Visual Medicine: Data Acquisition and Preprocessing

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Outline

Introduction

Basics of Medical Imaging

- **Medical Imaging Techniques**
- **Data Pre-Processing**
- Visualization and Navigation Techniques
- Visual Programming …

Afternoon:

Advanced Topics in Visual Medicine

Discussion

Basics

New book on that topic

(check Morgan-Kaufmann booth at Vis)

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)

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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
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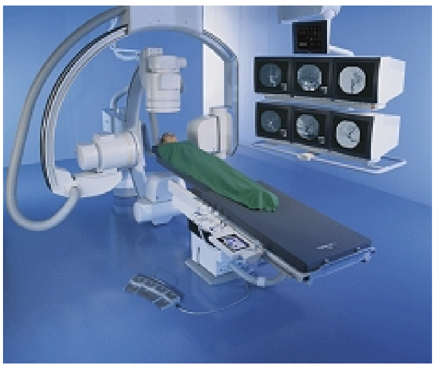
- Only 2D

Hand of wife of C. Röntgen

Medical Imaging Techniques (2)



Rotational Angiography

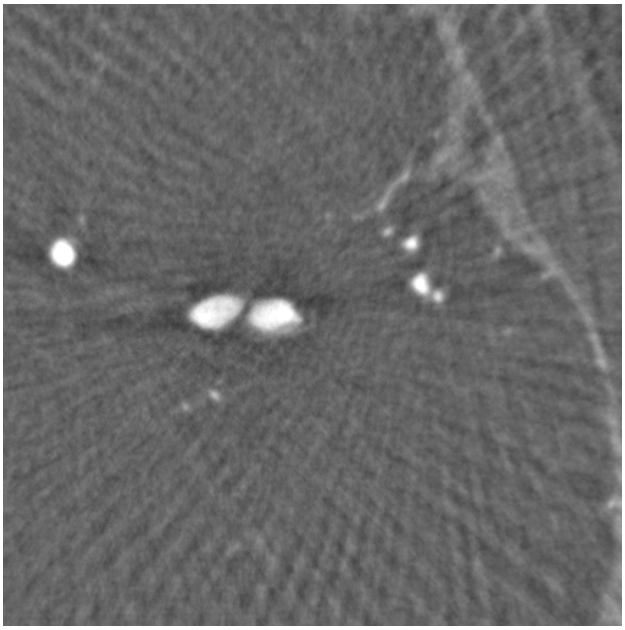
3D volume is reconstructed from **series of X-ray** scans

- 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)

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Computed Tomography (CT/CAT)

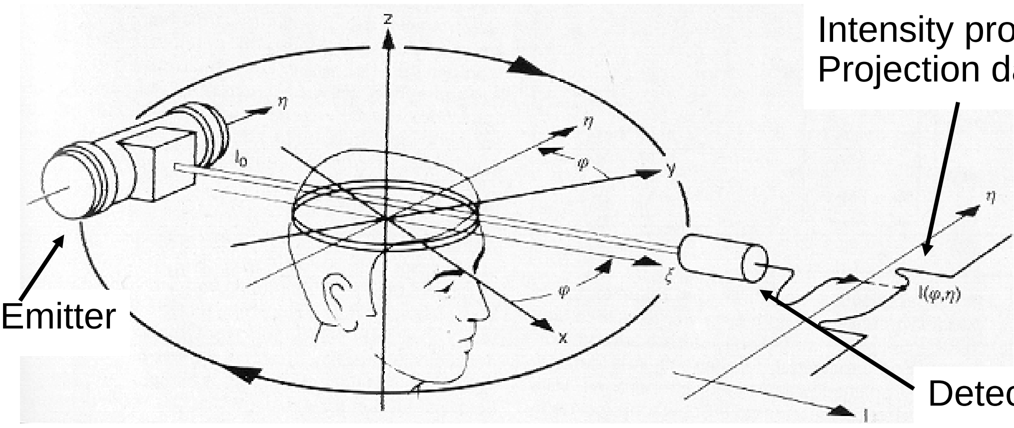
3D volume is reconstructed from X-ray projections
(Spiral CT, Multi-Slice CT 4/16)

- Fast image acquisition
- High resolution
- Different reconstruction approaches

Medical Imaging Techniques (6)

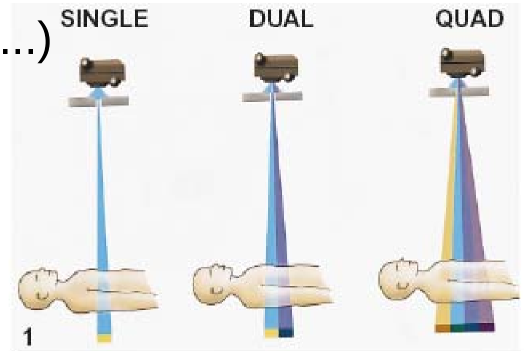
Computer Tomography (CT):

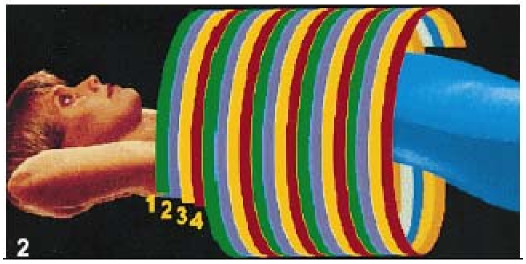
- Radon-Transformation reconstructs images from projection data/-profiles
- Based on Fourier-Transformation



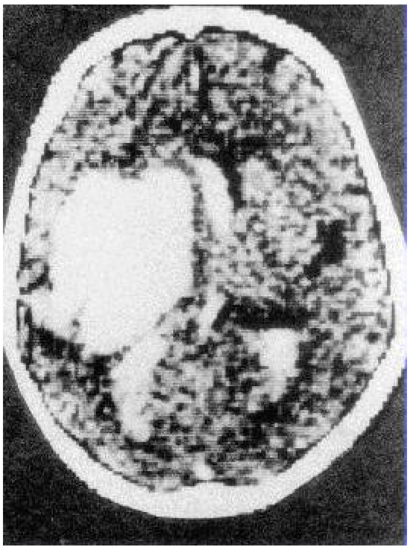
Computer Tomography (CT):

- 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





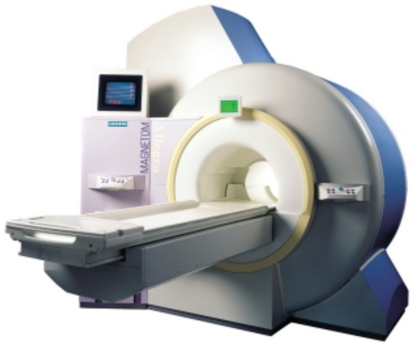
Computer Tomography (CT):



First images from Hounsfield

Abdomen CT

Medical Imaging Techniques (9)



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Magnetic Resonance Imaging (MRI)

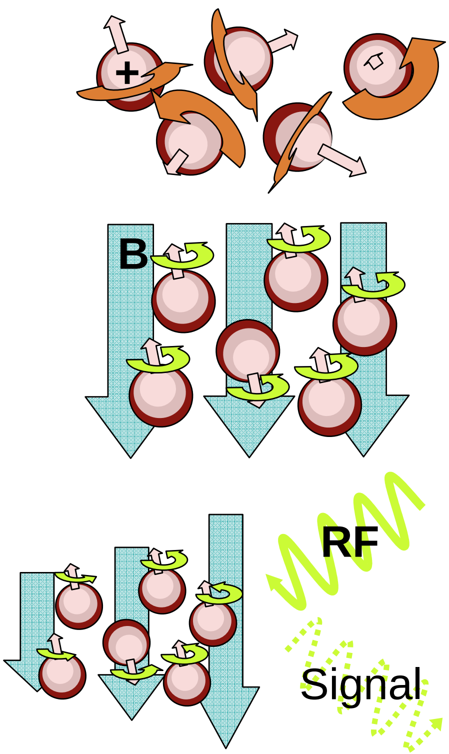
3D volume is reconstructed from measured proton (H_2-nuclei) spin (1.5T, 3T, ...)

