

Medical Image Analysis

NBE-E4010



Aalto-yliopisto
Aalto-universitetet
Aalto University

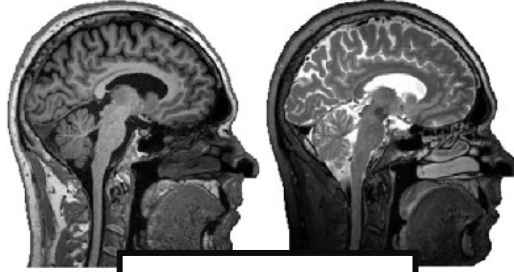
Koen Van Leemput

Fall 2026

AI in medical imaging



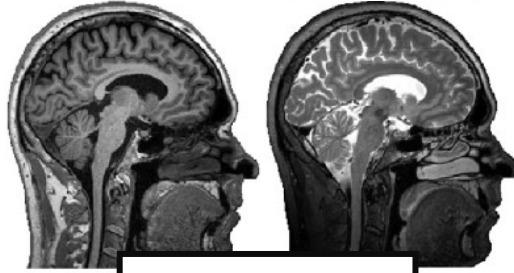
scanner



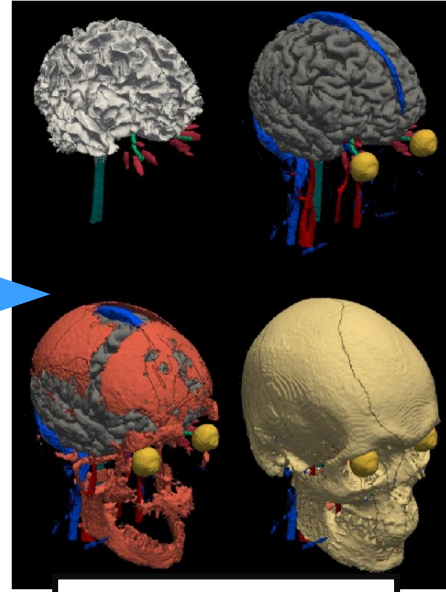
images

- acquire images faster
- visualize more details

AI in medical imaging



images



information

- expose the “unseeable”
- measure more consistently
- analyze images faster

Exposing the “unseeable”

