

Medical Image Analysis

NBE-E4010



Aalto-yliopisto
Aalto-universitetet
Aalto University

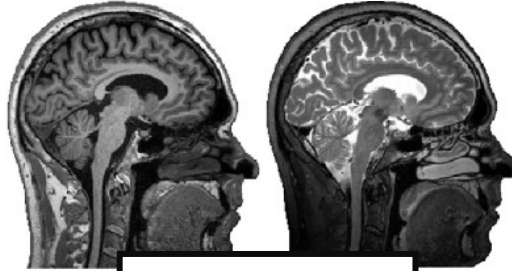
Koen Van Leemput

Fall 2024

AI in medical imaging



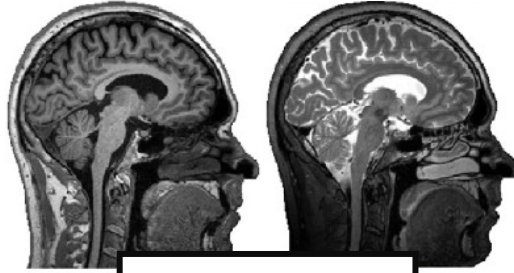
scanner



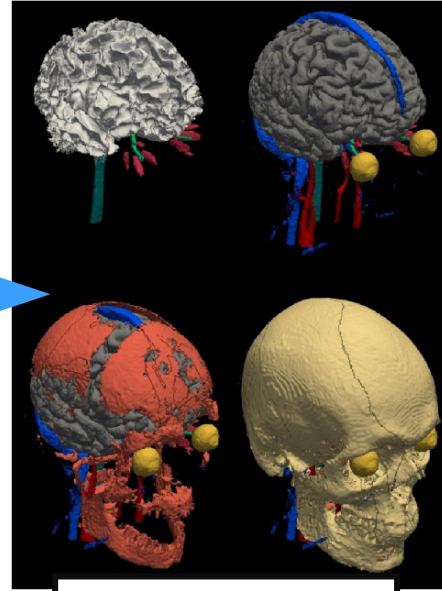
images

- acquire images faster
- visualize more details

AI in medical imaging



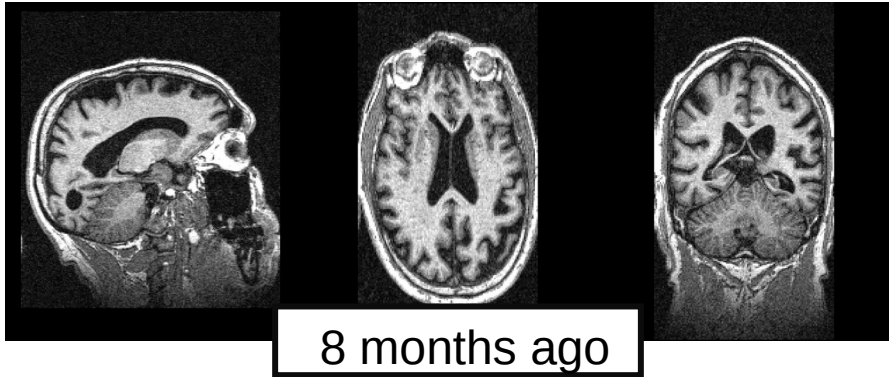
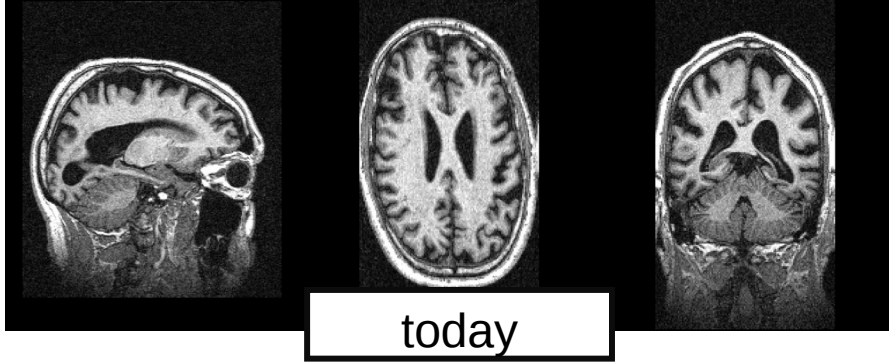
images



