DTU

Course 22525

Medical Image Analysis Introduction

Axel Thielscher

Lecturers

Axel Thielscher (DTU Health Tech, course responsible)

Koen Van Leemput (Aalto U Finland, former course responsible)

Rasmus Paulsen (DTU Compute)

Oula Puonti (Athinoula A. Martinos Center for Biomedical Imaging, Harvard U)

TA: Merle Diedrichsen (DTU Health Tech)

TAs (Aalto U):

Ida Granö

Raymond Khazoum

Audience: Who are you?

36 students from …

- Biomedical Engineering
- Mathematical Modelling and Computation
- Quantitative Biology and Disease Modelling
- Computer Science and Engineering
- Autonomous Systems Engineering
- Human-Centered Artificial Intelligence
- Earth and Space Physics and Engineering
- Electronics Engineering
- Bachelor program in Artificial Intelligence and Data
- Bachelor program in General Engineering
- Guest students

+ 67 students at Aalto University

Practical Information

Lectures

- Tuesdays 13:15-15:00 (approx.) in B325-IT017
- streamed between Aalto U and DTU – no recording due to GDPR

Exercises – Reports – Student Presentations

- Weekly exercises covering the majority of course topics
- directly after the lecture in the same room (TA present)
- done in **groups of three (4 as exception)**
- are turned into **reports**, which are handed in on Learn
- Reports are reviewed in a **peer review system** on Learn
- Each student will once be assigned to **present one report**

Practical Information

Exercises

- should be implemented in **Python** (MATLAB is also OK, but main guidance and support – including supply of some "code snippets" – will focus on Python)
- Exercise material and additional information will be provided on the course github

  https://github.com/oulap/MIA

  and the course homepage

  https://oulap.github.io/MIA/
- For each exercise, a **jupyter notebook** is provided with information and instruction on the setup and environment

- The github also contains a link to the course webpage, where lecture slides will be available
- Python and Jupyter Notebooks:
  - https://lectures.scientific-python.org/
  - https://www.dataquest.io/blog/jupyter-notebook-tutorial/

Practical Information

Reports

- Each report covers one course topic and is prepared by each group (not individually)
- Handed in as one (!!) pdf file on Learn
- Mandatory structure:
  - **Background**: Short introduction to the topic. Equations and concepts should be shortly explained here.
  - **Methods and Results**: Your jupyter notebook including the code, comments and explanations (where necessary) and output like graphs/figures.
  - **Discussion**: Review the learning objective and discuss if your result match the expected output (and why?)

The reports will be the starting point of the discussion during the oral exam and should be used as exam preparation!

Practical Information

Peer review system for the reports on Learn

- Each student will be assigned two reports of other groups on which they should provide feedback based on a provided questionnaire
- Each group will receive anonymous feedback on their report from students and feedback from the TA
- Review should be done within one week after hand-in

Presentations

- Each student will be once part of combined groups of 6 to present the exercise solution based on the reports
- Presentations are held during the exercise session
- Presentation should include a 15 min power point talk covering the background, methods, results and discussion of the report

Practical Information

Exam

- Individual oral exams (20 min) on **13.12** and **14.12**
- Upon arrival, you will randomly draw a report that you then will present
- Reports that are relevant as potential exam material will be announced in due time

- 20 min preparation time in a separate room - all means allowed
- 5 min presentation of assigned report at the start of the exam
- Followed by questions of the examiners after presentation (not limited to report topic)

Questions??

Course Schedule

Lecture	Date	Who	Topic
1	Tue 5 Sep	AT, MD	Course intro
2	Tue 12 Sep	KVL	Regression and coordinate systems
3	Tue 19 Sep	KVL	Linear spatial transformations, landmark-based registration, interpolation
4	Tue 26 Sep	KVL	Intensity-based methods for registration
5	Tue 3 Oct	KVL	Non-linear deformations
6	Tue 10 Oct	KVL	Generative models for segmentation I
	Tue 17 Oct	HOLIDAY	
7	Tue 24 Oct	KVL	Generative models for segmentation II
8	Tue 31 Oct	KVL	Neural Networks for medical image analysis
9	Tue 7 Nov	RRP	Surface-based registration
10	Tue 14 Nov	AT	Surface-based metrics
11	Tue 21 Nov	OP	Neural Networks for medical image analysis
12	Tue 28 Nov	OP	Neural Networks for medical image analysis

AT	Axel Thielscher
KVL	Koen Van Leemput
RRP	Rasmus R. Paulsen
OP	Oula Puonti
MD	Merle Diedrichsen