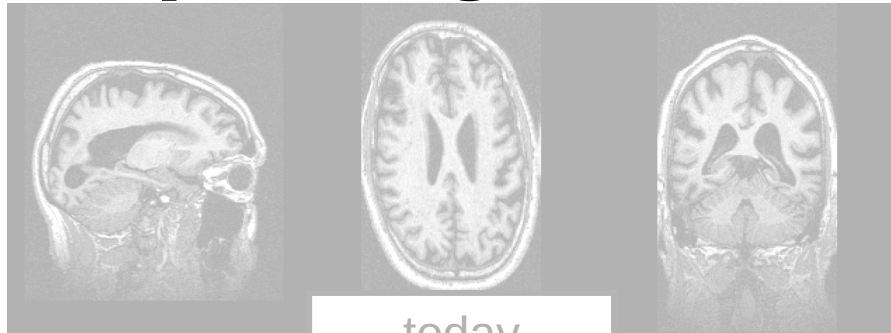


today

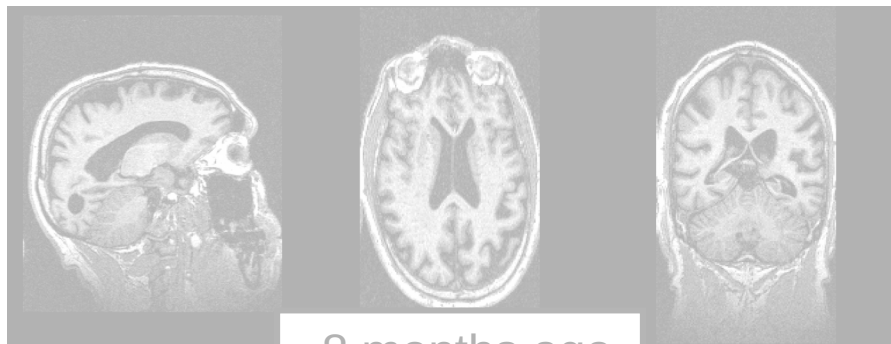


8 months ago

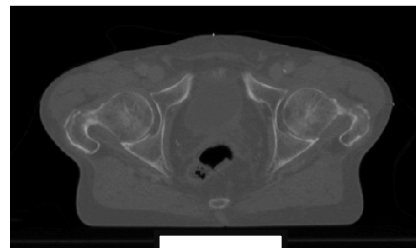
Exposing the “unseeable”



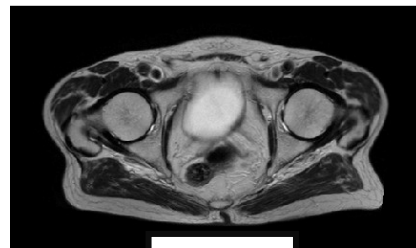
today



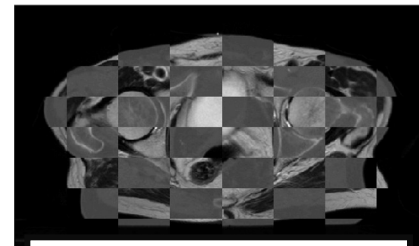
8 months ago



CT

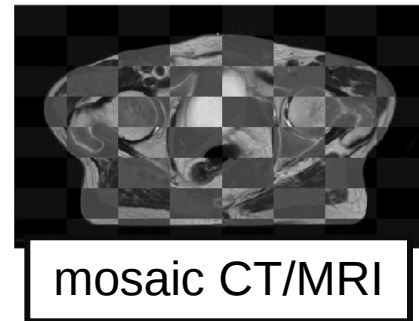
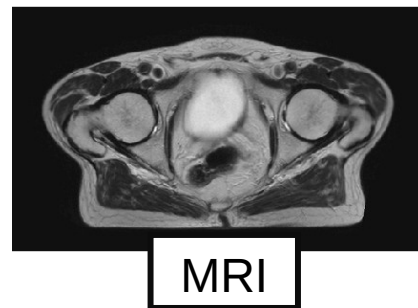
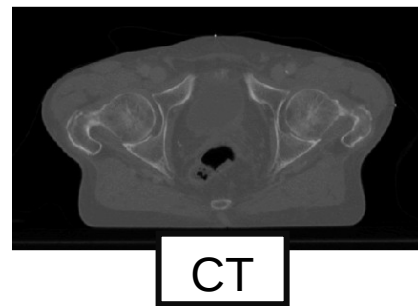
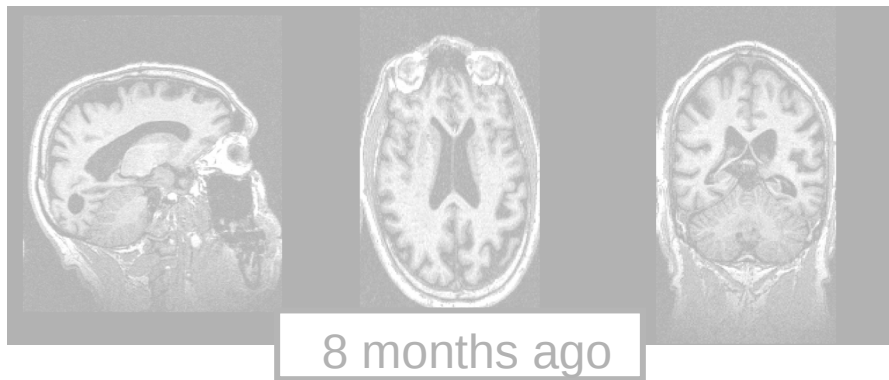
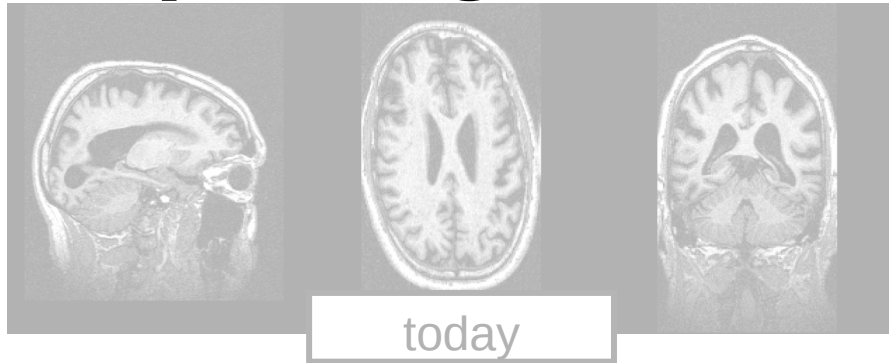


