Medical image analysis: Introduction

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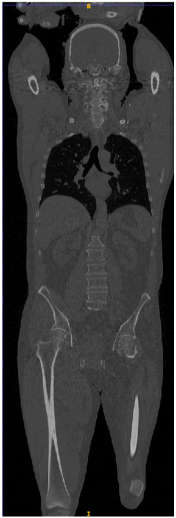
Outline

- What and why
- Main tasks in medical image analysis
- Image formats
- Toolkits

Outline

- What and why
  - Medical imaging
  - What is medical image analysis?
  - Why do we need medical image analysis?
- Main tasks in medical image analysis
- Image formats
- Toolkits

Medical Imaging



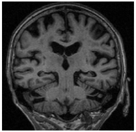
Anatomy and physiology

Computed Tomography

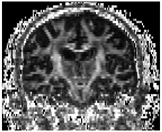
Computed Tomography Angiography

[H. Alkhadi]

Magnetic Resonance Imaging

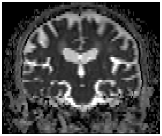


T1-weighted structural



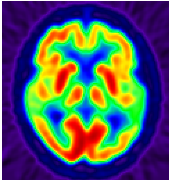
Fractional Anisotropy

MR Angiography

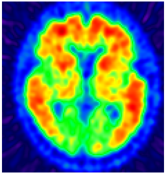


Apparent Diffusion Coefficient

[J. Polimeni]

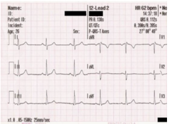


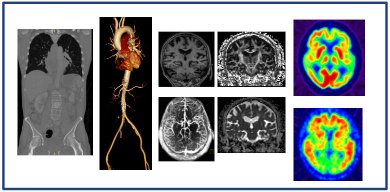
FDG-PET

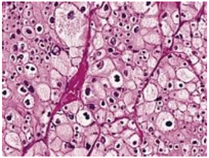


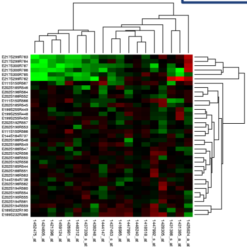
PIB-PET

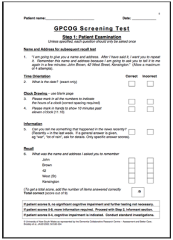
One of many observations











Patient name: ________ Date: ________

GPCOG Screening Test

Step 1: Patient Examination

Unless specified, each question should only be asked once

Name and Address for subsequent recall test

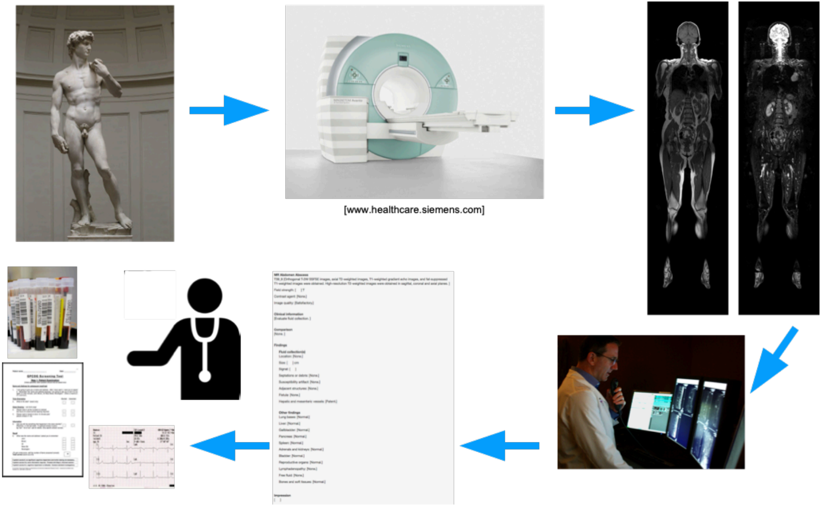
1. *"I am going to give you a name and address. After I have said it, I want you to repeat it. Remember this name and address because I am going to ask you to tell it to me again in a few minutes: John Brown, 42 West Street, Kensington."* (Allow a maximum of 4 attempts).