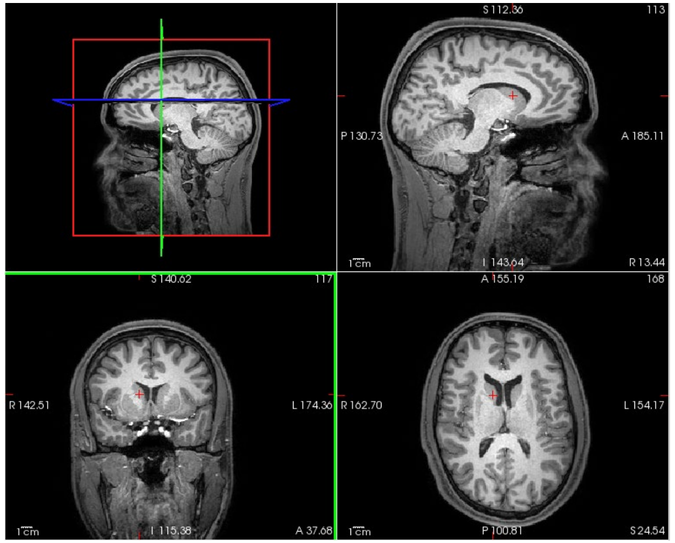
Characteristics of Medical Images

Medical images are amazing diagnostic tools, but present some specific challenges for automatic analysis methods

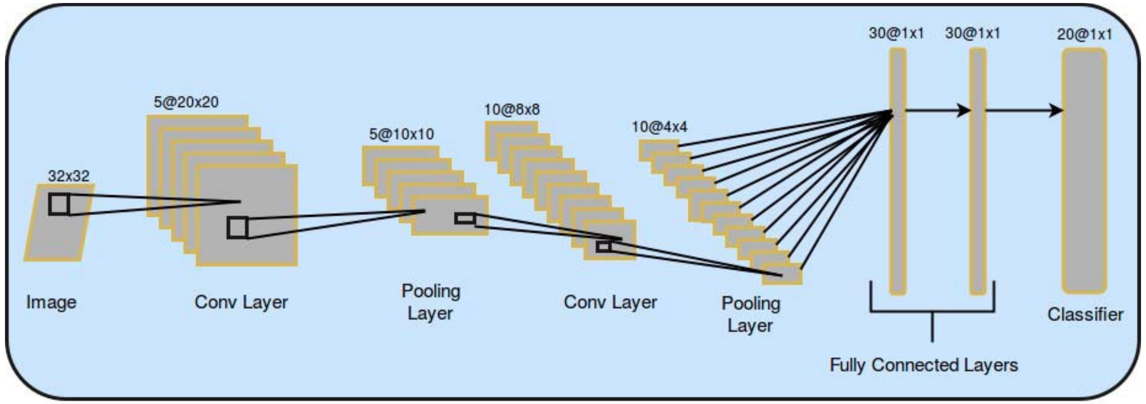
1) Often volumetric (3D) data (voxel -> mm) :

- Visualization not straightforward

- Methods for (2D) image analysis don't work "out of the box"



Deep convolutional NN



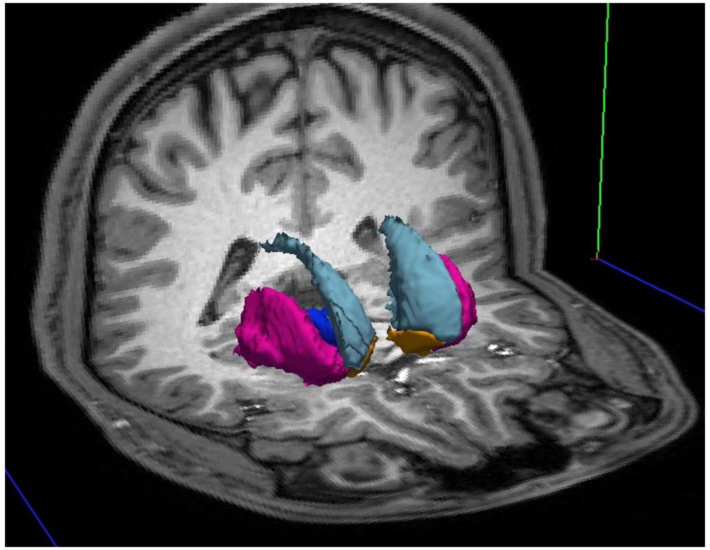
Neena, Geetha IEEE ICCSP 2017

Characteristics of Medical Images

2) Often complex object geometries and textures, with individual and disease-related anatomical variability