MRI



mosaic CT/MRI

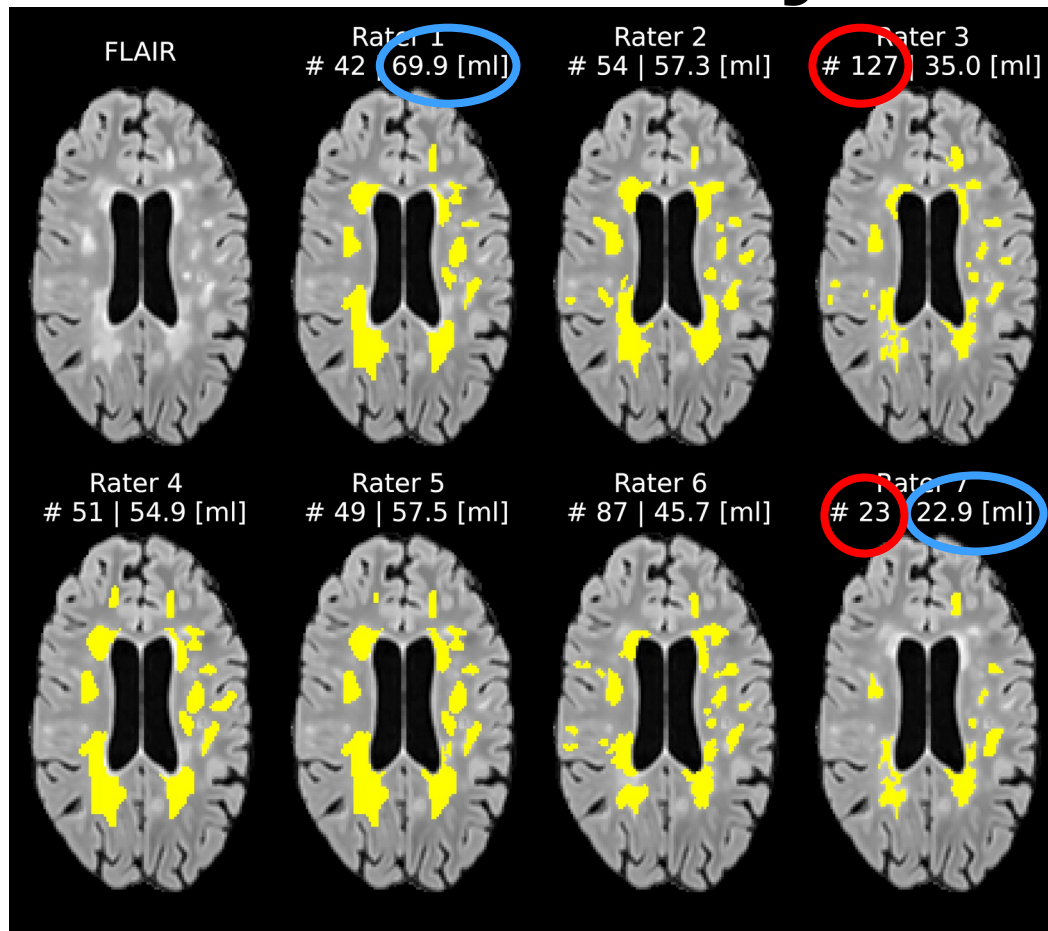
Exposing the “unseeable”



