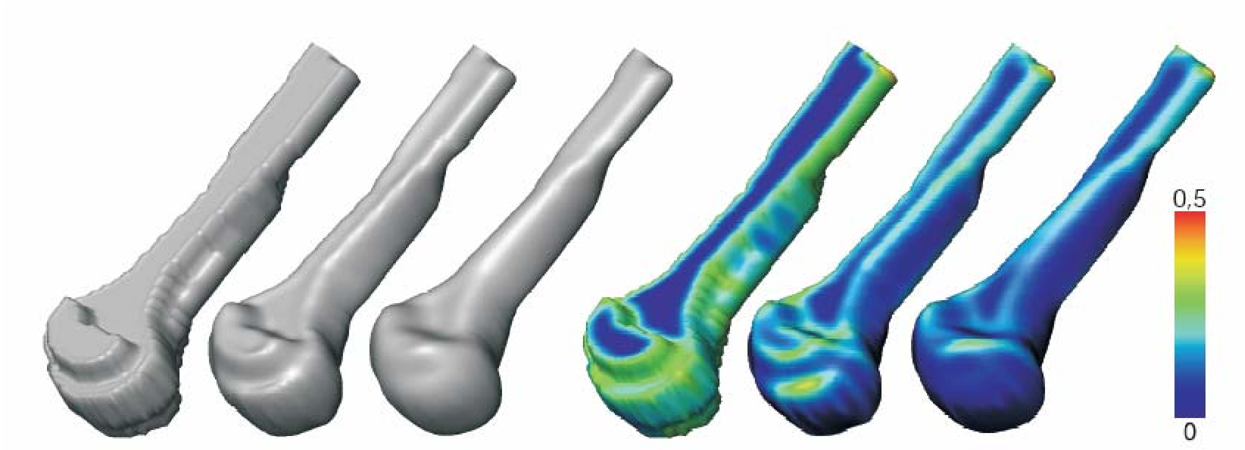
A. Neubauer, IEEE Vis 2004



MR Data 3D Vis Image
R. Bade, Univ., Magdeburg

Filtering (4)

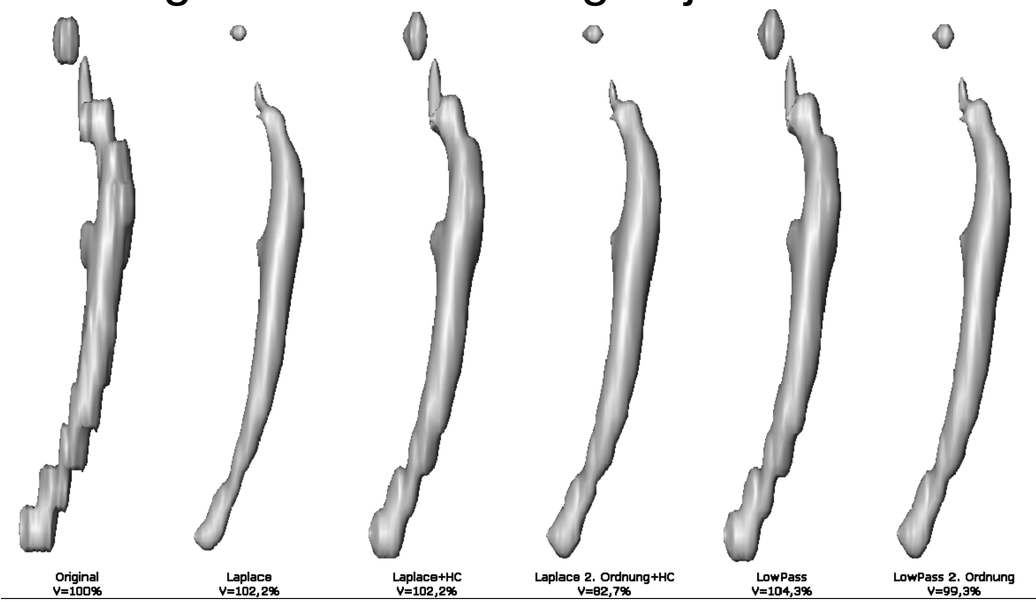
Smoothing and Curvature Plot
(Original, local low-pass, extended low-pass)



R. Bade, Univ., Magdeburg

Filtering (5)

Smoothing of small and long objects is difficult



R. Bade, Univ., Magdeburg

Windowing (1)

3D Scanner data are usually **12-16 bits**, while volume datasets / display provide often only **8 bits**

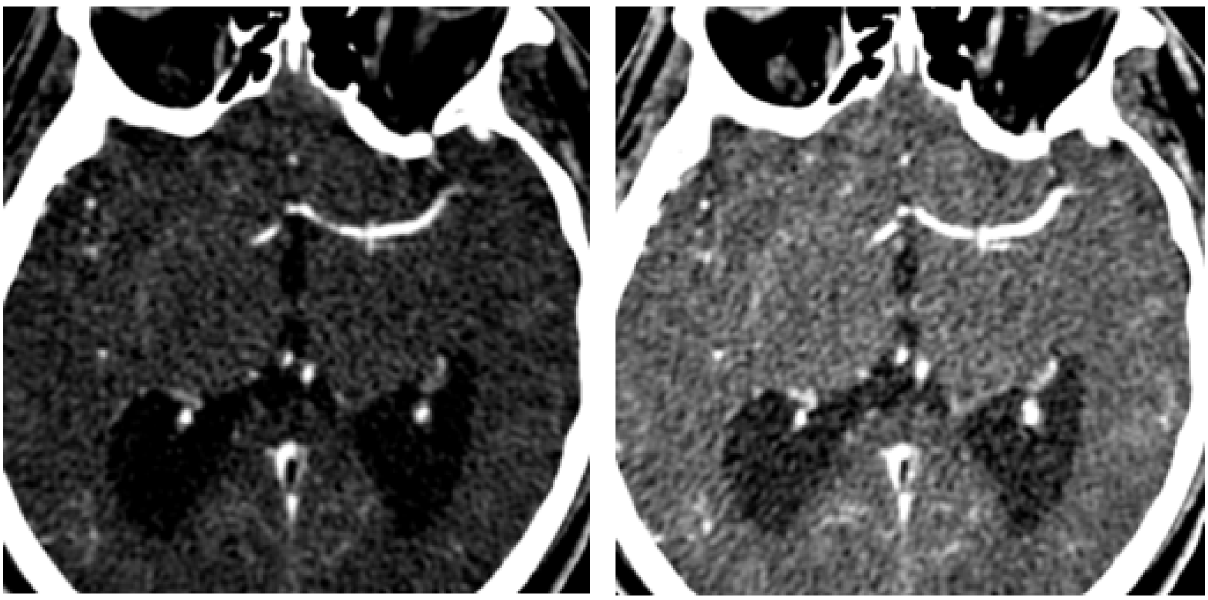
➜ requires **windowing**:

- select **sub range** of data

- **down sample** data

- inappropriate window can ruin contrast

Windowing (2)