Deep brain areas

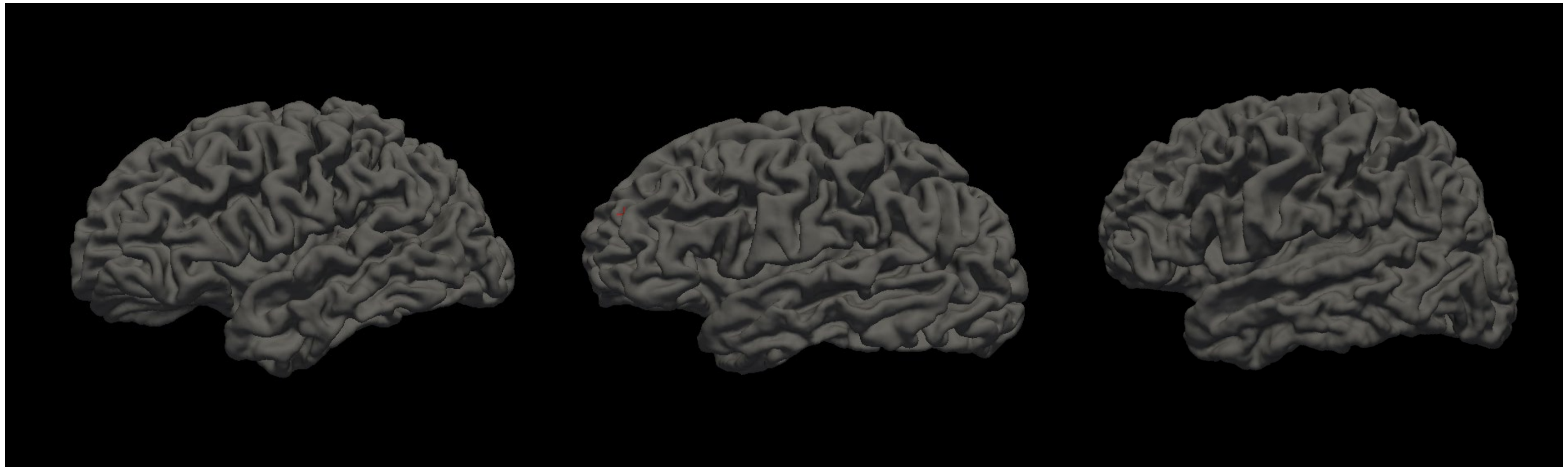
Relatively stereotypic geometries



vs

Cortex folding

Individual and complex

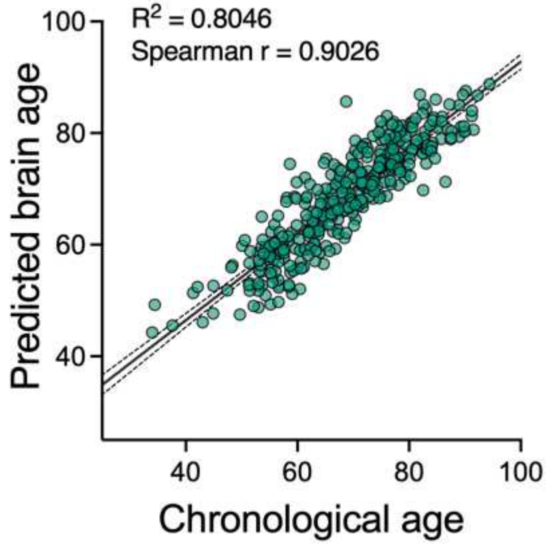


Characteristics of Medical Images

3) Applications and outcome metrics relevant for diagnostics, e.g.

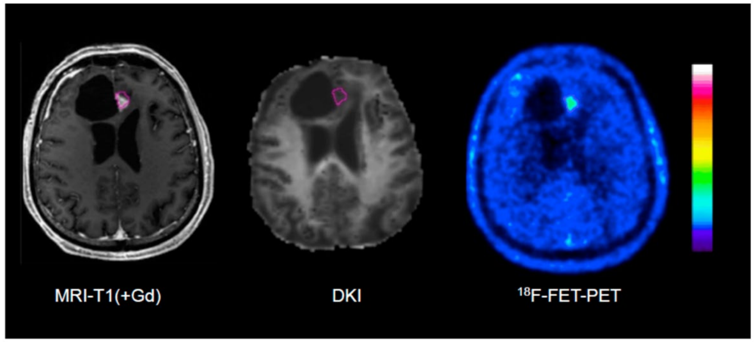
- Bring images in spatial correspondence
- Segmentation and volume quantification
- Localization and characterization of pathological changes
- Prediction/early detection of diseases