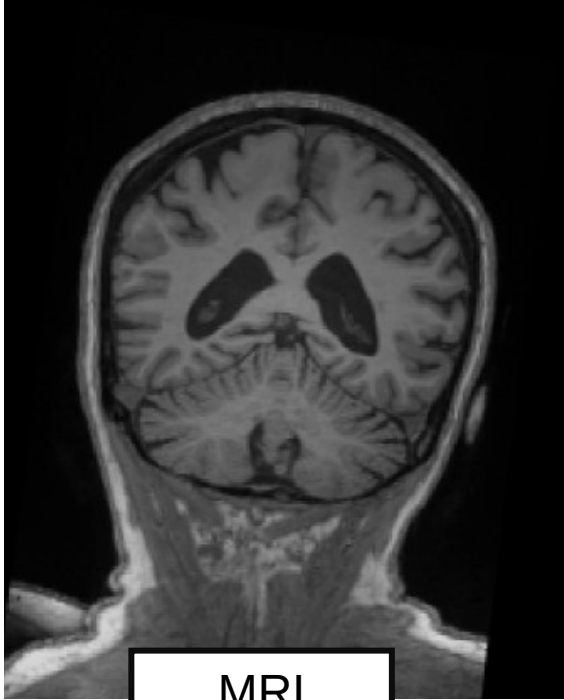
Measuring more consistently

Quantifying lesions in multiple sclerosis (MS):

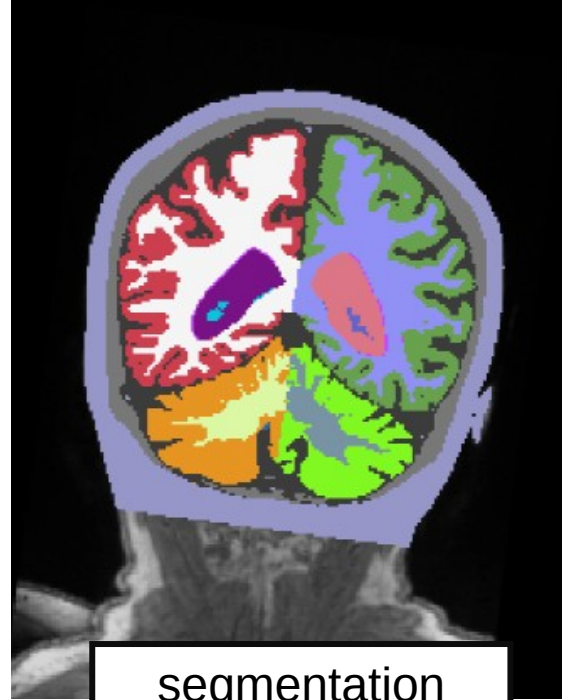
- number (#)
- volume (ml)