	Correct	Incorrect
Time Orientation		
2. *What is the date?* (exact only)	☐	☐
Clock Drawing – use blank page		
3. *Please mark in all the numbers to indicate the hours of a clock* (correct spacing required)	☐	☐
4. *Please mark in hands to show 10 minutes past eleven o'clock* (11.10)	☐	☐
Information		
5. *Can you tell me something that happened in the news recently?* (Recently = in the last week. If a general answer is given, eg "war", "lot of rain", ask for details. Only specific answer scores).	☐	☐
Recall		
6. *What was the name and address I asked you to remember*		
John	☐	☐
Brown	☐	☐
42	☐	☐
West (St)	☐	☐
Kensington	☐	☐

(*To get a total score, add the number of items answered correctly*
Total correct (score out of 9) /9

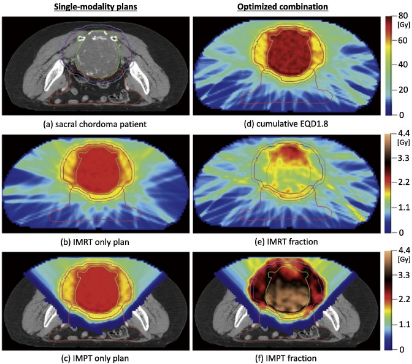
If patient scores 9, no significant cognitive impairment and further testing not necessary.
If patient scores 5-8, more information required. Proceed with Step 2, informant section.
If patient scores 0-4, cognitive impairment is indicated. Conduct standard investigations.

Life cycle of a medical image for diagnosis

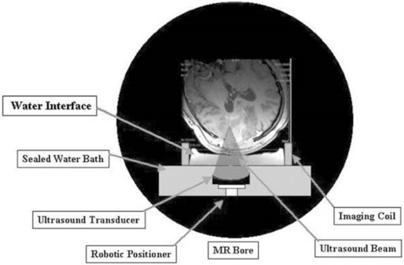


[www.healthcare.siemens.com]

Medical imaging in intervention



Treatment planning for photon and proton treatment
[Unkelbach et al. Radiotherapy and Oncology 2018]
[Unispital Zurich / University of Zurich]



MR guided high-intensity focused ultrasound surgery
[Ram et al. Neurosurgery. 2006;59(5):949-956]

Imaging modalities - not a complete list at all

Structural information

- Anatomical and microstructural information
- X-ray - 2D
- Ultrasound - 2D and 3D
- Computed Tomography (CT) - 3D
- Magnetic Resonance Imaging (MRI) - 2D / 3D
  - T1-weighted, T2-weighted, FLAIR, ...
  - Diffusion-weighted
  - Angiography
  - Spectroscopy

Temporal / Dynamic information

- Ultrasound
- Dynamic CT
- Dynamic MRI

Physiologic and metabolic information

- Perfusion imaging
- Flow imaging
- Functional MRI
- Positron Emission Tomography (PET)
- Single-photon Emission Tomography (SPECT)

Microscopic information

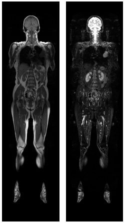
- Microscopic images - histology
- Optical Coherence Tomography (OCT)
- Micro CT (μCT)

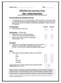
Very rich in terms of imaging modalities
They are different sources of information
Different glasses for the same underlying tissue

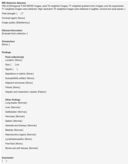
What is medical image analysis?