Brain age from MRI



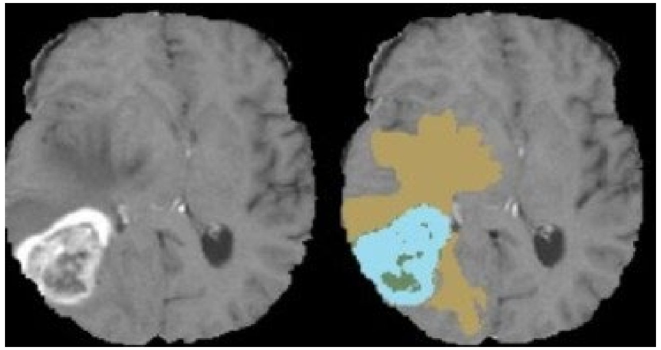
Lee et al Nat. aging 2022

MR – PET co-registration



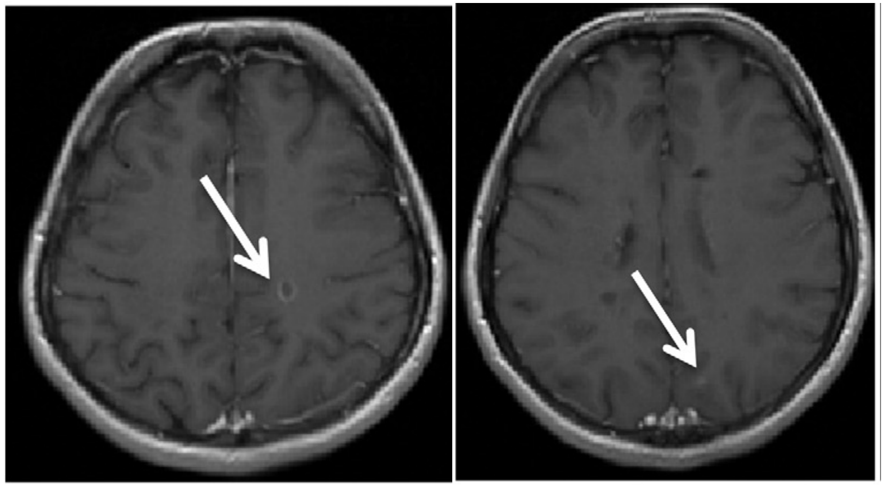
Langen et al, Cancers 2023

Glioblastoma segmentation



BRaTS 2021 Dataset

MS lesion localization



Grazianoa et al NI Clinical 2015

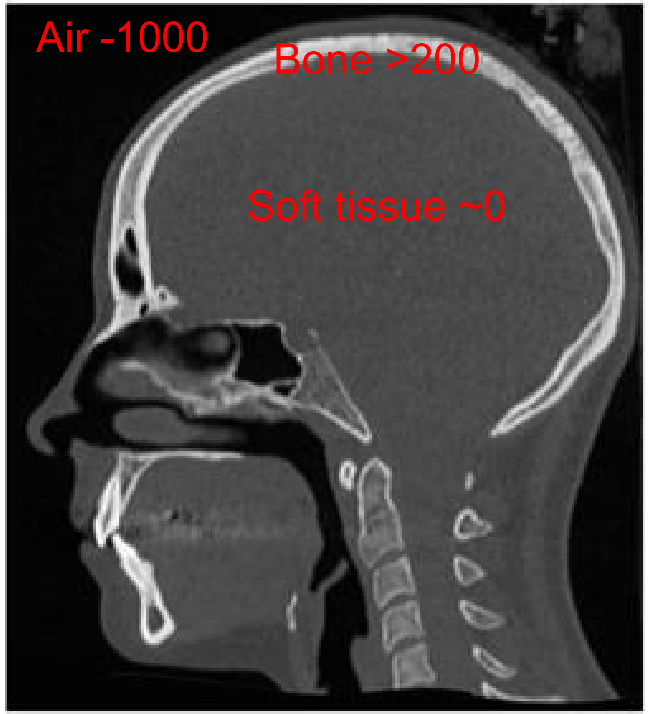
Characteristics of Medical Images

3) Varying contrasts, resolutions and coverage: Little standardization

CT: Hounsfield units (HU)

a relative quantitative measurement of radio density

-> absolute intensity levels facilitate analyses



“Segmentation” by simple thresholding

Characteristics of Medical Images

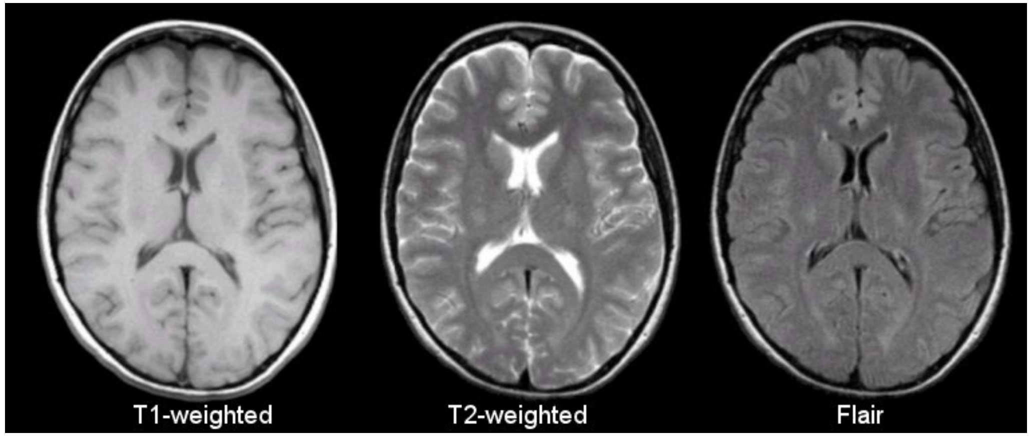
3) Varying contrasts, resolutions and coverage: Little standardization