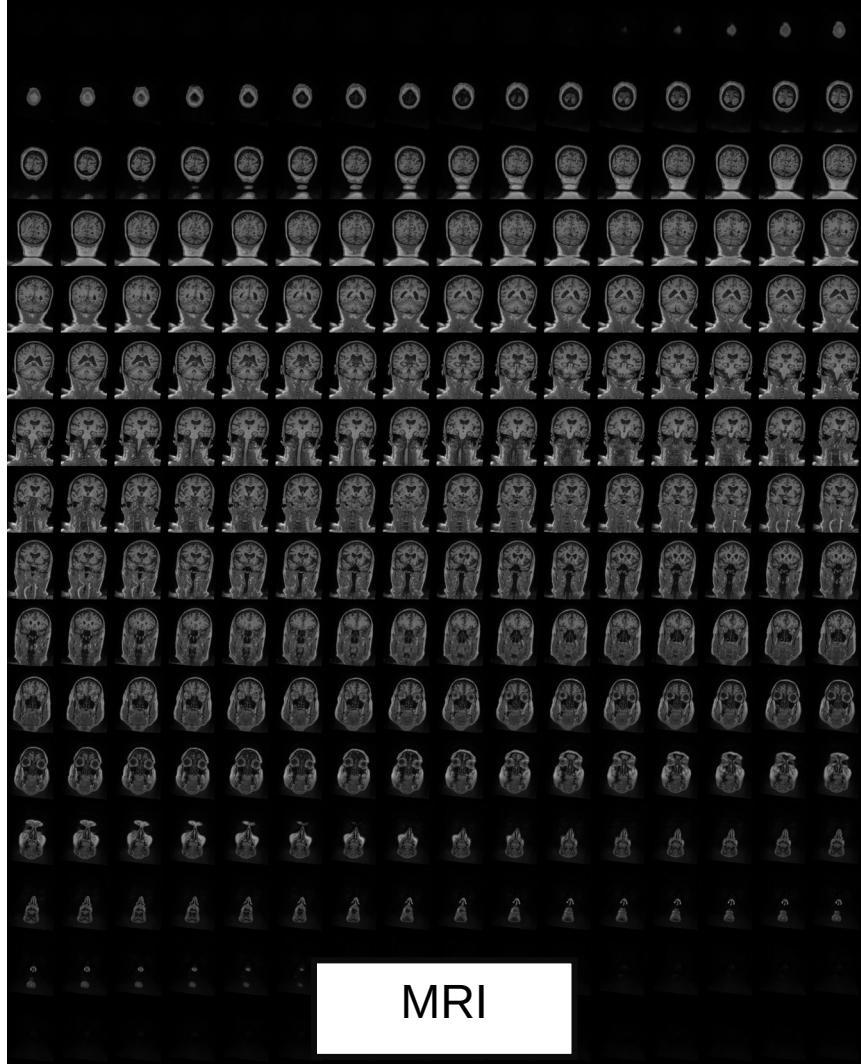
Analyzing images faster



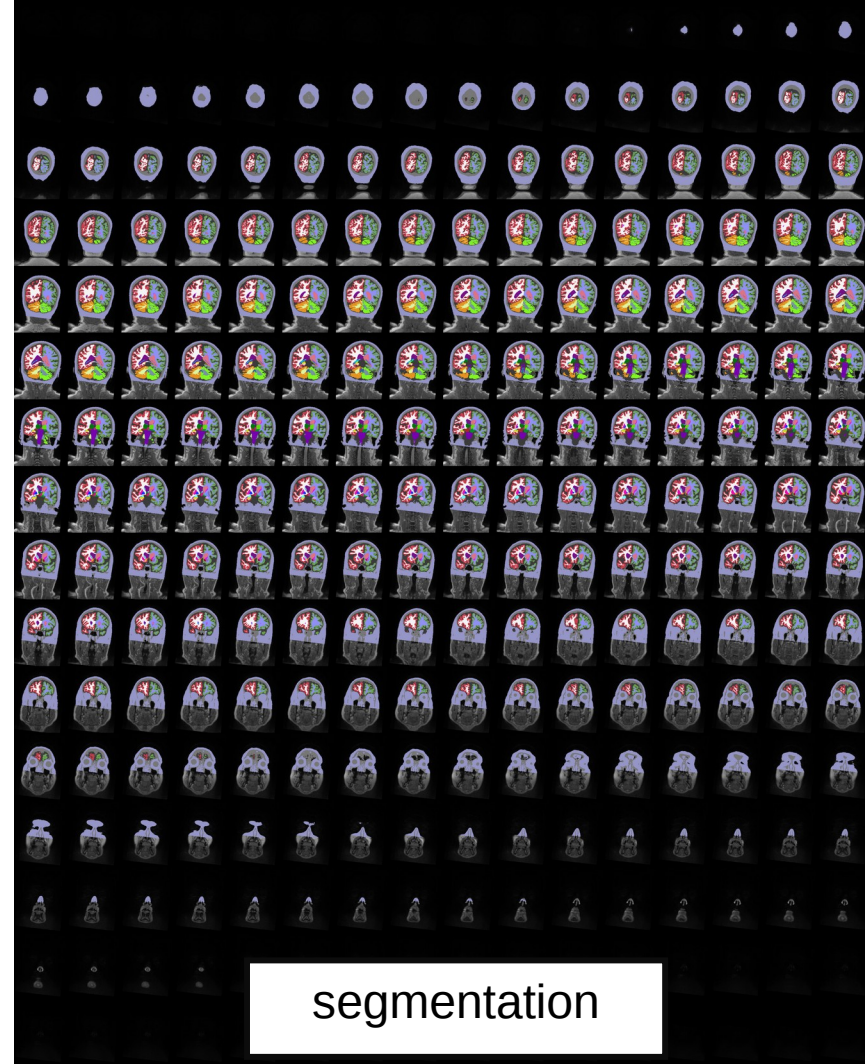