- 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” ⇒ 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)

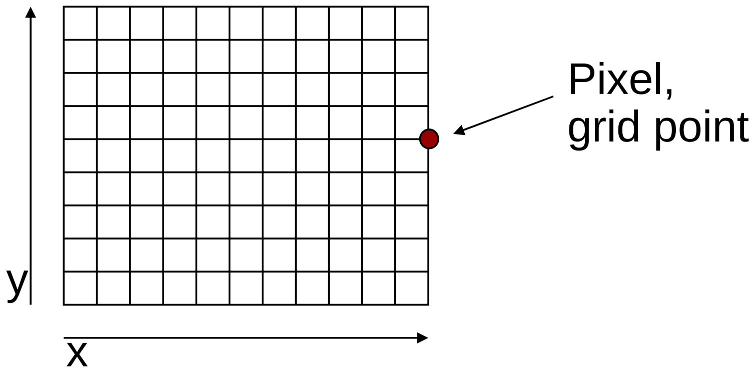
Many other imaging techniques:

- 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)

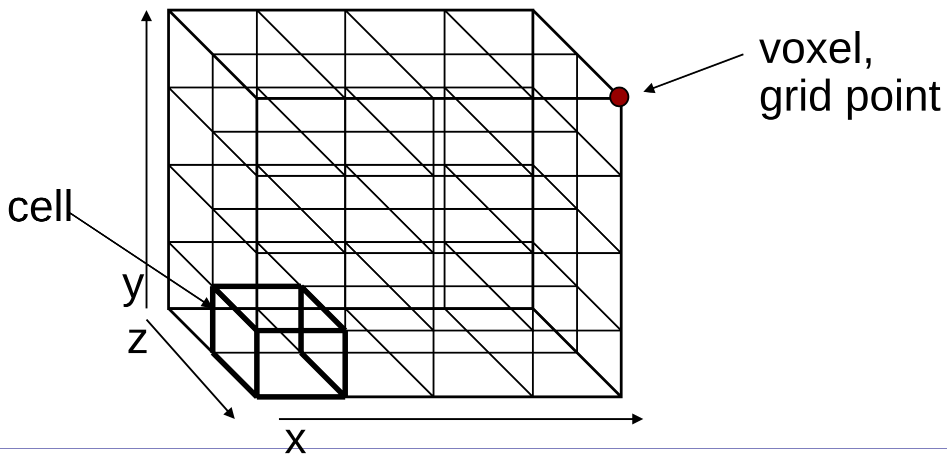
Volume data / stack of images:

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



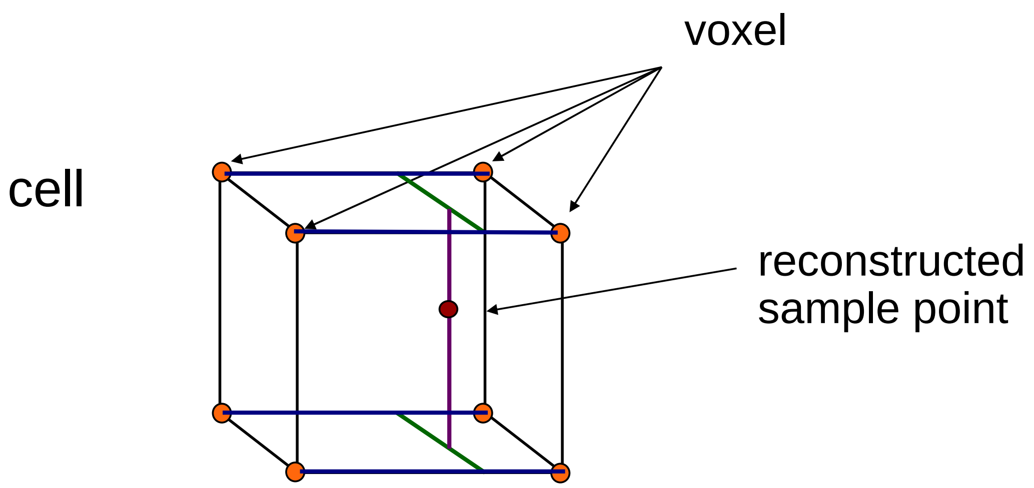
Medical Imaging Techniques (16)

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



Medical Imaging Techniques (17)

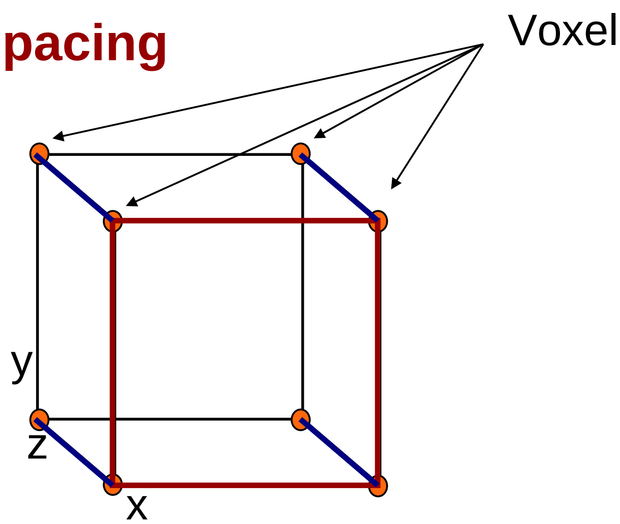
Trilinear volume interpolation:



Medical Imaging Techniques (18)

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



Medical Imaging Techniques (19)

Limitations of volume data
- Aliasing problems

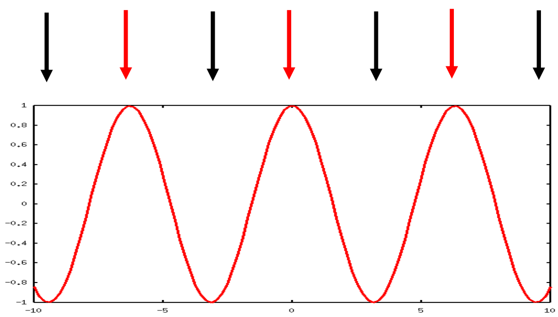
Most image/volume artifacts can be traced back to

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

Medical Imaging Techniques (20)

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**)



1x +1x => 2x

Medical Imaging Techniques (21)

Sampling Theorem:

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

Medical Imaging Techniques (22)

Partial Volume Effects:

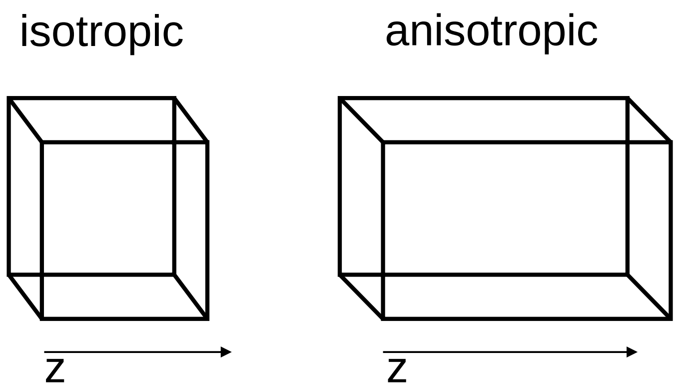
- Basically also due to **undersampling** (at volume reconstruction)
- Large **intensity difference** between neighboring materials
- Sampling does not reflect high frequencies

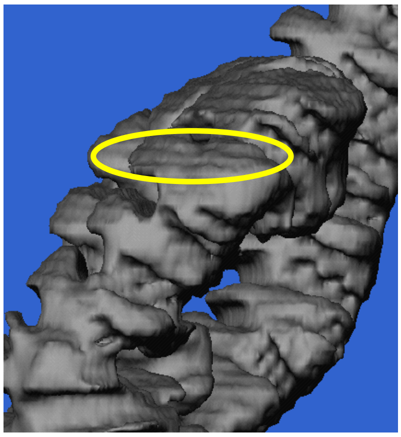
➔ **Material interface artifacts** (ie., holes, false connections) due to inherent

Medical Imaging Techniques (23)

Stair case artifacts

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





Foundations

Data Acquisition
using medical imaging techniques

Pre-Processing
segmentation, classification, etc.