MR: normally **not quantitative**, very flexible in terms of contrast

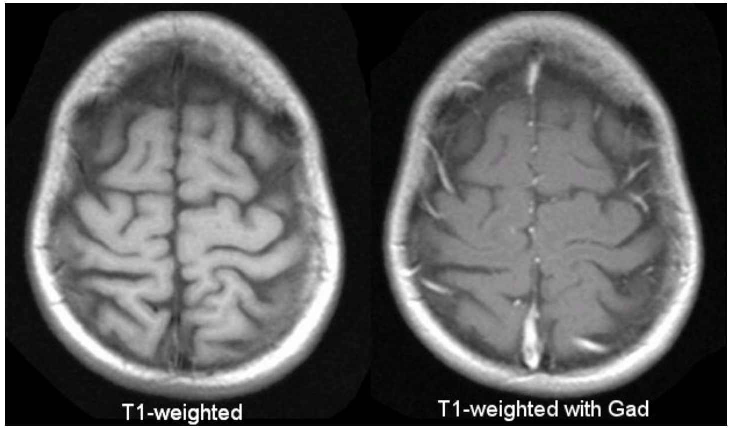
+ Optimize acquisition for targeted pathology

- Makes automatized analyses more challenging

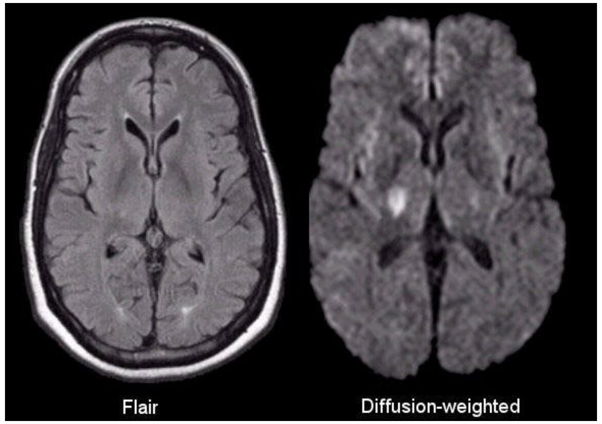
Leveraging different MR relaxation mechanisms



Contrast enhanced



Water-diffusion weighted



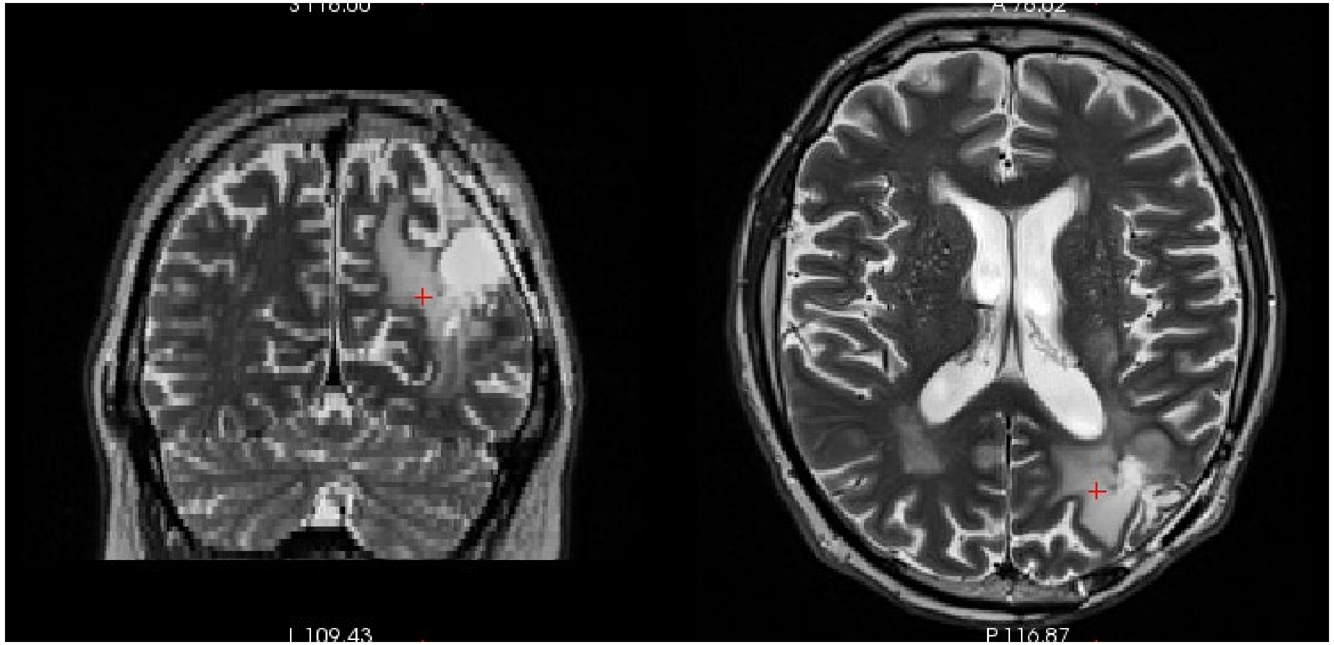
https://case.edu/med/neurology/NR/MRI%20Basics.htm