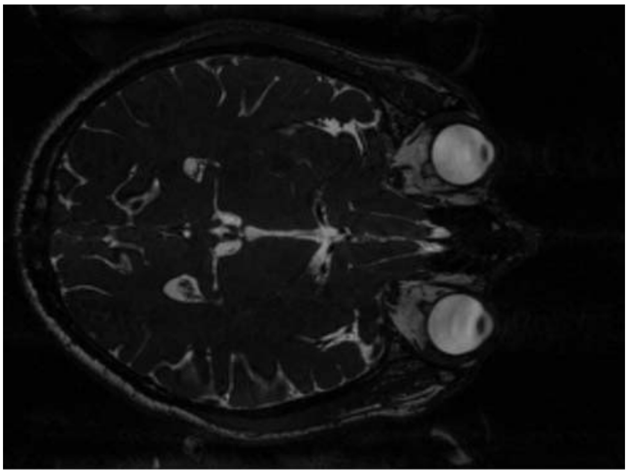


Different window ranges

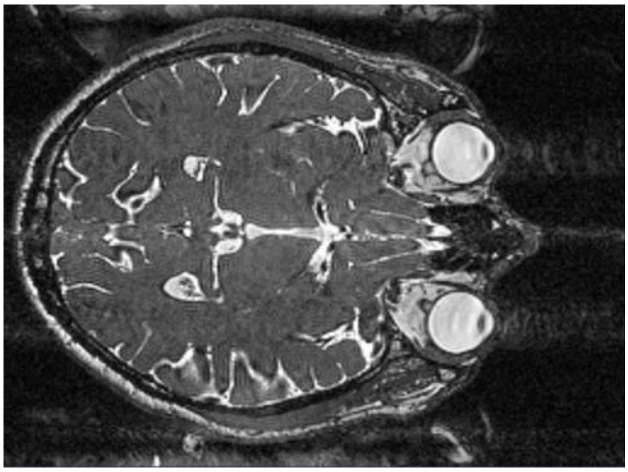
Windowing (3)

Enhancing of inadequate Data
(High Dynamic Range Operator)

8bit MRT CISS

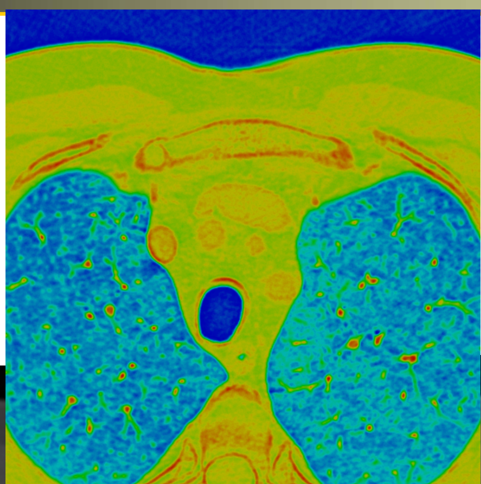


8bit MRT CISS/PTR

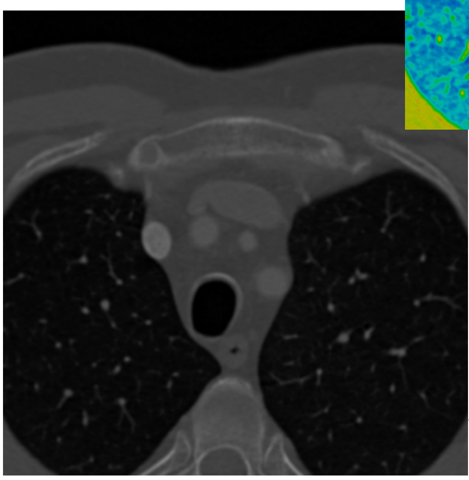


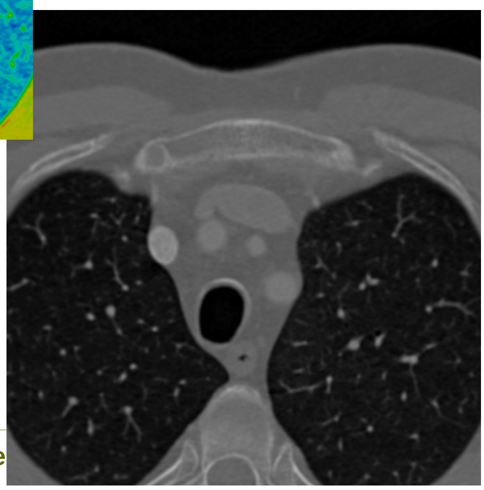
Windowing (4)

CT Thorax,
12bit/voxel



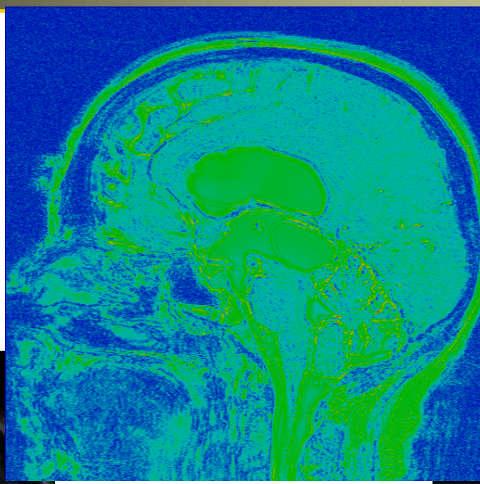
Relative Difference



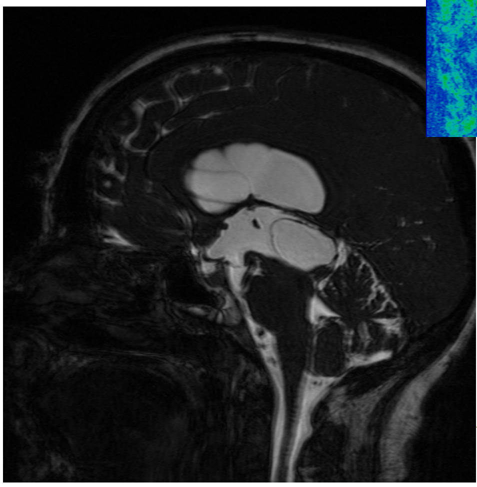


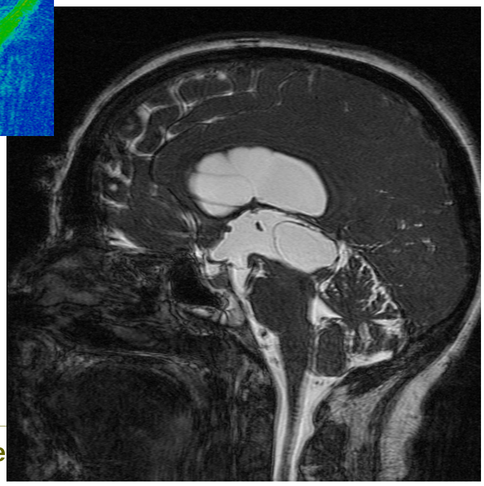
Windowing (5)