MRI



segmentation

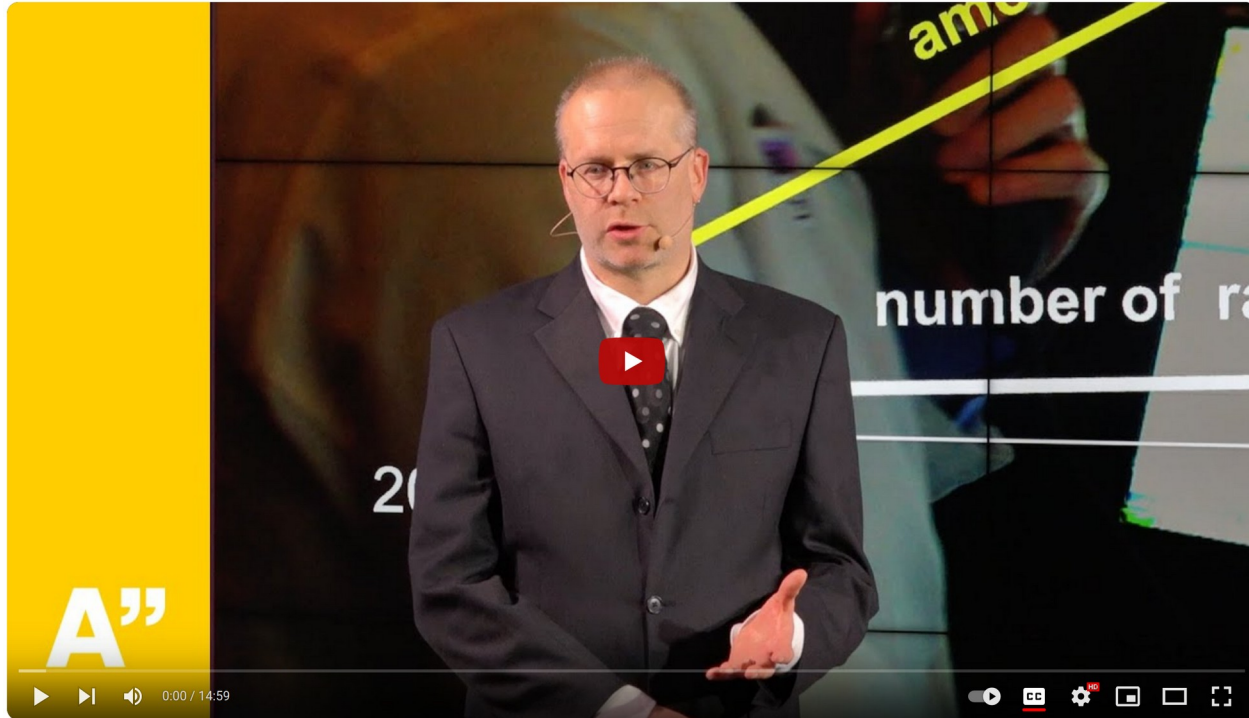


MRI



segmentation

Want to know more?