Characteristics of Medical Images

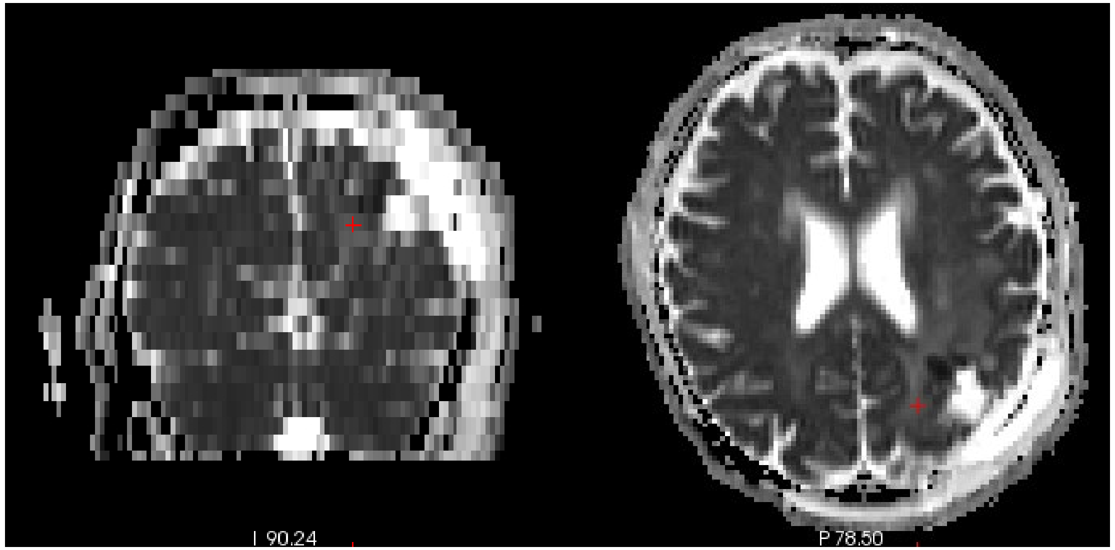
3) Varying contrasts, resolutions and coverage: Little standardization

Resolution and coverage are usually set according to local clinical needs (acquisition as short as possible) & technical scanner specifications

T2-w, 0.8x0.8x2.0 mm, axial slices



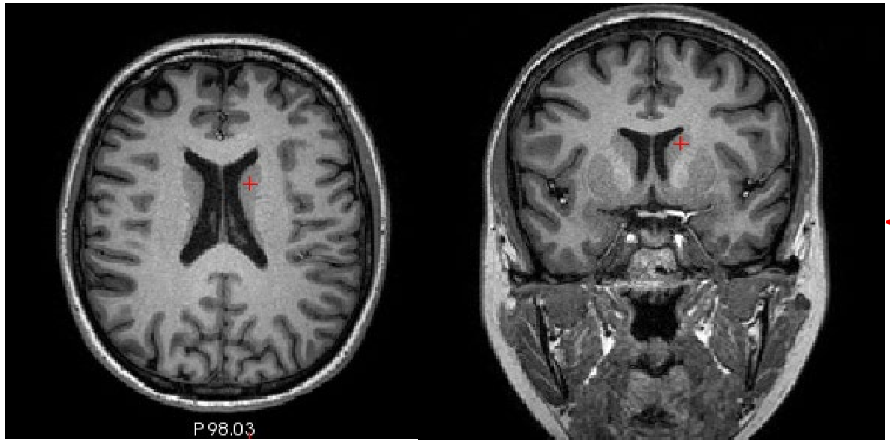
DWI ADC, 1.8x1.8x6.5 mm, axial slices



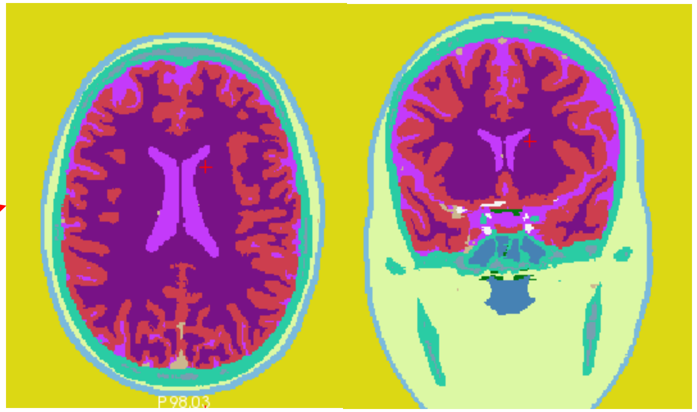
Characteristics of Medical Images

4) Usually small dataset sizes, in particular for manual “ground truth” segmentations

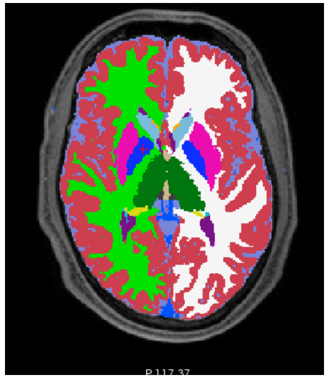
Manually segmenting a high-resolution 3D brain or head scan takes ~1 week for a trained person