MRT CISS,
10bit/voxel



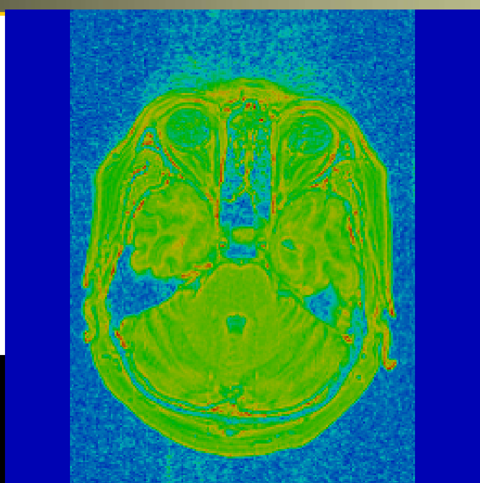
Relative Difference



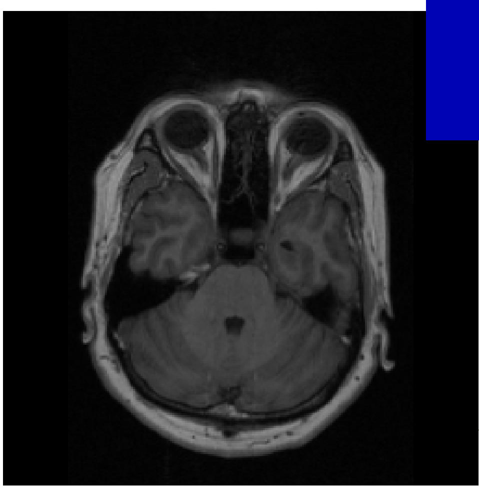


Windowing (6)

MRT FLASH,
9bit/voxel



Relative Difference



Segmentation (1)

Problem: Structures easily detected by the human eye are **difficult to specify** for a computer

- **Many different segmentation** approaches and variations available
- **Specific image acquisition** protocols can ease segmentation difficulties

Segmentation (2)

- Automatic segmentation frequently segments **too much**, or **not all** structures
- Manual segmentation is usually **too expensive** for daily practice (ie., visible human datasets)
- Semi-automatic segmentation with little interaction only:
  can consist of **several steps**

Check out: http://www.itk.org

Segmentation (3)

Typical (and possibly most used) semi-automatic segmentation is 3D Region growing

- specify **seed point** inside structure of interest
- specify **threshold interval** which describes material interfaces
- successively **selects neighboring voxels** until threshold interval is violated

Segmentation (4)

Potential problems of 3D region growing:

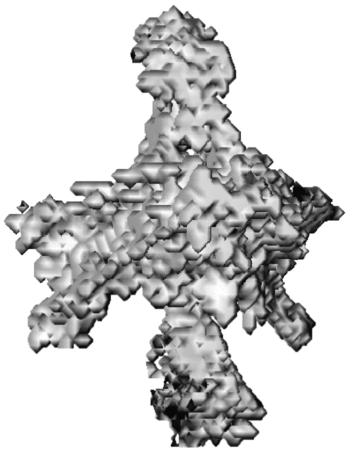
- Inappropriate threshold interval
- False/missing connections due to **partial volume effect** or **signal attenuation**
- Resolution too low
- Contrast too low; good contrast:
  feature intensity high, surrounding intensity low

Segmentation (5)

Binary segmentation can result in bumpy appearance due to interpolation artifacts (similar to staircasing)

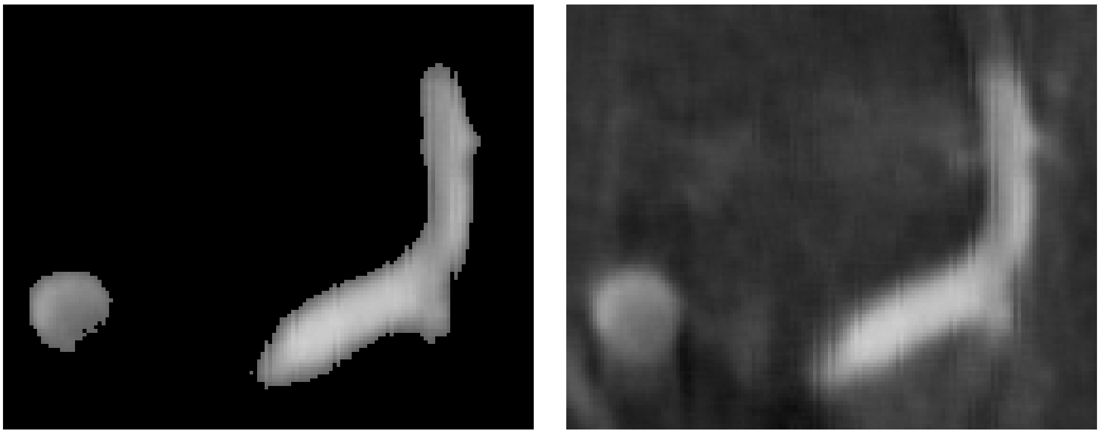
➔ **Add boundary** to segmentation

See also filtering.



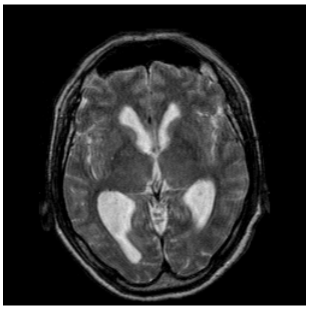
Segmentation (6)

Which is the correct threshold interval?

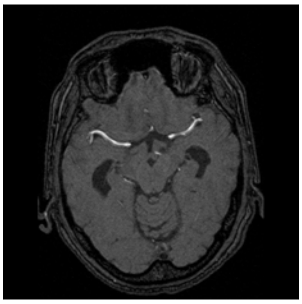


Segmentation (7)

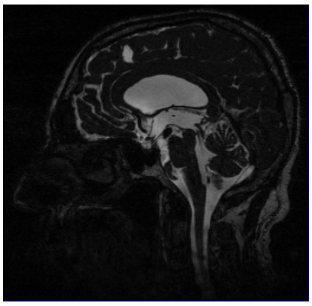
Examples of good contrast:



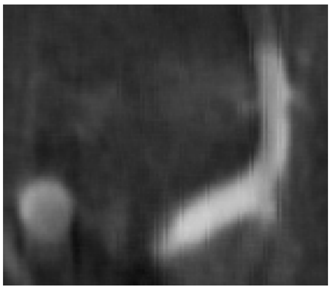
MRI TSE:
Fluid filled
cavities



MRI TOF:
blood vessels



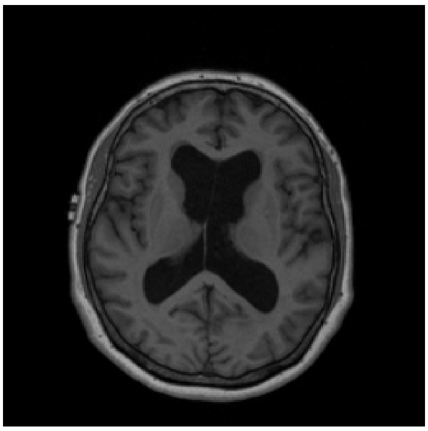
MRI 3D CISS:
Fluid filled
cavities



Rot. Angiography
contrast agent
enhanced cavities

Segmentation (8)

Examples of insufficient contrast:



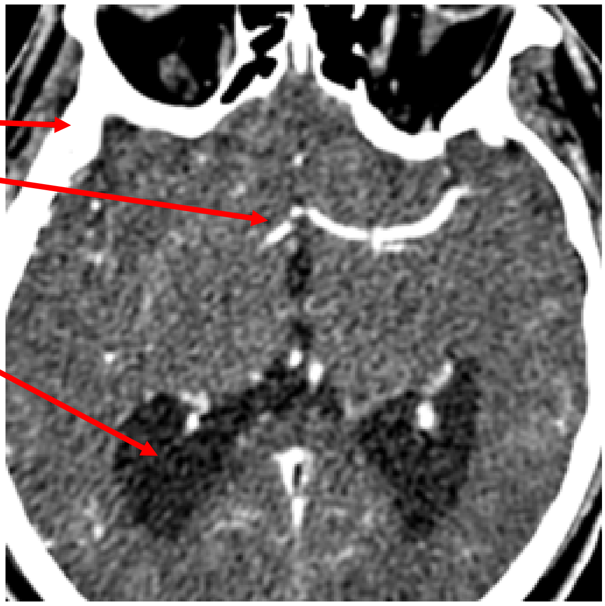
Differentiation
ventricles / empty space

Differentiation
corpus callosum / brain tissue

MRI Flash/T1

Segmentation (9)

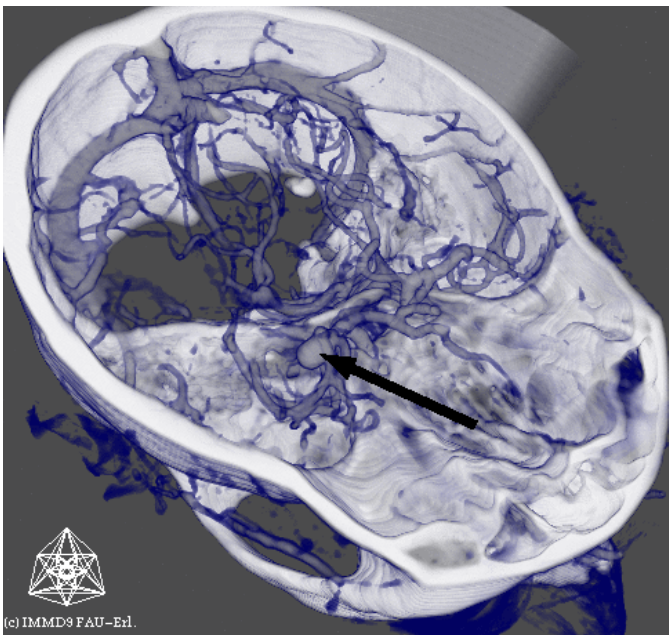
CT Angiography:
- good bone contrast
- good angio contrast
- poor contrast of ventricles (noisy surfaces)



Segmentation (9)

CT Angiography:
- good bone contrast
- good angio contrast
- poor contrast of ventricles (noisy surfaces)

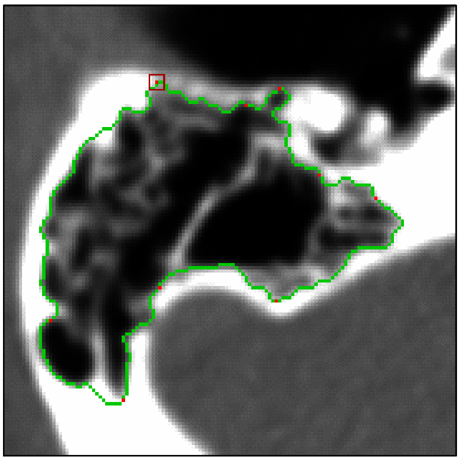
Hastreiter et al.,
Univ. Erlangen-Nürnberg



Segmentation (10)

LifeWire (Intelligent Scissors)
[Mortensens, Barret, SIGGRAPH 1995]

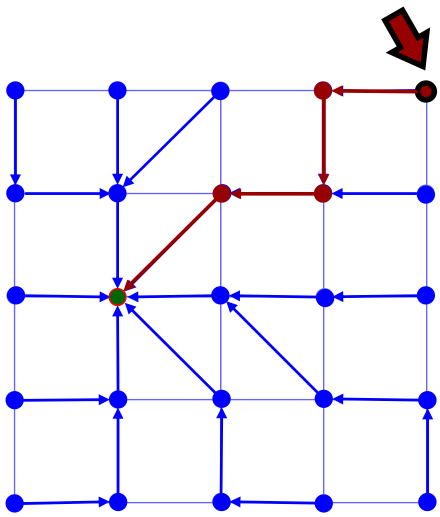
- Edge/contour oriented
- Interactive approach
- Minimizes cost function
- Interprets segmentation as graph problem



Segmentation (11)

LiveWire

- Extraction of object contours
- Dijkstra‘s Minimal-Path-Algorithm
- Pixels $\rightarrow$ graph nodes
- Edges are costs
- Seed point

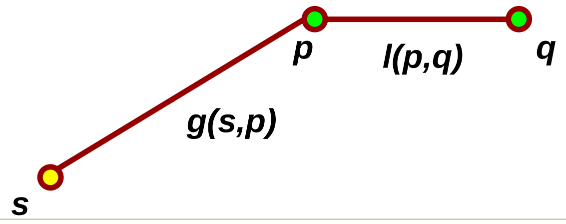


Segmentation (12)

LiveWire – Cost Function

- Local cost function l(p,q)

- Total cost function of a path g(s,q)



g(s,q) = g(s,p) + l(p,q)

Segmentation (13)

LiveWire – Cost Function

- Paths of minimal costs → object contours
- Edge detecting methods:
  - Zero-crossing of Laplace filtered image → f_Z
  - Magnitude of gradient → f_G
  - Direction of gradient → f_D

$$l(p,q) = \omega_Z \cdot f_Z(q) + \omega_G \cdot f_G(q) + \omega_D \cdot f_D(p,q)$$

zB. ω_Z=0.43, ω_G= 0.43, ω_D= 0.14

Segmentation (15)