Exploration
using visualization and navigation techniques

Data Pre-Processing

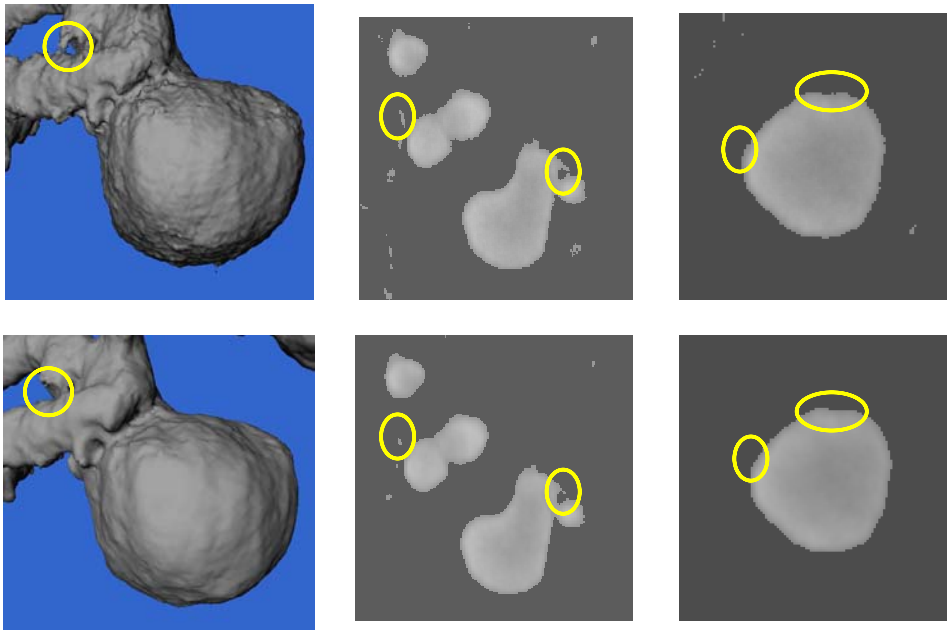
Several pre-processing operations:

- 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

Filtering (2)



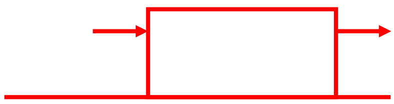
Filtered

Windowing (1)

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

➜ requires **windowing**:

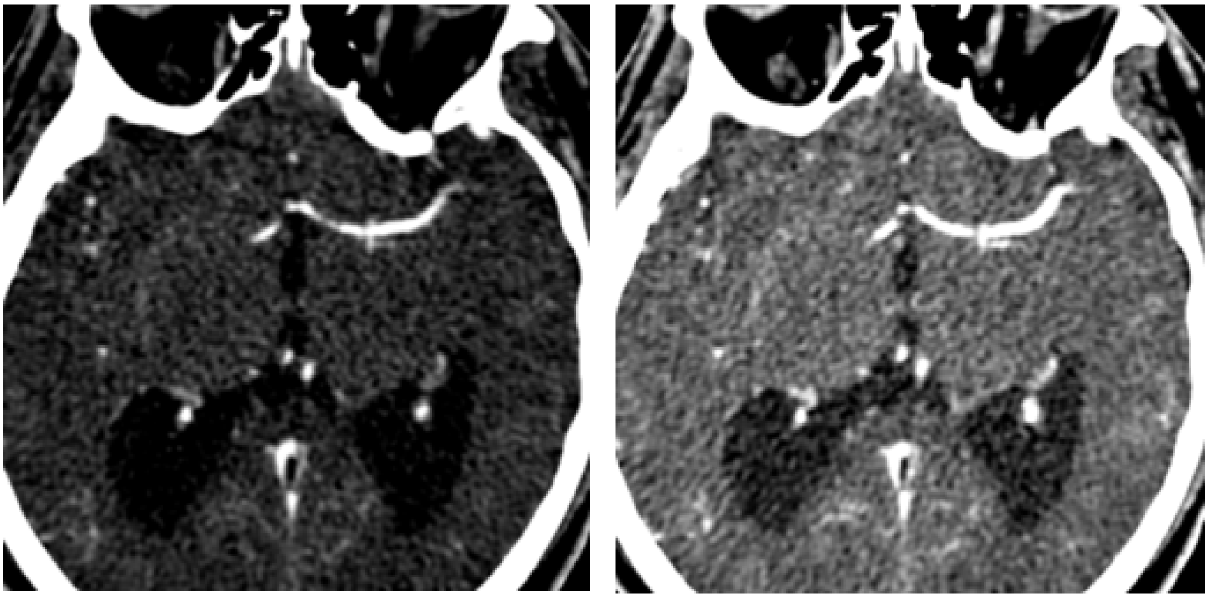
- select **sub range** of data



- **down sample** data

- inappropriate window can ruin contrast

Windowing (2)

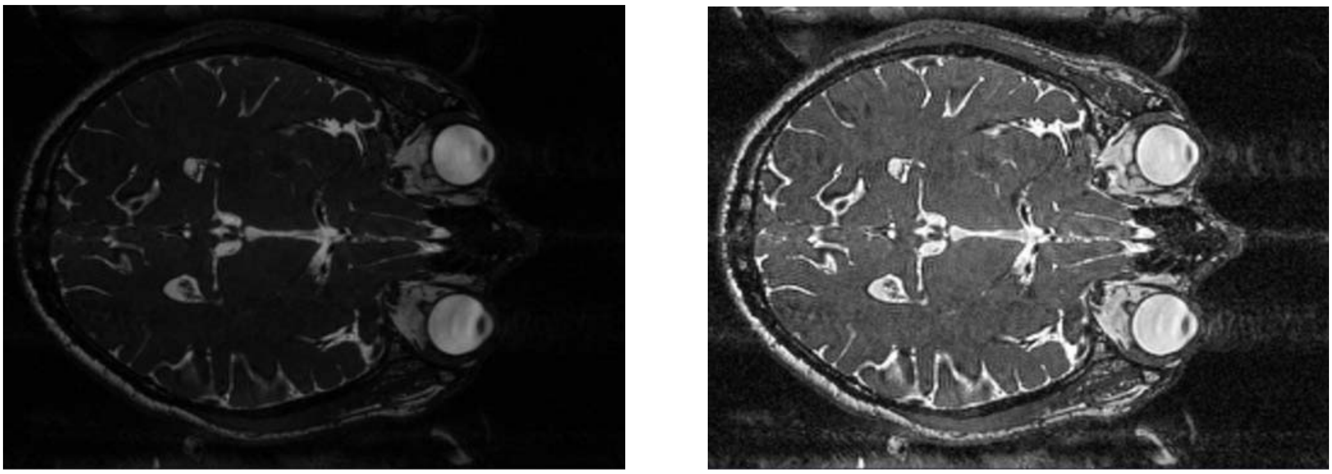


Different window ranges

Windowing (3)