Main head tissues:
2-3 days (semi-automatic)



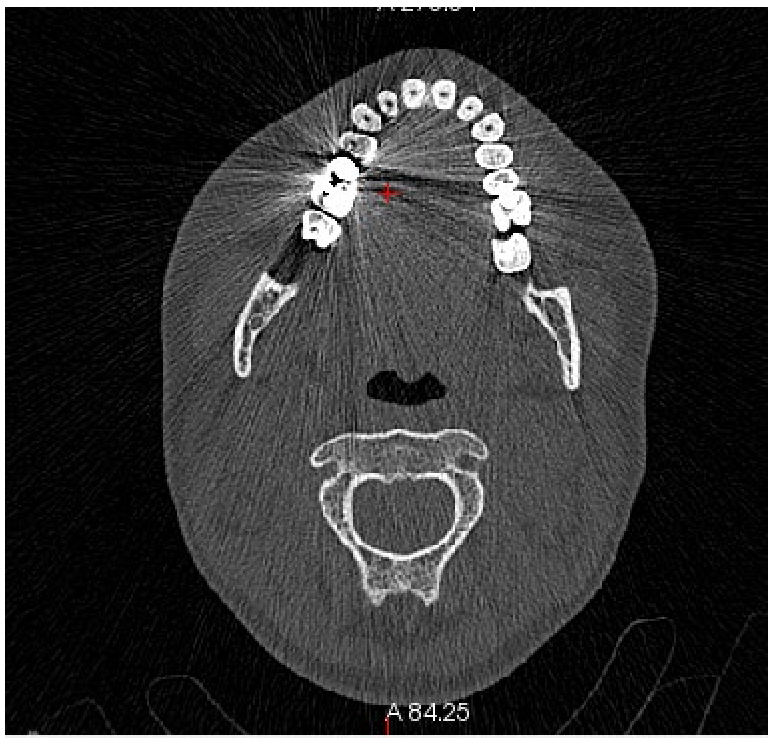
Brain regions:
1 week (manual)