Artificial Intelligence in medical imaging: From research to clinical practice – Koen Van Leemput

Learning objectives

After this course you should be able to:

- ✓ **Implement** image smoothing and interpolation techniques
- ✓ **Use** spatial coordinate systems in medical images
- ✓ **Perform** landmark-based and intensity-based image registration
- ✓ **Solve** segmentation problems using generative models
- ✓ **Perform** image segmentation using discriminative methods (neural nets)

A “do” course

Who are we?

- ✓ Koen Van Leemput, teacher (Professor, Neuroscience and Biomedical Engineering)
- ✓ Karl Olsson-Lalor, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)
- ✓ Alessandro De Florio, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)



Who are **you**?

- ✓ Master's Programme in Life Science Technologies (ELEC): 21
- ✓ Exchange studies (SCI): 10
- ✓ Master's Programme in Life Science Technologies (SCI): 5
- ✓ Master's Programme in Life Science Technologies (CHEM): 2
- ✓ Master's Programme in Life Science Technologies (Science and Technology): 2

Teaching form

Lectures:

- ✓ Mondays 12.15-14.00 (U141 U3, Otakaari 1)
- ✓ Two guest lectures (one from industry, one from university hospital)
- ✓ The “correct” exercise solutions will be discussed in class

Exercises

- ✓ Tuesdays 10.15-12.00 (A123 A1, Otakaari 1)
- ✓ Python/NumPy + Jupyter notebooks
- ✓ Group-work (**2-3 students per group**)
- ✓ Six exercises in total, submission deadline after < 2 weeks (Friday evening)
- ✓ Peer grading + light review by TAs (**informal feedback**)

- try to find group members today
- go to MyCourses and select a group
- no 1-student “groups” please

Exam:

- ✓ **Individual oral exam**, determines your grade
- ✓ Blindly pick one of your own exercise reports and discuss
- ✓ Active course participation (peer grading, quality of exercise reports) is taken into account for grading

- get more detailed feedback by attending lectures and exercise sessions
- numerical scores don't directly affect your grade

- during weeks 30 Nov - 4 Dec or 7-11 Dec
- pick a suitable time slot in MyCourses (coming up)

Logistics

<https://leempko.github.io/mia/>

- ✓ Course material (book, slides)
- ✓ Schedule

<https://mycourses.aalto.fi/>

- ✓ Group selections
- ✓ Exercises (input data, report submissions, peer grading)
- ✓ Important announcements
- ✓ Discussion fora (secondary place to ask questions)

Week	Date	Activity	Location	Topic	
1	Mon 31 Aug	Lecture	U141	Introduction and group selection	- introduction: pdf - example jupyter notebook
2	Mon 7 Sep	Lecture	U141	Image smoothing and interpolation	- chapter 1 in the book (html pdf) - slides: html pdf
	Tue 8 Sep	Exercise	A123	Smoothing and interpolation	submission deadline: Fri 18 Sep at 23:59
3	Mon 14 Sep	Lecture	U141	Coordinate systems, linear spatial transformations, landmark-based registration	- sections 2.1-2.3 in the book (html pdf) - slides: html pdf
	Tue 15 Sep	Exercise	A123	Landmark-based registration	submission deadline: Fri 25 Sep at 23:59
4	Mon 21 Sep	Lecture	U141	Intensity-based registration	- section 2.4 in the book, excluding Gauss-Newton optimization (html pdf) - slides: html pdf
	Tue 22 Sep	Exercise	A123	Landmark-based registration (cont.)	submission deadline: Fri 25 Sep at 23:59
5	Mon 28 Sep	Lecture	U141	Nonlinear registration	- sections 2.2.2 and 2.4 in the book, especially Gauss-Newton optimization (html pdf) - slides: html pdf
	Tue 29 Sep	Exercise	A123	Intensity-based registration	submission deadline: Fri 9 Oct at 23:59
6	Mon 5 Oct	Lecture	U141	Model-based segmentation I	- sections 3.1-3.3 in the book (html pdf) - probability refresher: html pdf - slides: html pdf