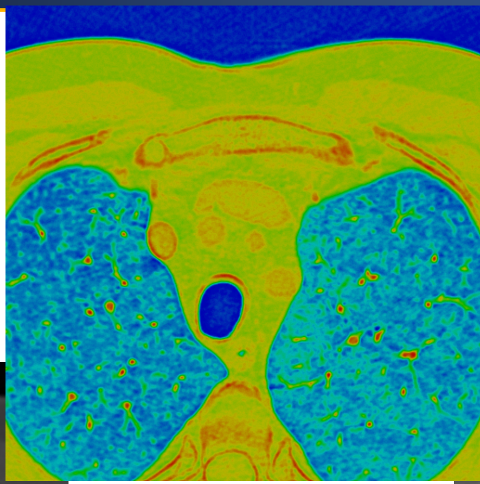
Enhancing of inadequate Data
(High Dynamic Range Operator)

8bit MRT CISS **8bit MRT CISS/PTR**

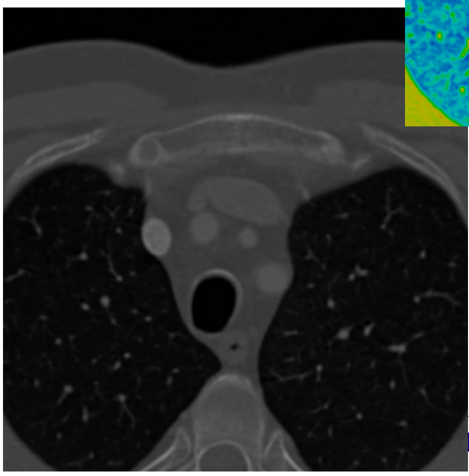


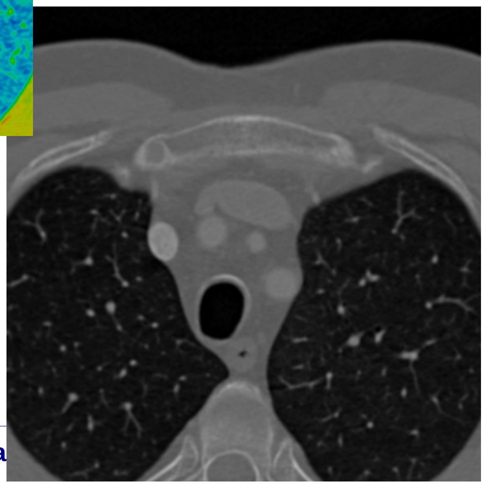
Windowing (4)

CT Thorax,
12bit/voxel



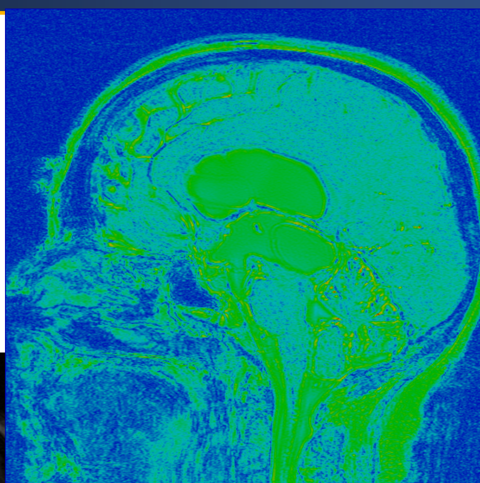
Relative Difference



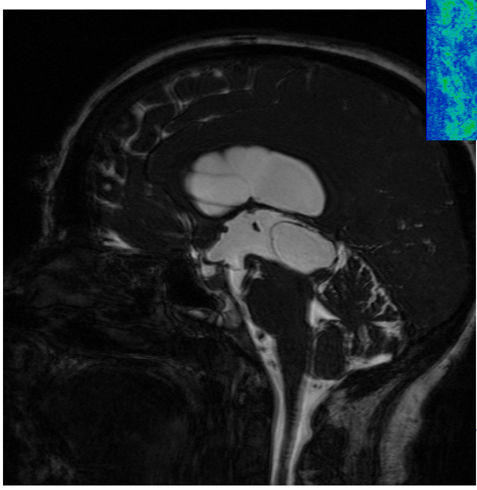


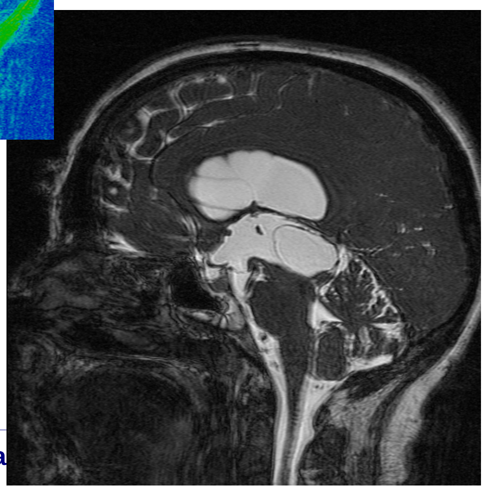
Windowing (5)

MRT CISS,
10bit/voxel



Relative Difference

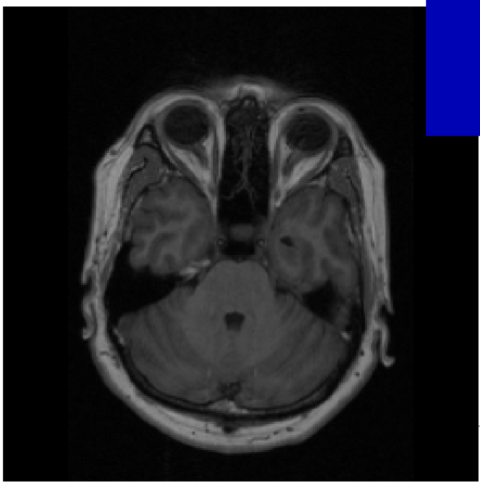


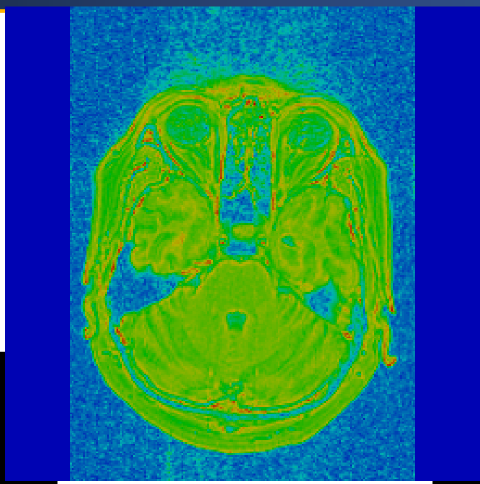


Windowing (6)

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)

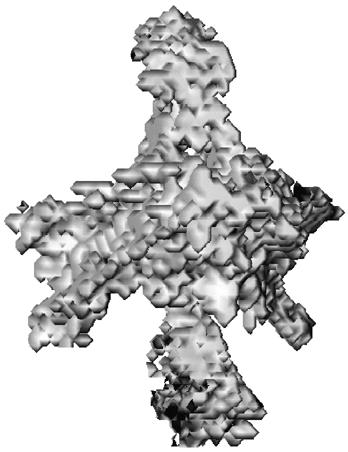
Potential problems of 3D region growing:

- 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)