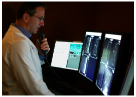
Algorithms for automatic interpretation of biomedical images

[www.healthcare.siemens.com]



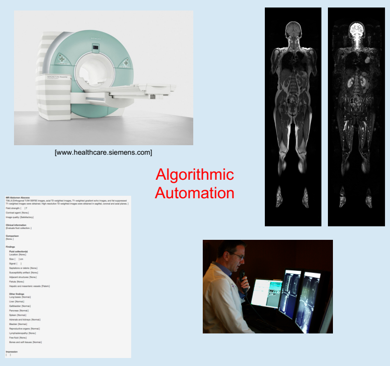




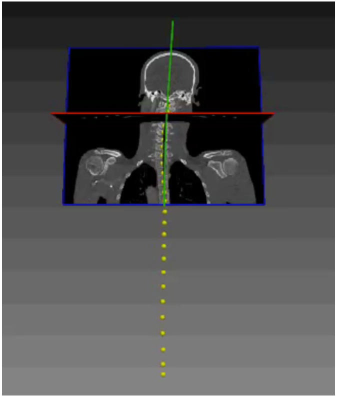


What is medical image analysis?

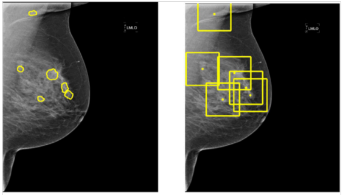
Algorithms for automatic interpretation of biomedical images

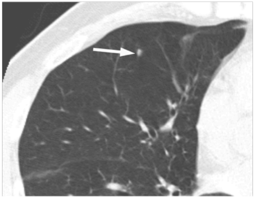


Detection and localization



[Kooi et al. Medical image analysis 2017]

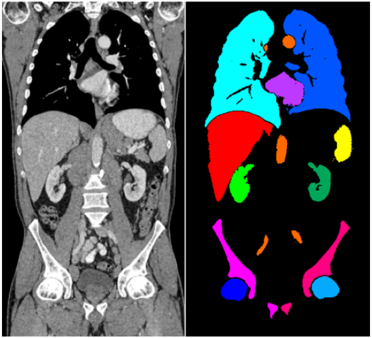




[Jeon et al. Academic Radiology 2013]

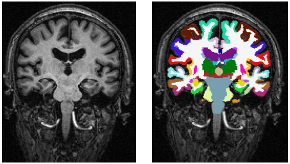
- Automatic positioning and recognition
- Visualization
- Transferring over network, search

Morphological assessment and parcellation

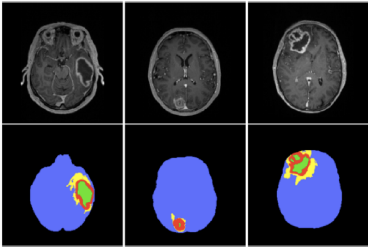


Entire organs

- Morphological measurements
- Quantification for diagnosis, staging
- First step in treatment planning



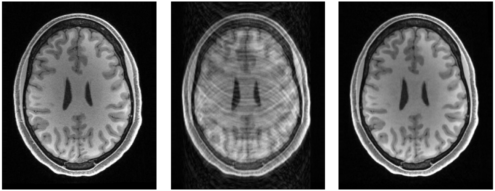
Finer scale substructures



Abnormal lesions

Image reconstruction and enhancement

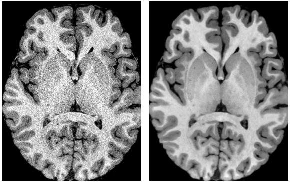
Reconstruction



Real image *Ground truth* | Observed Image | Reconstructed

[Tezcan et al. TMI 2019]

Higher SNR

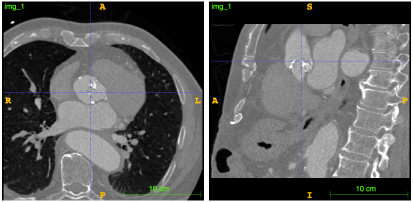


[Konukoglu et al. MICCAI 2013]

- Remove reconstruction artifacts
- Accelerate acquisition
- Improve resolution
- Improve signal-to-noise ratio (SNR)

Prediction

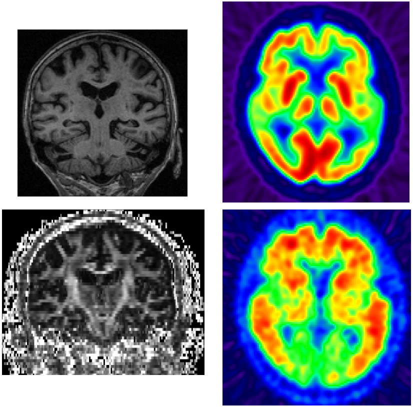
Cardiac CT with aortic calcification
Would the treatment cause a problem for this person?