Python/NumPy, Jupyter Notebooks

- ✓ Python: <https://lectures.scientific-python.org/>
- ✓ Jupyter Notebooks:
 - <https://www.dataquest.io/blog/jupyter-notebook-tutorial/>
 - <https://jupyter.cs.aalto.fi/>

<https://leempko.github.io/mia/>

Week	Date	Activity	Location	Topic
1	Mon 31 Aug	Lecture	U141	Introduction and group selection

- introduction: [pdf](#)
- example [jupyter notebook](#)

Jupyter exampleNotebook (autosaved)

File Edit View Insert Cell Kernel Widgets Help Not Trusted Python 3 (ipykernel)

Image Smoothing and Interpolation

Linear regression

Let $\mathbf{x} = (x_1, \dots, x_D)^T$ denote the spatial position in a D -dimensional space. In medical imaging, D is typically 2 or 3. Given N measurements $\{t_n\}_{n=1}^N$ at locations $\{\mathbf{x}_n\}_{n=1}^N$, a frequent task is to predict the value t at a new location $\mathbf{x}$. A simple model, known as `lemp` (linear regression), uses the function value

$$y(\mathbf{x}; \mathbf{w}) = w_0 + w_1 x_1 + \dots + w_D x_D$$

as its prediction, where $w_0, \dots, w_D$ are tunable weights that need to be estimated from the available measurements. A more general form uses nonlinear functions of the input locations instead:

$$y(\mathbf{x}; \mathbf{w}) = w_0 + \sum_{m=1}^{M-1} w_m \phi_m(\mathbf{x}),$$

which greatly increases the flexibility of the model. Here the functions $\phi_m(\mathbf{x})$ are known as `lemp` (basis functions), and it is often convenient to define an additional "dummy" basis function $\phi_0(\mathbf{x}) = 1$, so that the model can be written as

$$y(\mathbf{x}; \mathbf{w}) = \sum_{m=0}^{M-1} w_m \phi_m(\mathbf{x}),$$

where $\mathbf{w} = (w_0, \dots, w_{M-1})^T$ are M tunable parameters.

In order to find suitable values of the parameters of the model, the following energy can be minimized with respect to $\mathbf{w}$:

$$E(\mathbf{w}) = \sum_{n=1}^N \left(t_n - \sum_{m=0}^{M-1} w_m \phi_m(\mathbf{x}_n) \right)^2,$$

which simply sums of the squared distances between the measurements t_n and the model's predictions $y(\mathbf{x}_n; \mathbf{w})$.

```
In [4]: #
import numpy as np
from matplotlib import pyplot as plt
plt.ion()

#
N = 30;
ns = np.arange(N).reshape(-1, 1)
A = np.cos(np.pi * (ns + 0.5) * np.arange(3) / N)
A[:, 0] *= 1/np.sqrt(2) # DC component is scaled differently
plt.figure()
plt.plot(ns, A)
```

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<matplotlib.lines.Line2D at 0x7fdf2fc6fc70>

To conclude...

Physical attendance

- ✓ Is expected in the lectures and the exercise sessions
- ✓ Your primary way to ask questions and get feedback
- ✓ (It's technically possible to follow online, but strongly discouraged)

Solve exercises in groups **(2-3 students per group)**



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Questions?

Copyrights

"Accurate and robust whole-head segmentation from magnetic resonance images for individualized head modeling" by Puonti et al. NeuroImage (2020), licensed under CC-BY-NC-ND