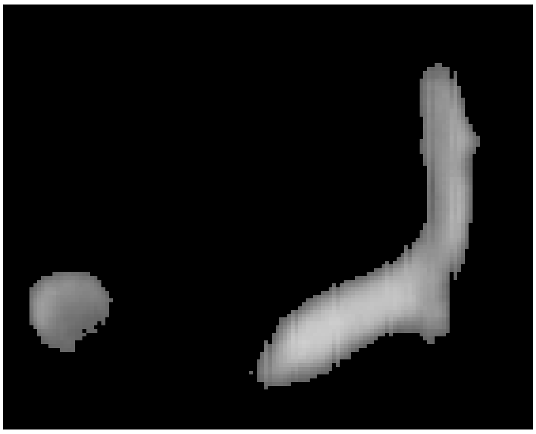
Binary segmentation can result in bumpy appearance due to interpolation artifacts (similar to staircasing)

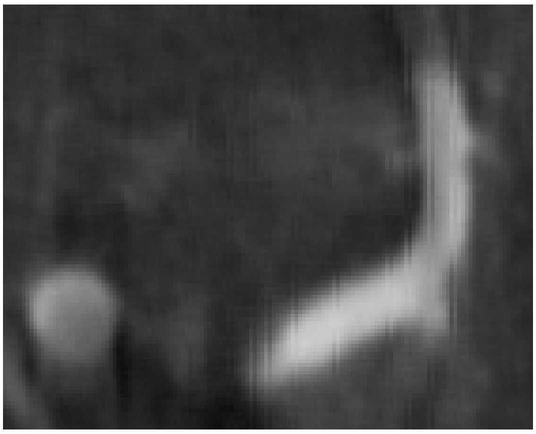
➜ **Add boundary** to segmentation



Segmentation (6)

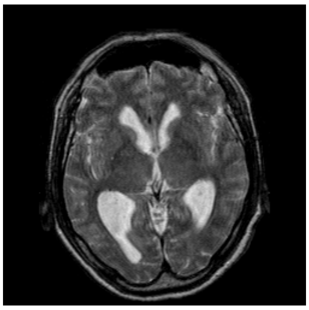
Which is the correct threshold interval?



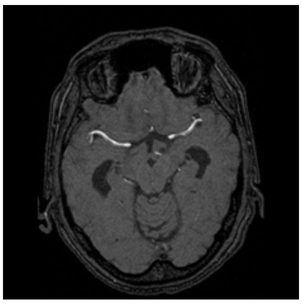


Segmentation (7)

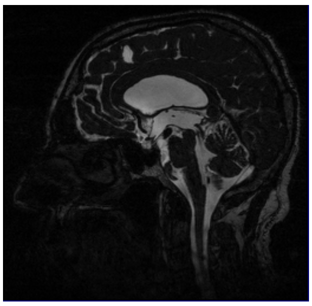
Examples of good contrast:



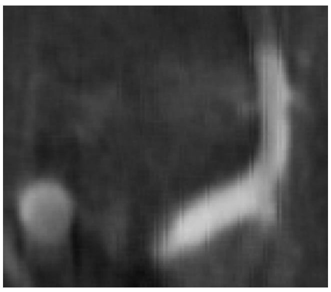
MRI TSE:
Fluid filled
cavities



MRI TOF:
blood vessels



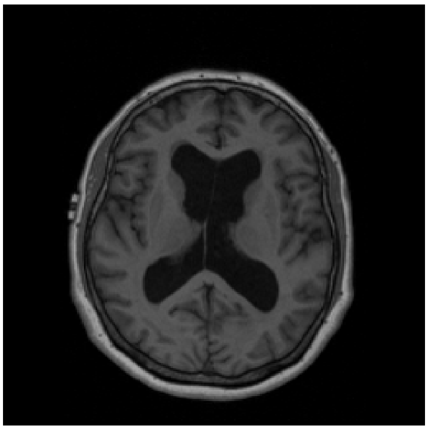
MRI 3D CISS:
Fluid filled
cavities



Rot. Angiography
contrast agent
enhanced cavities

Segmentation (8)

Examples of insufficient contrast:



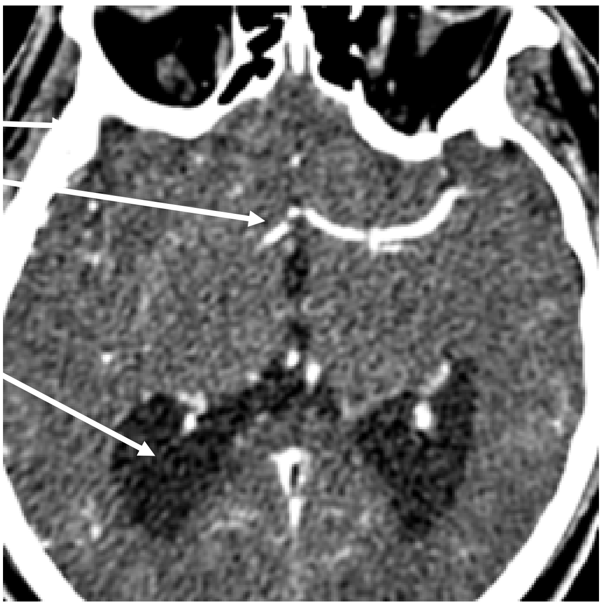
MRI Flash/T1

Differentiation
ventricles / empty space

Differentiation
corpus callosum / brain tissue

Segmentation (9)

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



Segmentation (9)

CT Angiography:
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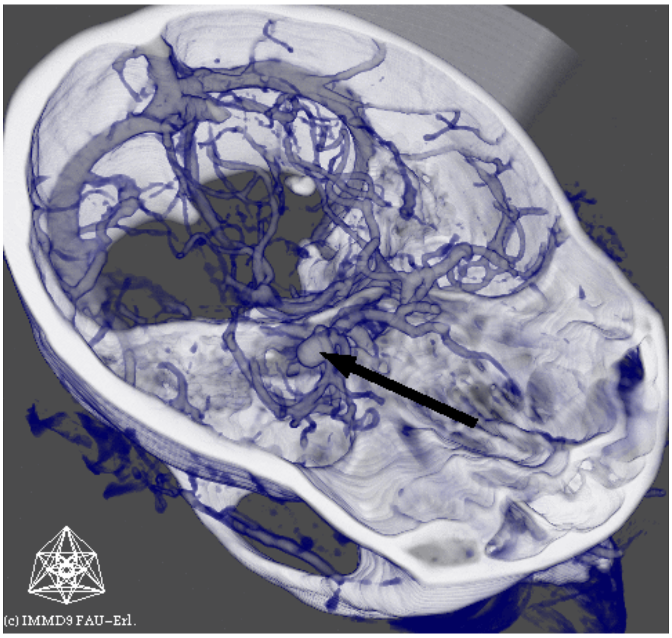
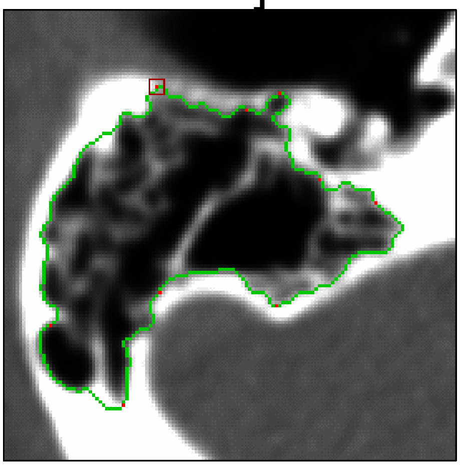


Hastreiter et al.,
Univ. Erlangen-Nürnberg

Segmentation (10)