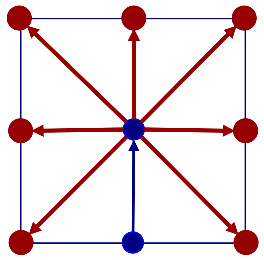
LiveWire – Cost Function

- Zero-crossing of Laplace filtered image (2. derivative) – **detects contours (edges)**
- Magnitude of gradient (1. derivative) – **contour strength**
- Direction of gradient (1. derivative) – **Smooth countours** (little changes of directions)

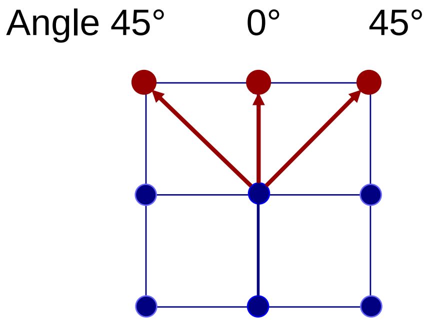
Segmentation (16)

LiveWire – Path Search

Full Path Search



Limited Path Search



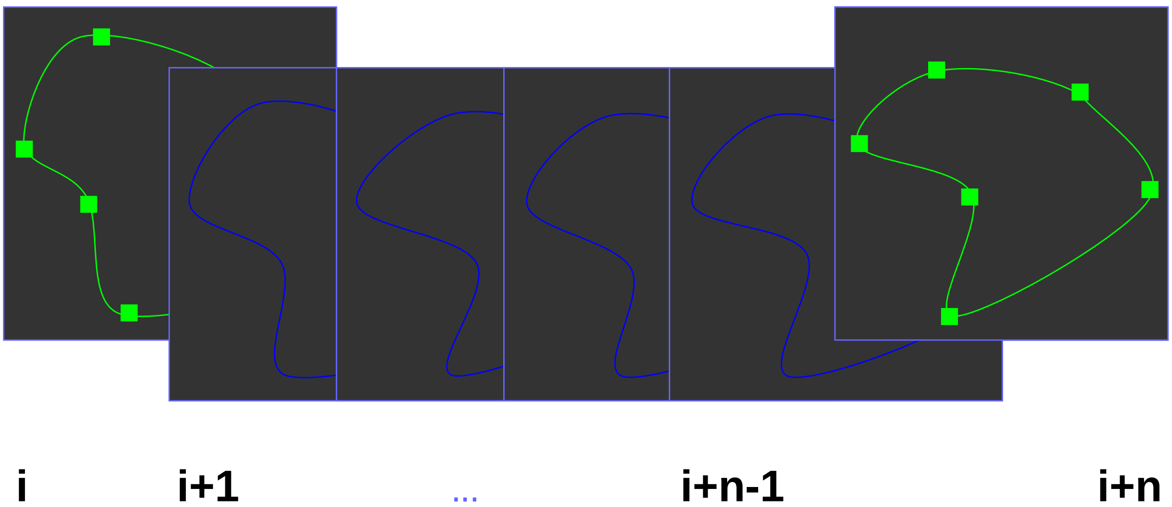
Segmentation (17)

LiveWire for Image Sequences

- Interpolation of LiveWire contours
- Propagation of seed points

Segmentation (18)

LiveWire for Image Sequences: Interpolation

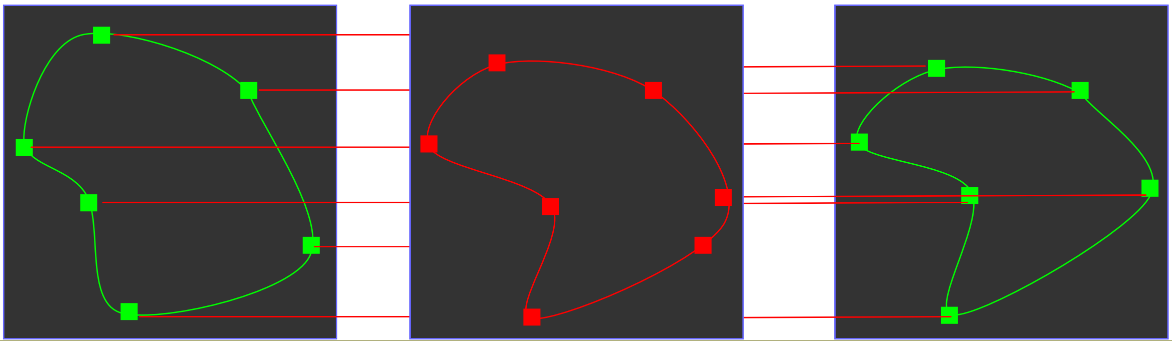


Segmentation (19)

LiveWire for Image Sequences: Interpolation

Optimization

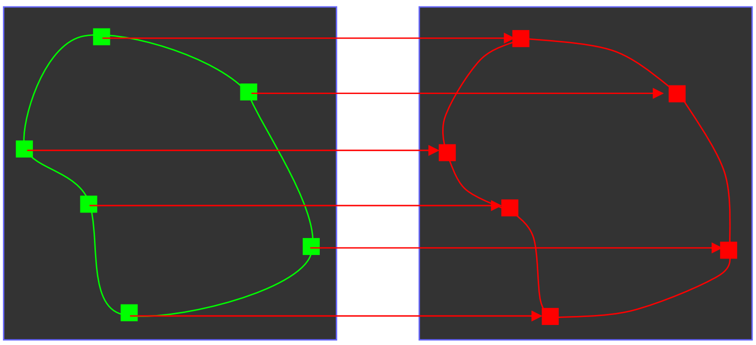
- Projection of seed points
- Computation of LiveWire contour



Segmentation (20)

LiveWire for Image Sequences: Propagation

- Propagation of seed points
- Automatic computation of LiveWire contour

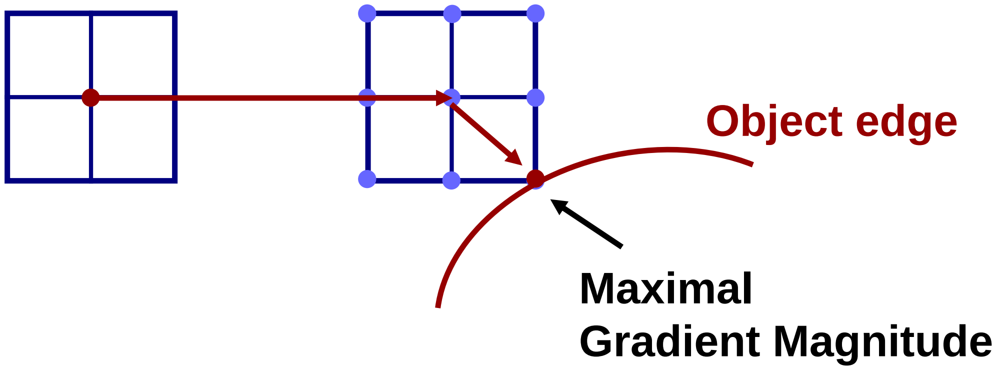


i **i+1**

Segmentation (21)