[Dan Linh, Hatem Alkhadi, Felix Tanner]

- Predicting diagnosis
- Predicting risk score
- Predicting treatment outcome

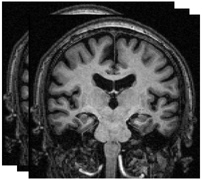
This person has Mild Cognitive Impairment
will she convert to Alzheimer's Disease?



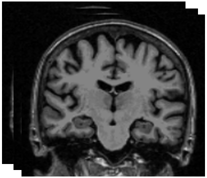
[ADNI dataset]

Statistical analysis

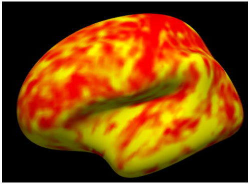
Data from population of both groups



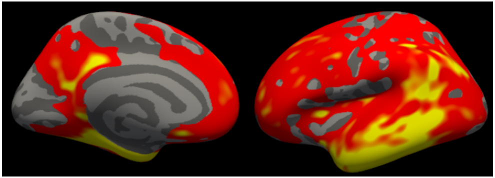
Healthy Controls



Cases



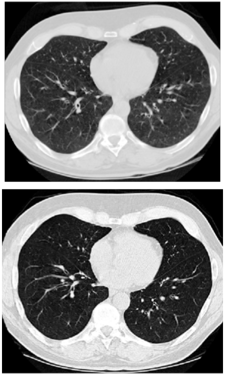
Cortical thickness



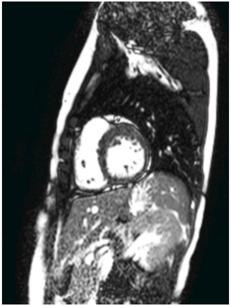
Population-wide maps showing group differences
AD effects computed from 290 subjects

Identifying anatomical / metabolic footprints of conditions

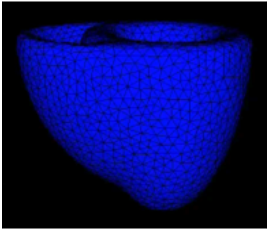
Many others: longitudinal analysis, spatio-temporal modeling,...



Has the nodule grown between these images? Is the change predictive of disease? Longitudinal analysis

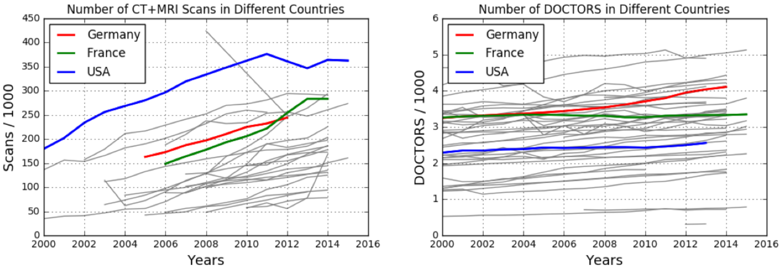


Extracting deformation fields to understand motion



Building mathematical models to describe and simulate physiological phenomena

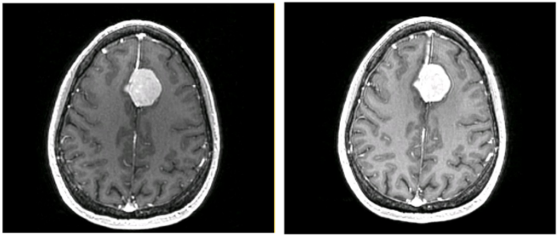
Why medical image analysis - throughput



[https://data.oecd.org]