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

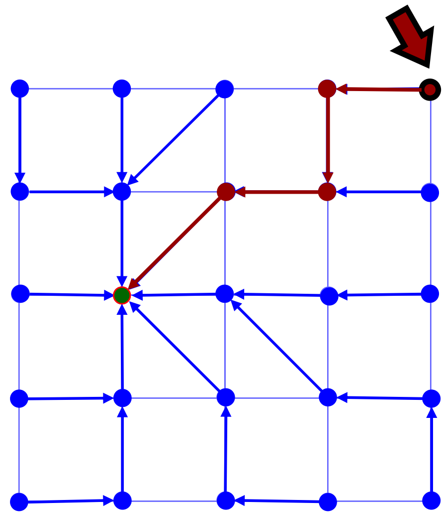
- Edge/contour oriented
- Interactive approach
- Minimizes cost function
- Interprets segmentation as graph problem



Segmentation (11)

LiveWire:

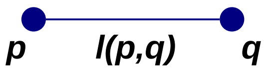
- Extraction of object contours
- Dijkstra's Minimal-Path-Algorithm
- Pixels → graph nodes
- Edges are costs
- Seed point



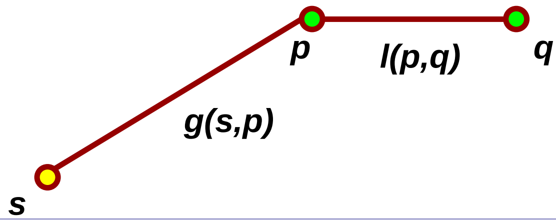
Segmentation (12)

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)

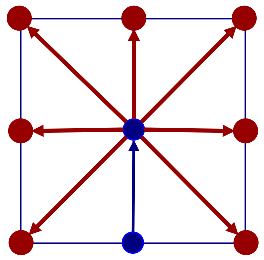
LiveWire – Cost Function:

- 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)

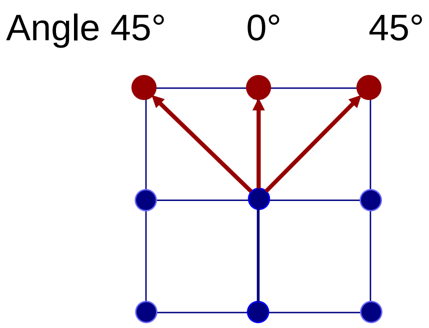
Segmentation (16)

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

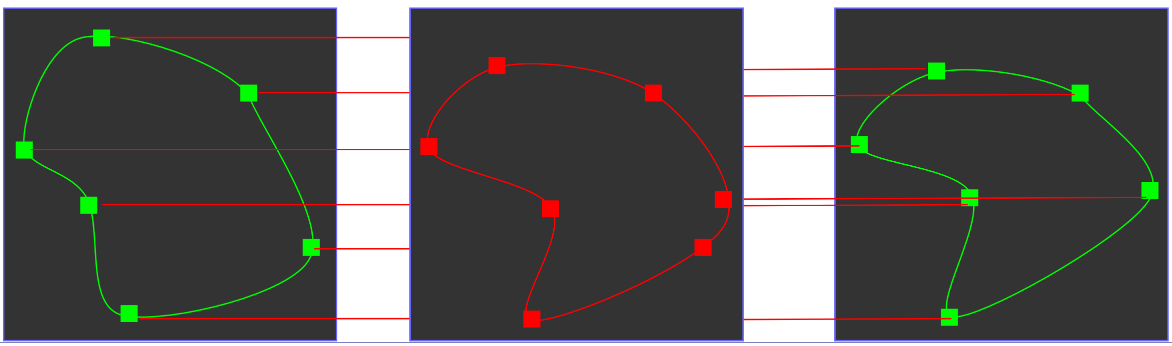
i i+1 ... i+n-1 i+n

Segmentation (19)

LiveWire for Image Sequences: Interpolation

Optimization

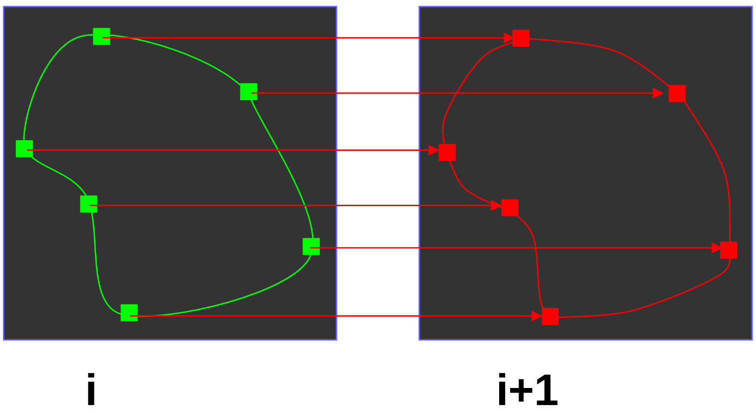
- Projection of seed points
- Computation of LiveWire contour



Segmentation (20)

LiveWire for Image Sequences: Propagation

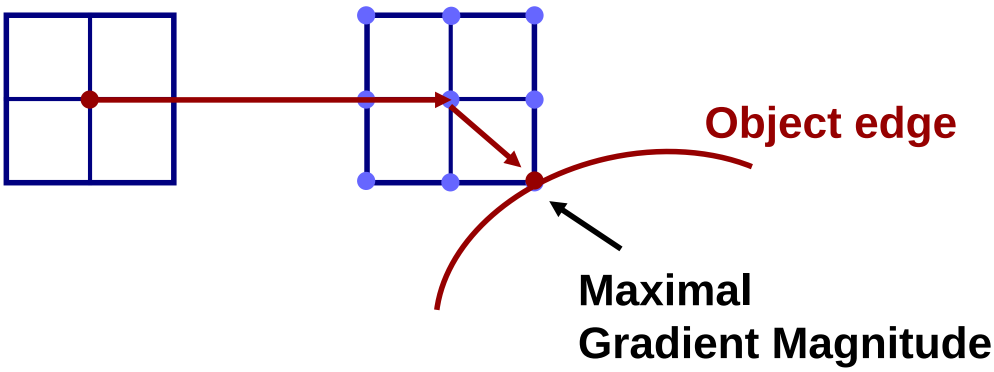
- Propagation of seed points
- Automatic computation of LiveWire contour



Segmentation (21)