LiveWire for Image Sequences: Propagierung

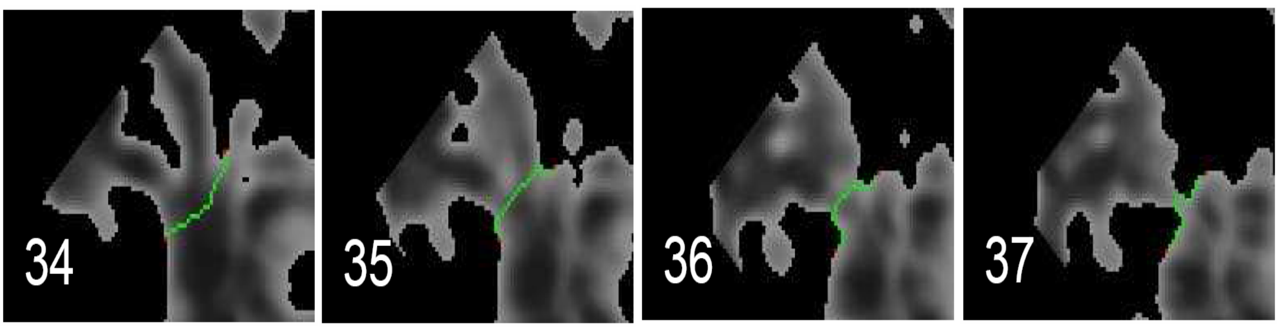
- Propagation of seed points



Segmentation (22)

LiveWire for Image Sequences: Propagierung

- Separation lines



1st Separation line is generated interactively (using live-wire)

Control points are propagated to the next slices to generate new separation lines

Unlike interpolation, propagation is applicable to **open contours**

Segmentation (23)

Other popular segmentation approaches

- Watershed transformation (very popular as well)
- Model-based approaches
    - Statistical shape models
    - Level-Sets
    - Physically-based models

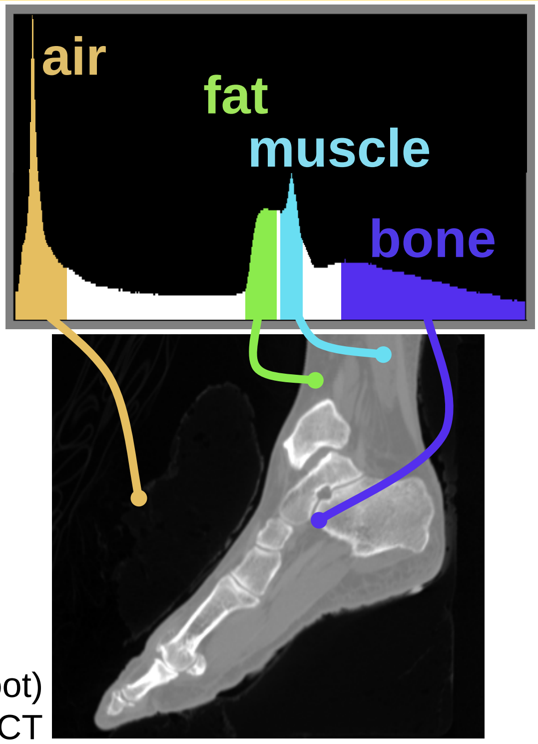
Classification (1)

- Classification specify **how data is rendered** (for direct volume rendering)
- Often **confused with segmentation**
- Are expressed by **transfer functions**
- Are usually based on **histogram**: every possible scalar value is assigned to a tuple of color and opacity
- Focuses on **material interfaces**
- May introduce **high frequencies**

Classification (2)

Example of transfer function

- Histogram:
- **Peaks indicate material interiors**
- **Valleys: material interfaces**
- **Transfer functions often emphasize interfaces more than interiors**

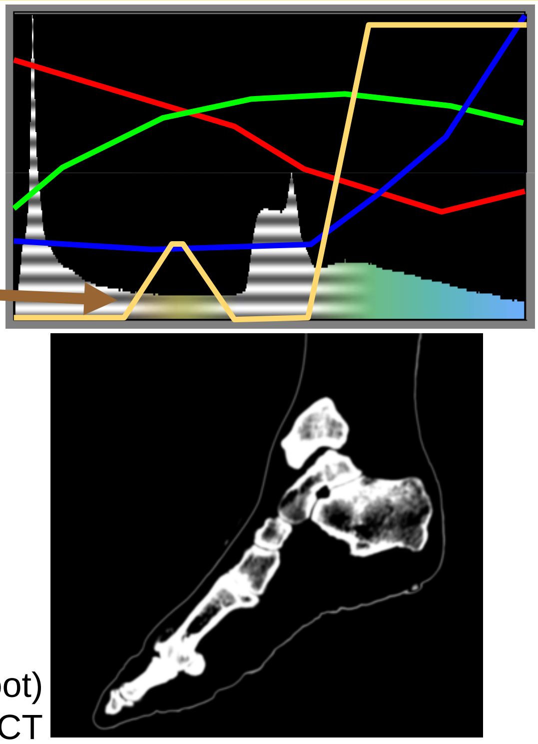


Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

- Histogram
- Opacity

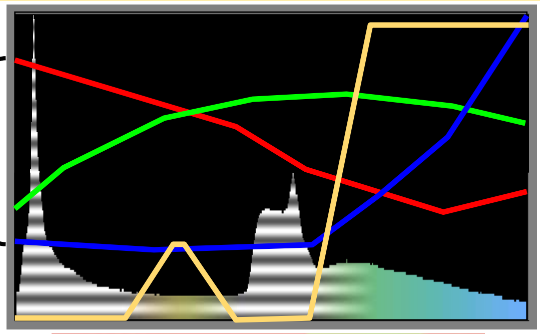


Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

- Histogram
- Opacity
- RGB channels

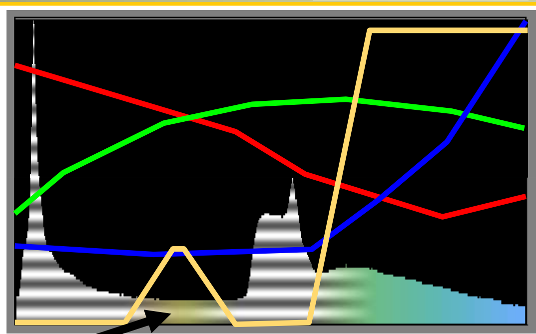


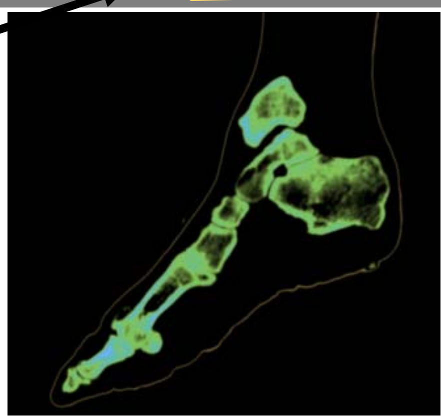
Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