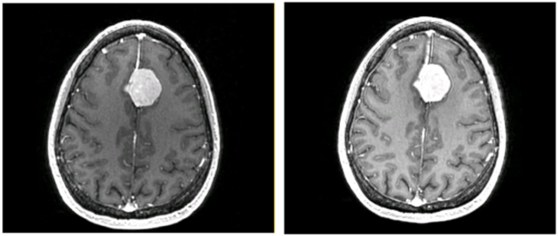
- Higher number of scans
- Finer resolution
- Higher number of modalities
- A lot of images to look at!
- Higher throughput

Why medical image analysis - quantitative analysis



1 year apart

Why medical image analysis - quantitative analysis



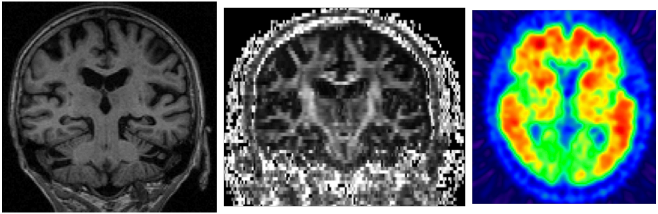
1 year apart

Growth	1%	3%	5%	11%	16%	22%
Accuracy of Detection (mean ± std)	8 ± 8 %	6 ± 6 %	28 ± 11%	44 ± 9%	52 ± 24%	88 ± 12%

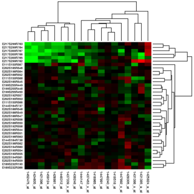
[Pohl, Konukoglu, et al. 2011]

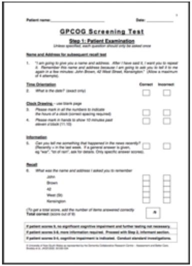
- Subtle changes for earliest detection
- Highly accurate measurements
- Repeatability
- Changes not visible to human eye, e.g. texture

Why medical image analysis - fusion of information



different physical and metabolic characteristics





GPCOG Screening Test

Step 1: Patient Examination

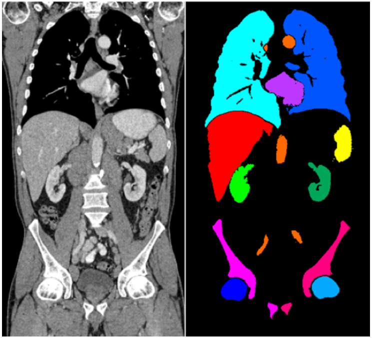
- combining information from different images
- image $\rightarrow$ numerical matrix
- fusion with other quantitative sources

Why do you want to learn medical image analysis?

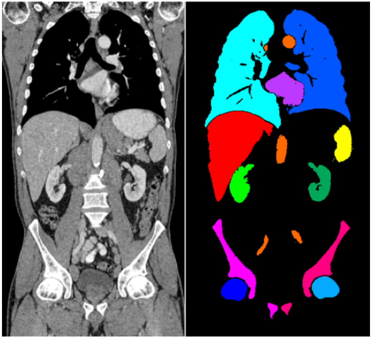
Outline

- What and why
- Main tasks in medical image analysis
  - Segmentation
  - Registration
  - Classification
- Image formats
- Toolkits

Segmentation principle



Segmentation principle



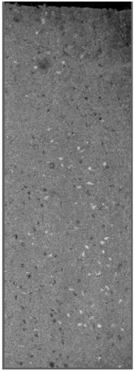
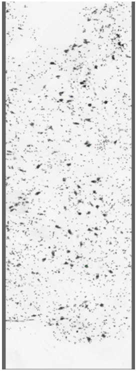
- At each pixel / voxel assign a label
- Labels can be
  - Organ: liver, spine, ...
  - Part of organs: individual vertebrae, ...
  - Lesions: tumors, pathologies, ...
- Information at each pixel
  - Intensity at and around the pixel
  - Intensity at different modalities

$x \in \Omega \subset \mathbb{R}^d$, $d = 2$ or $d = 3$
$f(x) = [I(x), I(\mathcal{N}(x)), J(\mathcal{N}(x)), \dots]$: Features
$L(x) \in \{0, \dots, N\}$: Labels
$L(x) \approx S(f(x))$: Segmentation approximating labels