LiveWire for Image Sequences: Propagierung

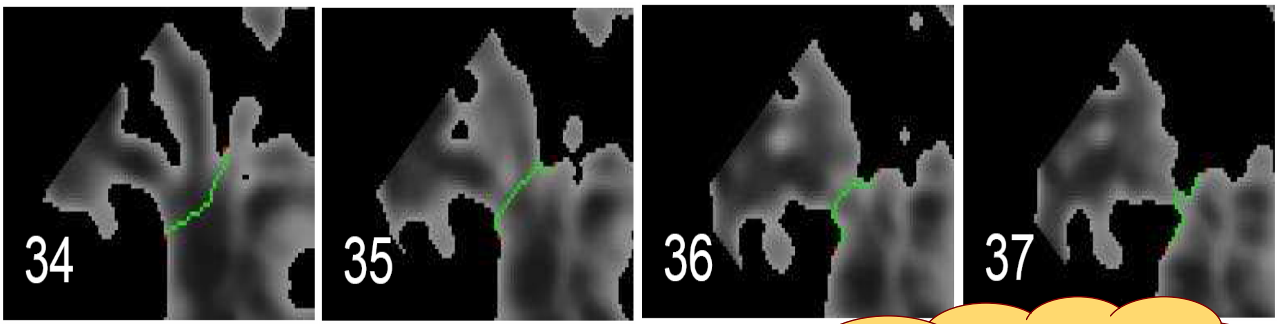
- Propagation of seed points



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

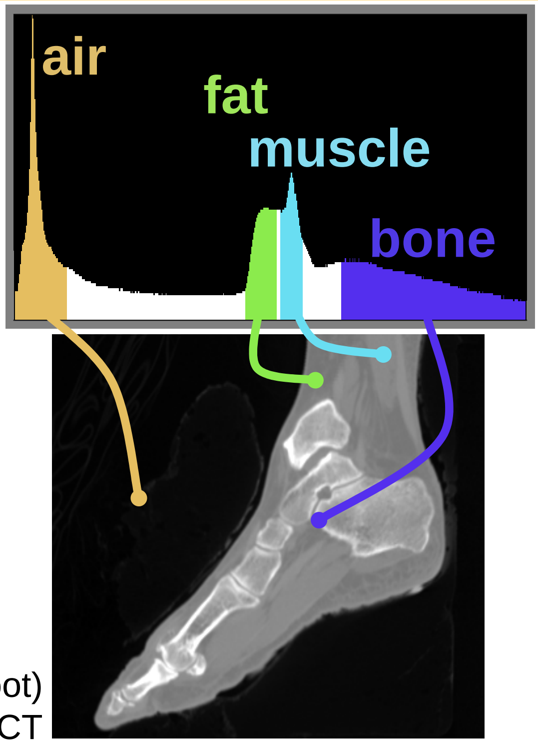
Classification (1)

- 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**

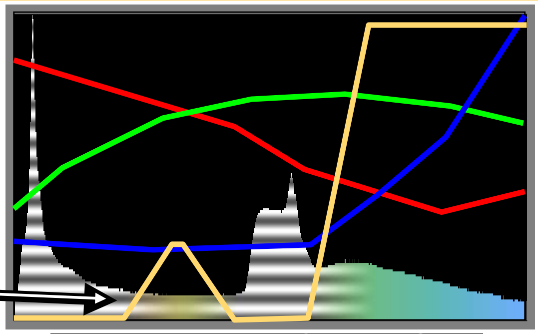


Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

- Histogram
- Opacity

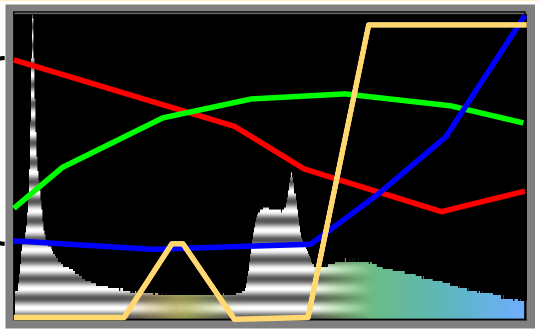


Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

- Histogram
- Opacity
- RGB channels

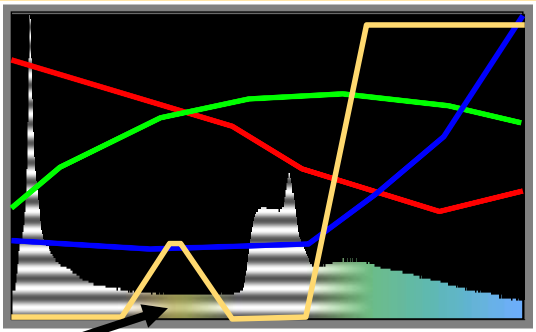


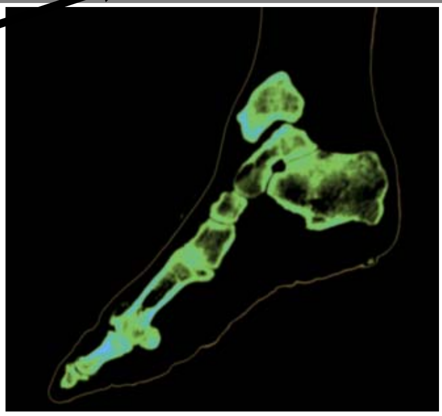
Visible Human (foot)
Female Fresh CT

Classification (2)

Example of transfer function

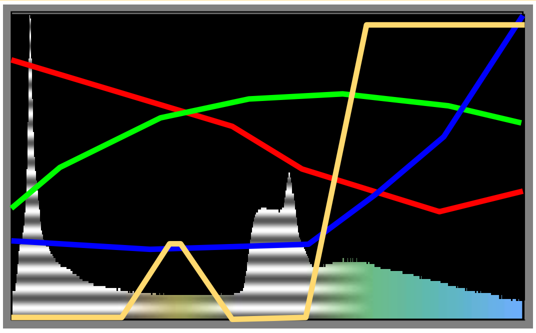
- Histogram
- Opacity
- RGB channels
- Resulting Color

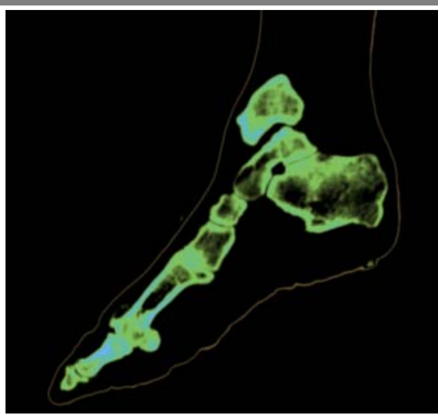




Visible Human (foot)
Female Fresh CT

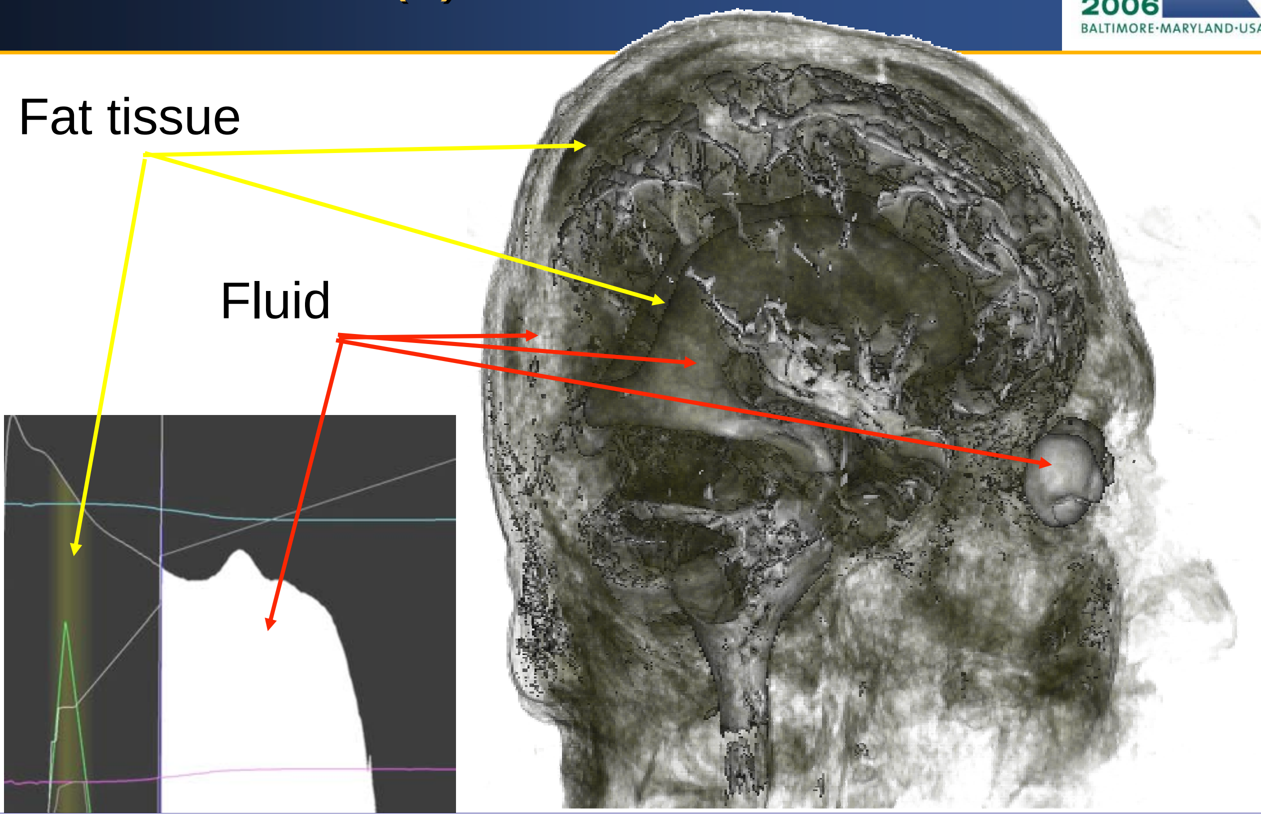
Classification (2)