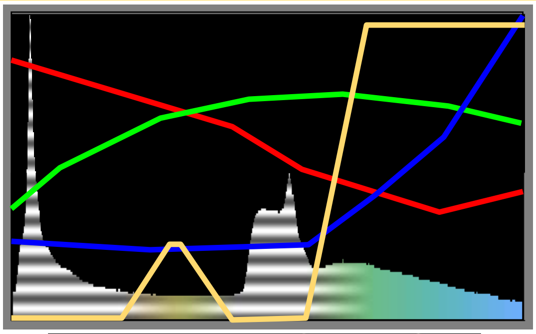
- Histogram
- Opacity
- RGB channels
- Resulting Color



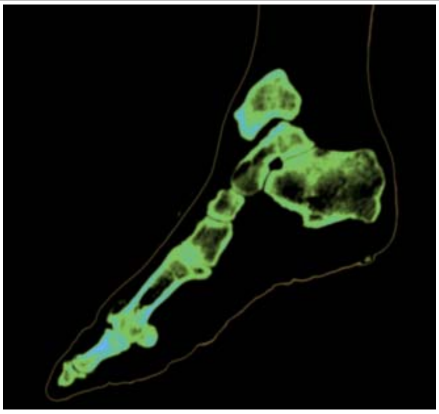


Visible Human (foot)
Female Fresh CT

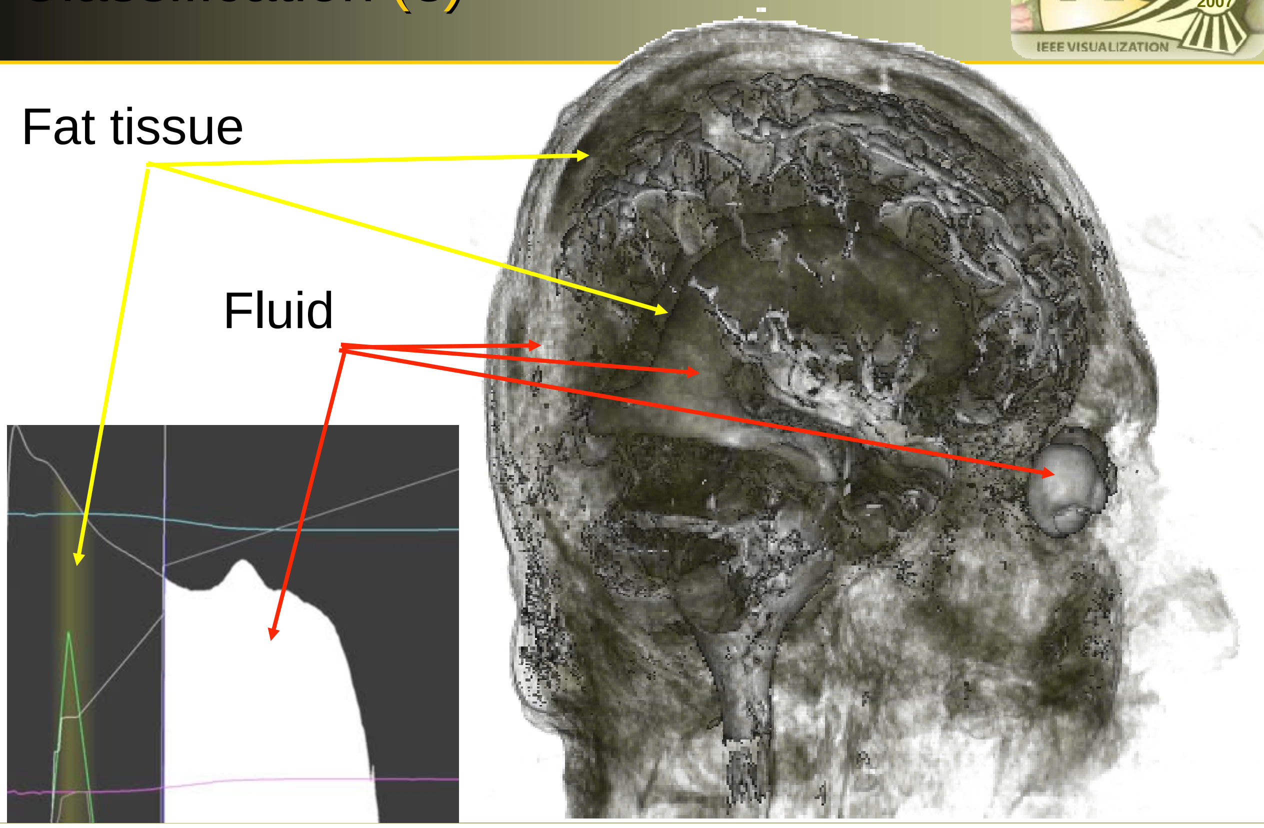
Classification (2)



Visible Human (foot)
Female Fresh CT

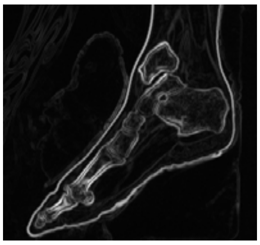


Classification (3)

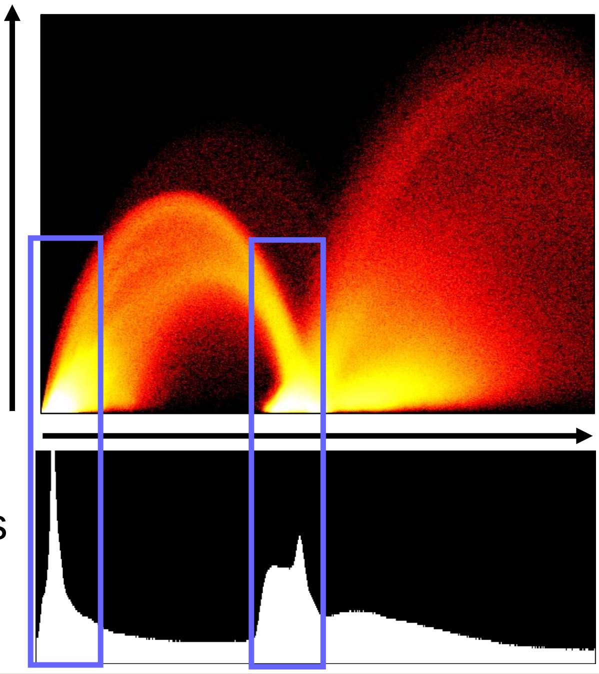


Classification (4)

2D (joint) histograms: data value vs. gradient magnitude



gradient magnitude



data (CT) value

2D domain may better distinguish between materials and interfaces

(more details this afternoon)

[G. Kindlmann et al., 1998]

Registration (1)

- Datasets are put in context with environment
- Also referred to as **matching**
- Provides a **reference frame** for tools, ie., scalpels, endoscopes, etc.
- **Intra-operative navigation systems** register dataset with OR coordinate system

Registration (2)