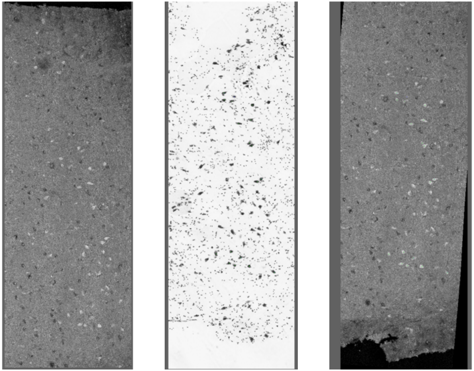
Segmentation techniques overview

- Thresholding and histogram
- Clustering
  - K-means
  - Unsupervised learning
  - Non-parametric modeling
  - ...
- Graph partitioning methods
  - Watershed
  - Graph-cuts
  - Random walker
  - Minimum spanning forest
  - ...
- Region growing
- Variational and PDE-based
  - Chan-Vese model
  - Mumford-Shah model
  - Active-shape models
  - Level sets
  - Fast marching
  - ...
- Discriminative modeling based
  - Random forest
  - Conditional random fields
  - Supervised convolutional neural networks
  - ...
- Generative modeling based
  - Expectation-maximization
  - Markov random fields
  - Atlas-based segmentation
  - Variational inference
  - ...

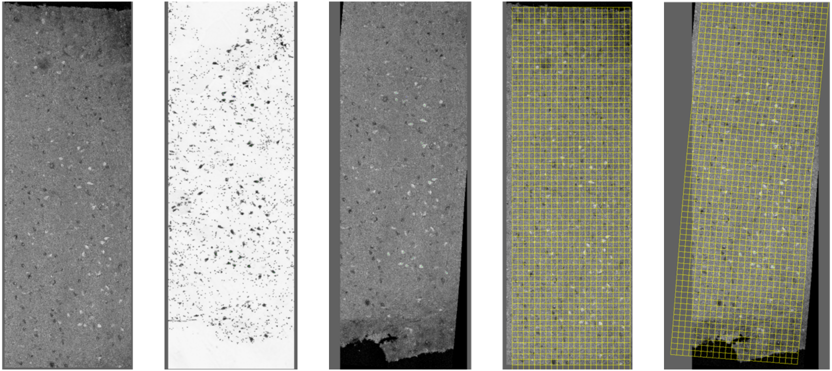
Registration principle

Registration principle

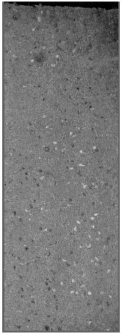


Registration principle

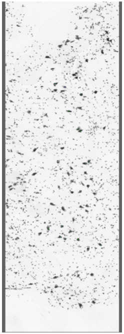


Moving Target Aligned Grid Deformed

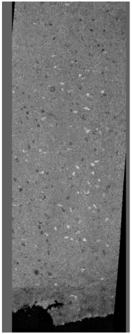
Registration principle



Moving



Target



Aligned

- Determine spatial transformation between two images
  $I(x), J(x)$: the two images
  $T(x) : \Omega \to \mathbb{R}^d$: spatial transformation
  $J(T(x)) = I(x)$: mapping the images
- Creates a correspondence between points
- $T(\cdot)$ can be linear or non-linear
- Often the problem might be ill-posed and regularization is used
  $R(T(x))$: regularization imposing some physical constraint

Registration techniques overview

Problem-based taxonomy

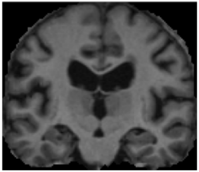
- Intra-subject
- Inter-subject
- Unimodal
- Multimodal

Transformation-based taxonomy

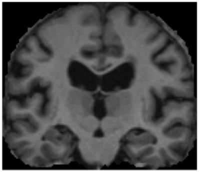
- Linear
  - Rigid
  - Similarity
  - Affine
- Non-linear / Deformable

- Landmark based registration
- Linear basis function modeling
  - B-spline registration
  - RBF registration
  - ...
- Dense field models
  - Demons, Diffeomorphic demons
  - Large deformation diffeomorphic metric mapping (LDDMM)
  - Poly-affine
  - ...
- Discrete optimization (DROP,...)
- Feature based (HAMMER,...)