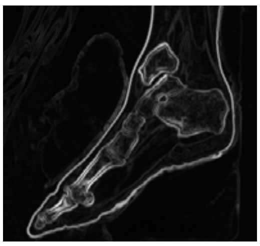
Visible Human (foot)
Female Fresh CT

Classification (3)

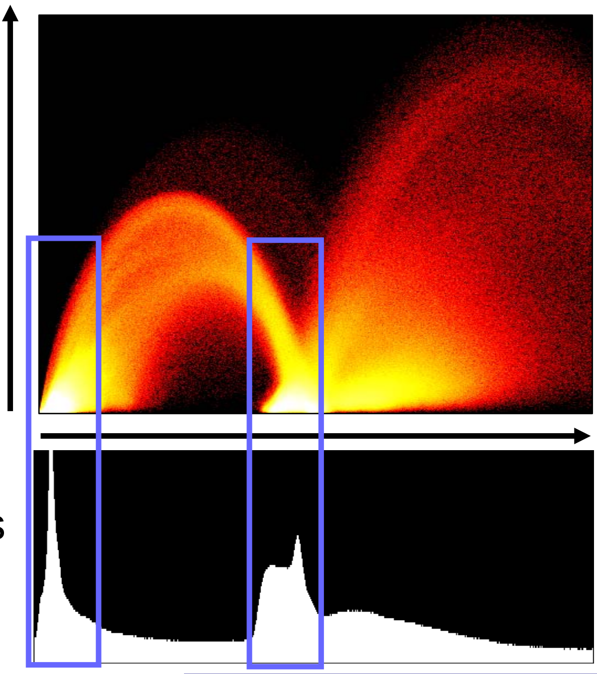


Classification (4)

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

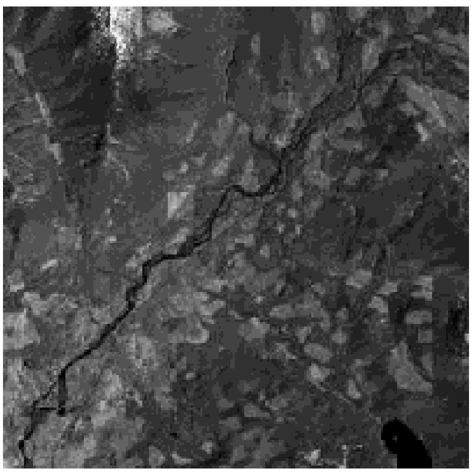
Registration (3)

- **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



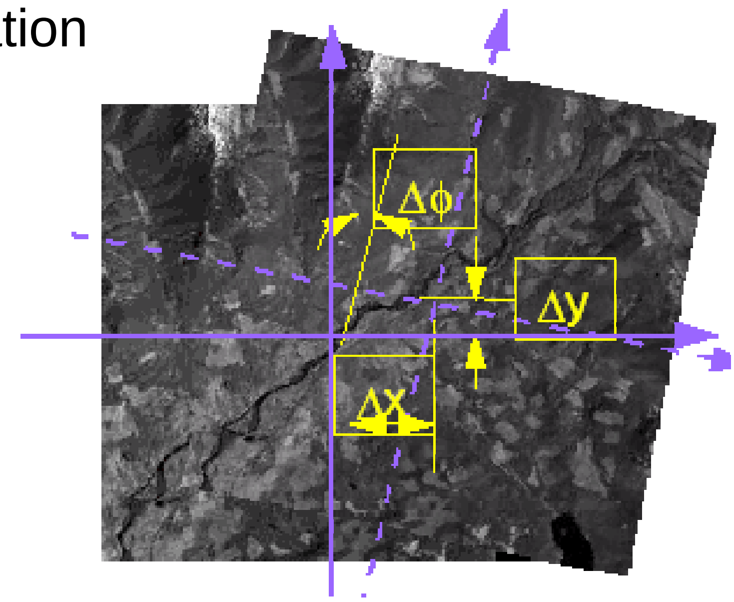


image source: http://lis1.iis.sinica.edu.tw

Registration (5)

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

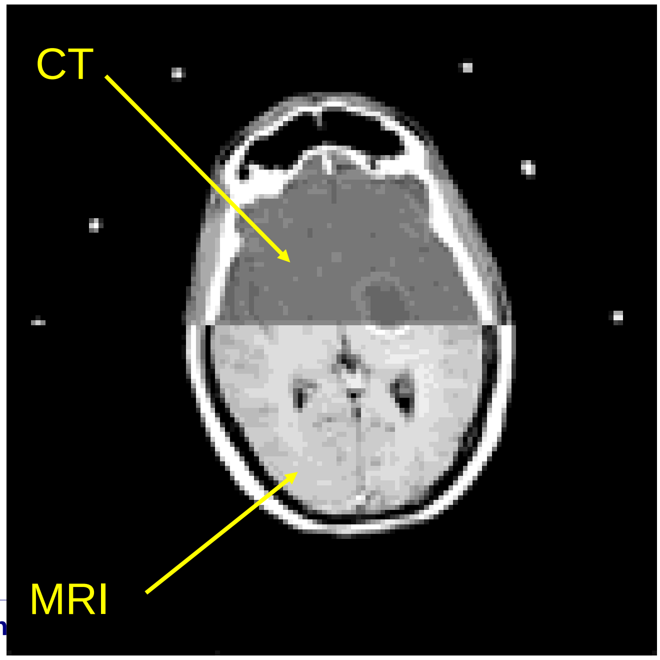
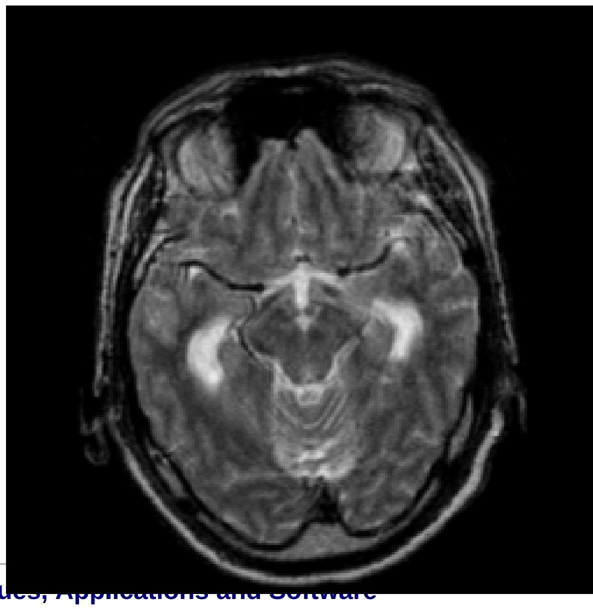


image source: http://???

Registration (6)

Registration can be very simple:



Registration (7)

Registration can be very simple:

- Only vertical translation and scaling
- 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