- Usually an **optimization problem**
- Optimized are
  - Mutual information (entropy) or
  - Landmark matching
- The more data points, the higher the accuracy

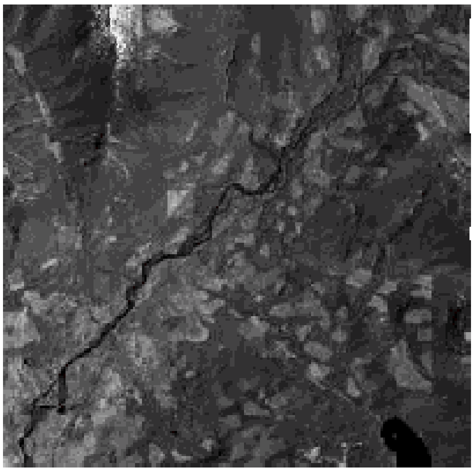
Registration (3)

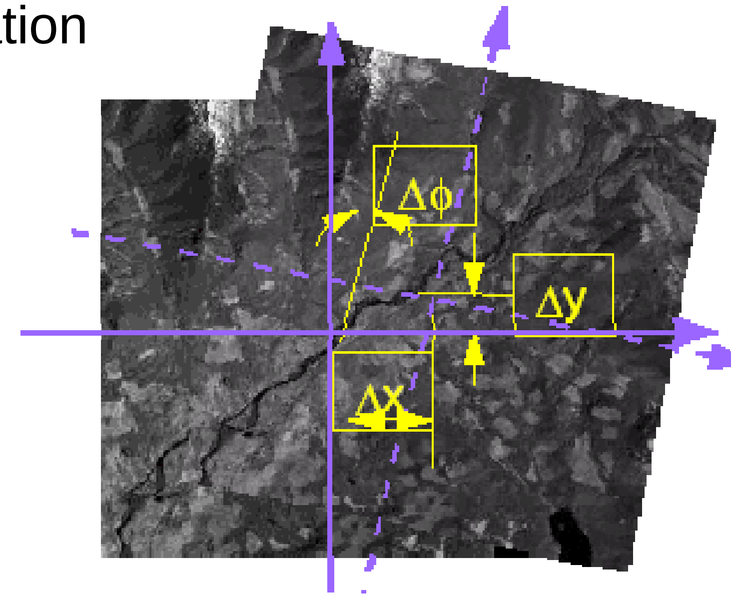
- **Rigid registration**: linear transformations (translations, scaling, rotations, ...)
  of data volume/images (2D or 3D)
  - Rigid: Translation, Rotation
  - Affine: Translation, Rotation, Scaling, …
- **Non-rigid registration**: non-linear deformations of data volume; usually only 3D
- Check: http://www.image-registration.com
  and http://www.itk.org

Registration (4)

Registration of aerial photography

- Translation and rotation





images source: http://lis1.iis.sinica.edu.tw

Registration (5)

- The **more sample points**, the better the **accuracy**

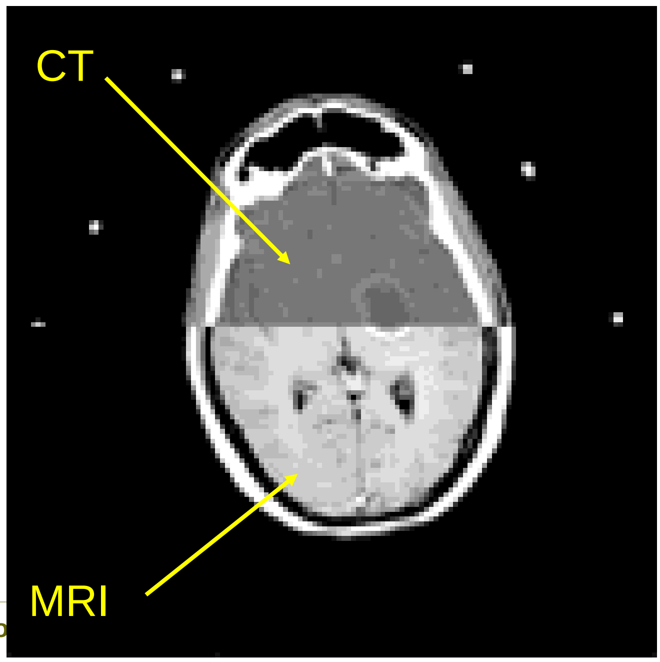
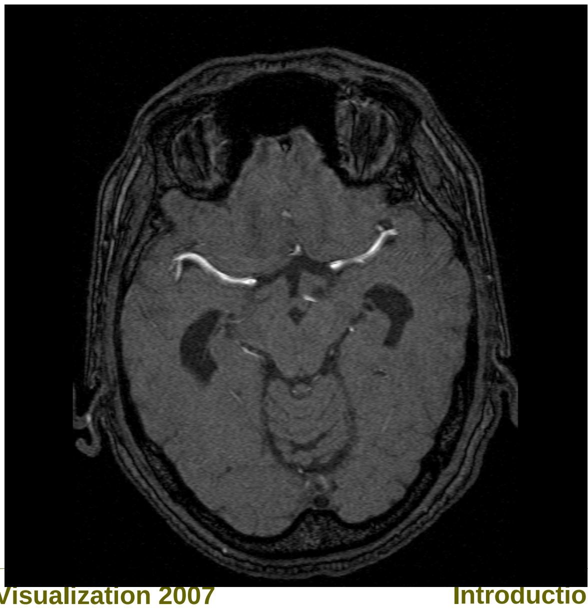


image source: http://???

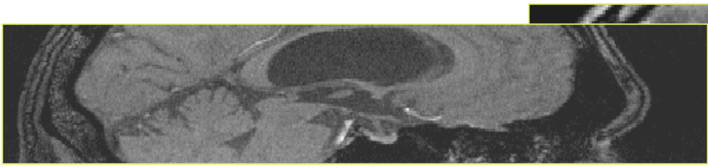
Registration (6)

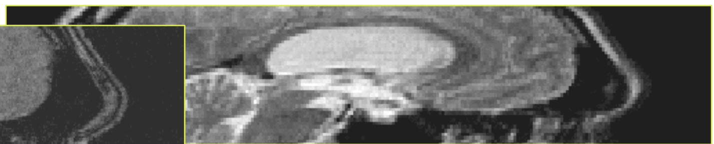
Registration can be very simple:



Registration (7)

Registration can be very simple:





Patient movement negligible

Registration (8)

Most clinically used registration approaches (all rigid):

- Landmark-based matching
- Point cloud matching (Iterative Closest Point ICP)

Data Fusion (1)

- Combined representation of different datasets
- Usually requires registration
- Datasets can be from different modalities (ie., CT, MRI, rotational angiography, ...)
- Can be from different sources: Fully segmented/annotated medical atlas and patient datasets

Data Fusion (2)

Consider rendering parameters how to incorporate data from different sources:

- (Relatively) simple for surfaces
- Difficult for accumulative volume rendering