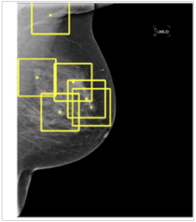
Classification / Regression principle

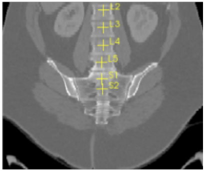


How old is she?



Is she at risk for AD?





- Mapping from image to label
  Classification:
  $F : \Omega_c \subseteq \Omega \to \{0, \dots, N\}$
  Regression:
  $F : \Omega_c \subseteq \Omega \to \mathbb{R}^N$
- Labels can be
  - Diagnosis: Disease/Healthy
  - Outcome prediction: Success/Complication
  - Presence of an object
- Ω_c can be the entire image, i.e. $F(I)$, for diagnosis, outcome prediction
- Ω_c can be part of an image, $F(I_c)$, for localization
- Segmentation / registration can be thought as classification / regression tasks with special structure, i.e. per pixel/voxel prediction

Classification techniques overview

- Feature extraction
  - morphological descriptors
  - texture features
  - SIFT, HOG, ...
  - multimodal
- Supervised classification
  - Linear regression: both prediction and statistical analysis
  - Support vector machines, Kernel machines, ...
  - Random forests, Adaboost, ...
  - Neural networks

Outline

- What and why
- Main tasks in medical image analysis
- Image formats
  - Anatomical axes and basic properties
  - DICOM and volumetric formats
- Toolkits

Anatomical axes

Superior

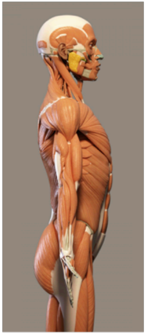
Right

Left

Inferior

Superior

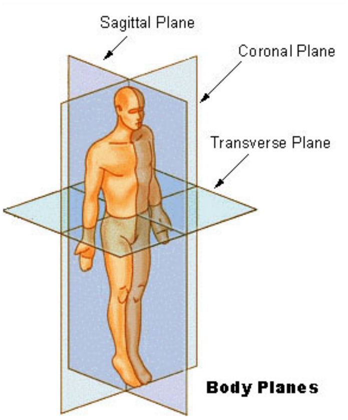
Posterior



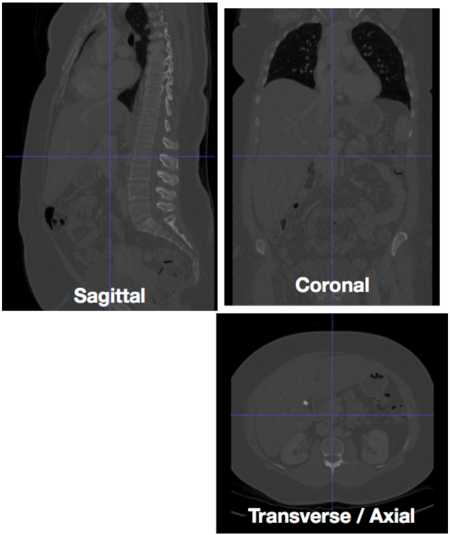
Anterior

Inferior

Cross sections in a volumetric image



[NIH]

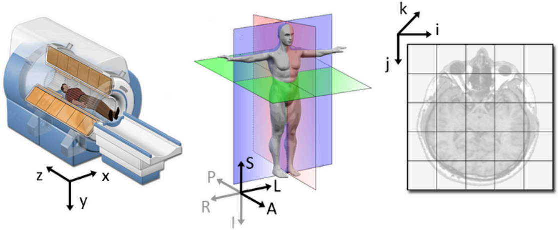


Basic image properties - volume

- Image size
  - number of pixels / voxels
  - 2 or 3 integers
  - e.g. 256x256x128
- Pixel / Voxel size
  - the size a pixel / voxel occupies in the real world
  - 2 or 3 real numbers
  - e.g. 0.6x0.6x3.5 mm^3
  - Sometimes called resolution, however, pixel size and resolution are two different things for acquisition people
- Field-of-view (FOV)
  - the size an entire image occupies in the real word
  - 2 or 3 real numbers
  - product of image size and pixel/voxel size
  - e.g. 153.6x153.6x448 mm^3