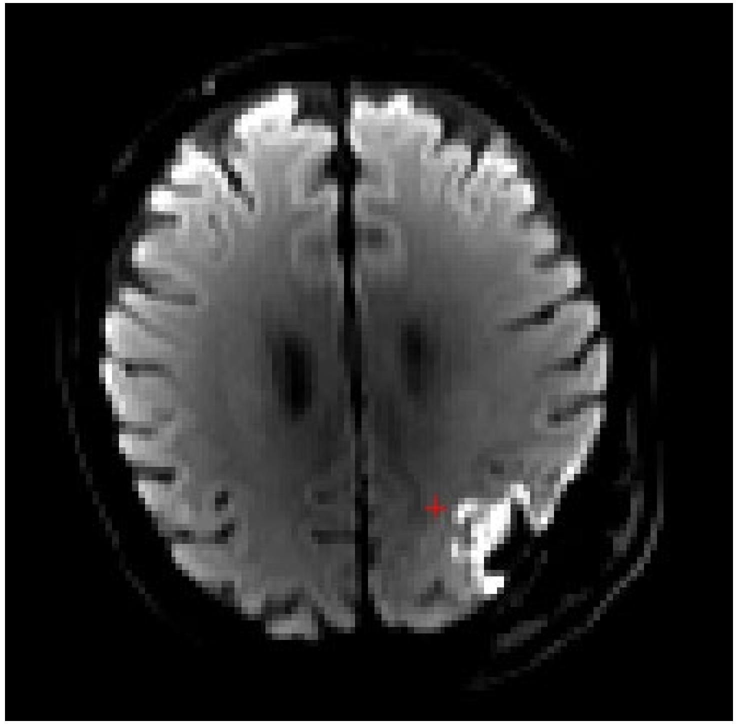
Characteristics of Medical Images

5) Artefacts and imperfections

CT metal artefact



MR bias field

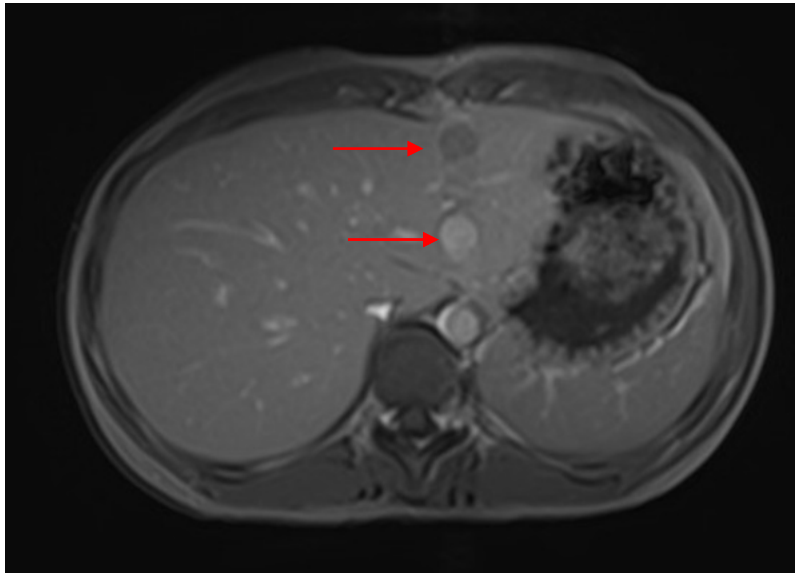


Characteristics of Medical Images

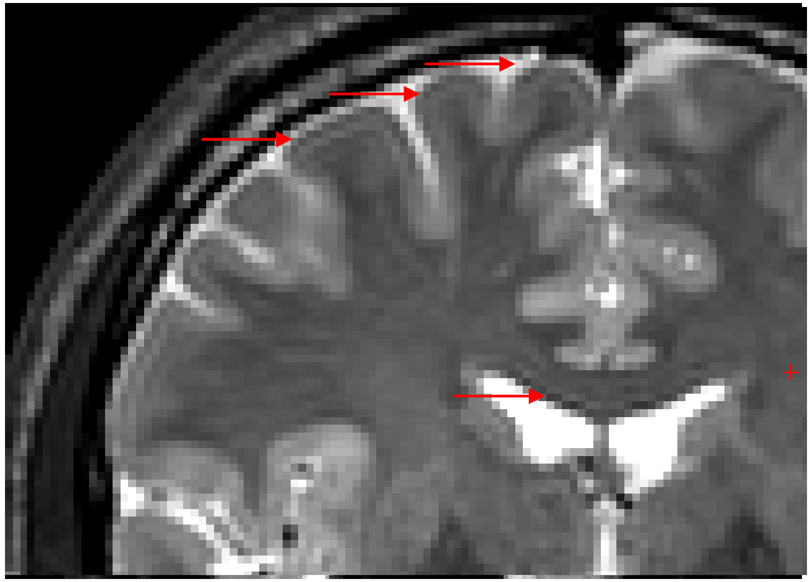
5) Artefacts and imperfections

MRI has a lot to “offer” in terms of artifacts…

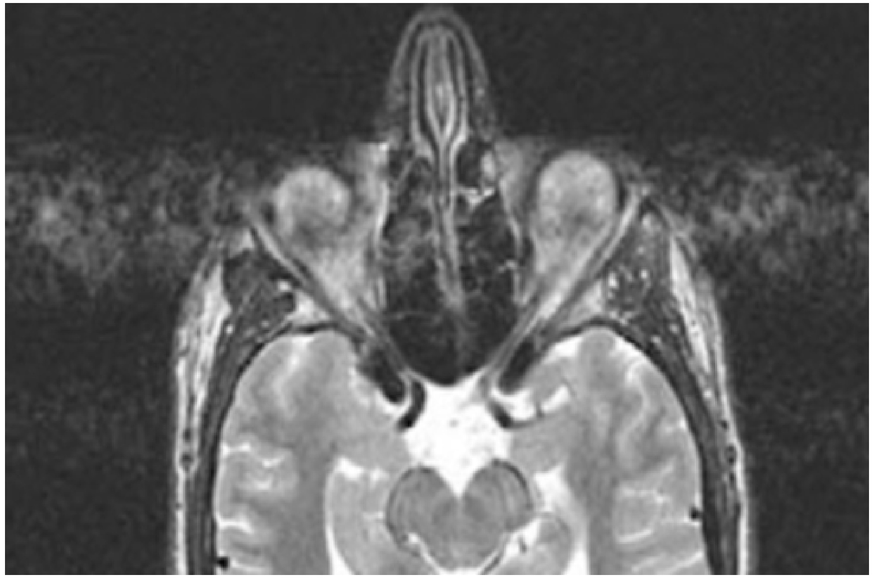
Ghosting due to pulsation



Gibbs ringing



Ghosting due to eye movements



https://mriquestions.com

Characteristics of Medical Images

Take-home message

Medical images have a number of specific properties that makes their automated analyses challenging (and interesting…), and that

- require adaptation and extension of image analyses methods originally designed for other domains
- have triggered the development of domain-specific methods

Not mentioned: Time-dependent measurements (e.g. heart, blood flow, breathing)

Learning Objectives

After this course you should be able to:

- ✓ Implement **smoothing and interpolation** operations in images
- ✓ Explain **coordinate systems** used in medical imaging
- ✓ Perform landmark-based, intensity-based, and surface-based image **registration**
- ✓ Select the most appropriate **similarity measure** for specific image registration problems
- ✓ Implement rigid, affine and nonlinear **spatial transformation models**
- ✓ Solve segmentation problems using **generative models**
- ✓ Perform image segmentation using **example-based learning**
- ✓ Weigh the advantages and limitations of model- vs. example-based techniques
- ✓ Weigh the advantages and limitations of **voxel- and surface-based** medical image analyses