Basic image properties - beyond

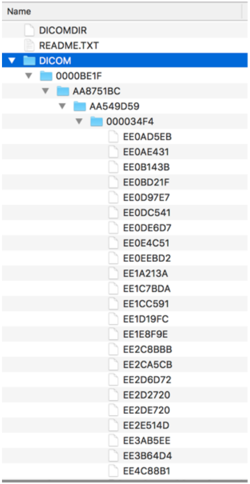
- Temporal information
  - Additional dimension in the image, e.g. a volumetric image would have 4 dimensions with time
  - Additional number indicating number of images
  - Temporal resolution
  - functional MRI, perfusion, dynamic cardiac imaging, ...
- Metabolic information
  - Additional dimension
  - Additional number indicating number of metabolites
  - MR spectroscopy
- Transformations
  - Transformation matrices between voxel coordinates and real world coordinates - patient position on the table



[https://www.slicer.org/wiki/File:Coordinate_sytems.png]

DICOM

- Need to keep the image and all the basic information
- Need to keep additional information
  - Scanner
  - Scan type
  - Ordering physician, conducting physician
  - Patient information
  - ...
- Digitial Imaging and Communications in Medicine (DICOM)
- Standard for storing and transmitting data
- Most commonly used format in practice
- All vendors, all centers, all doctors
- Used in clinical practice
- Turns out to be difficult to manage for processing



Volumetric formats

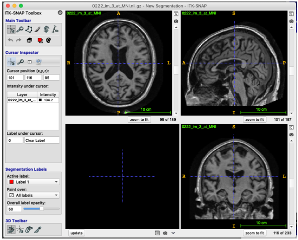
- Luckily people came up with many volumetric formats
- Sometimes institutional proprietary formats
- Analyze file format from Mayo Clinic
  https://en.wikipedia.org/wiki/Analyze_(imaging_software)
- NIFTI (Neuroimaging Informatics Technology Initiative)
  replacement for Analyze
  https://nifti.nimh.nih.gov/nifti-1/
- NRRD (Nearly raw raster data)
  https://en.wikipedia.org/wiki/Nrrd
- Which format to use depends on your preferences
- Useful for engineering purposes but need to be able to deal with DICOM if you want to work with clinicians

Outline

- What and why
- Main tasks in medical image analysis
- Image formats
- Toolkits
    - Visualization and simple manipulations
    - Processing

Visualization and simple manipulations

- ITK-snap
  `http://www.itksnap.org/pmwiki/pmwiki.php`
  Great tool for basic visualization of volumetric data
  Simple routines for image segmentation
- OSIRIX
  `http://www.osirix-viewer.com/`
  Popular, especially among clinicians
- Freeview
  `https://surfer.nmr.mgh.harvard.edu/`
  Visualization tool from freesurfer
- Medinria
  `http://med.inria.fr/`
- Mango
  `http://ric.uthscsa.edu/mango/`
- Paraview
  `https://www.paraview.org/`
  Scientific visualization, great for meshes



ITK-Snap

Processing

- Libraries
  - ITK (Insight Toolkit), https://itk.org/
  - VTK (Visualization Toolkit), https://www.vtk.org/
  - Tensorflow
  - PyTorch
  - Scikit-learn
  - Nibabel - to read medical volumes in python
  - Iso2Mesh - to generate mesh from volumetric data
  - GitHub resources...
- Software suites - combination of executables
  - Freesurfer https://surfer.nmr.mgh.harvard.edu/
  - FSL https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/
  - Camino http://camino.cs.ucl.ac.uk/
  - SPM https://www.fil.ion.ucl.ac.uk/spm/
- Visualization and processing with GUI
  - Slicer3D https://www.slicer.org/
- Many more...