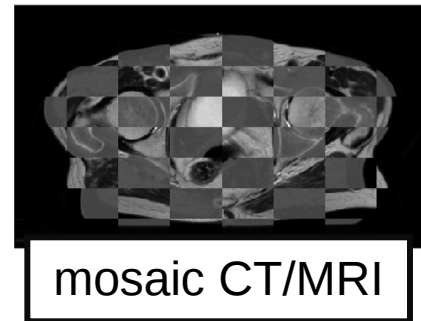
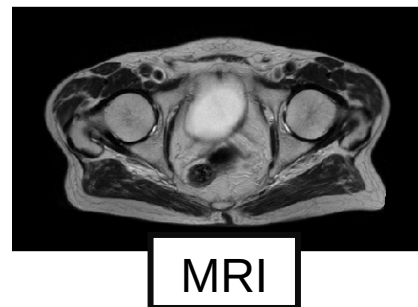
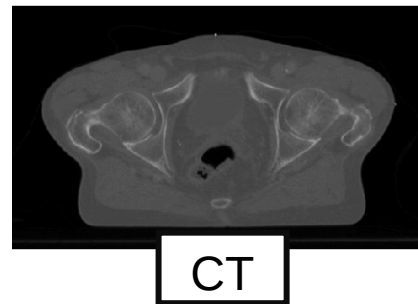
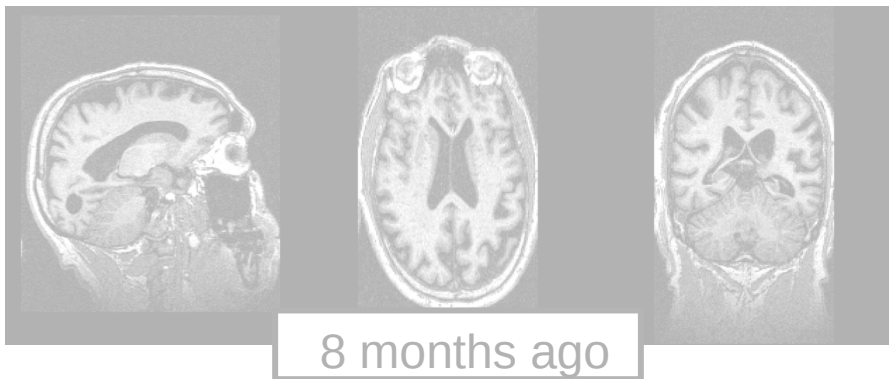
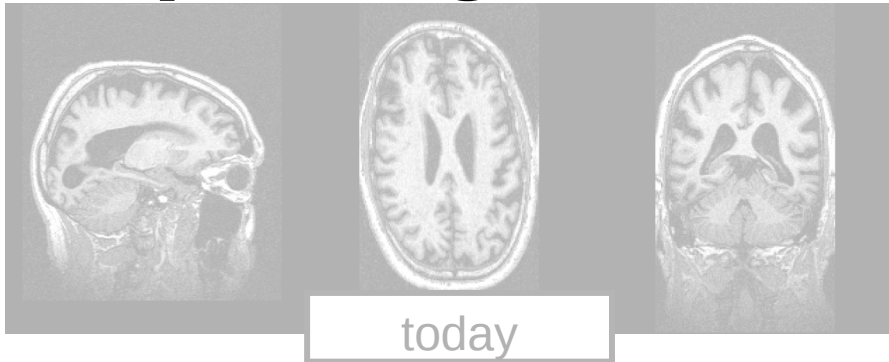
information

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

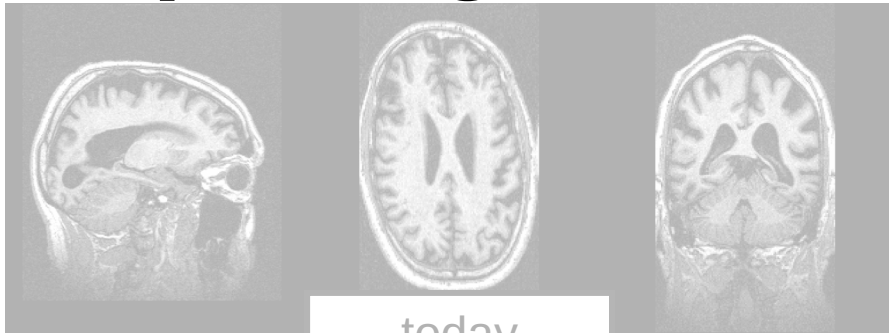
Exposing the “unseeable”



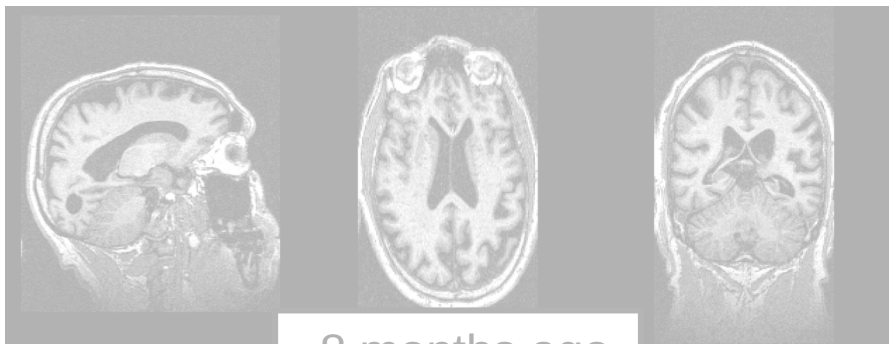
Exposing the “unseeable”



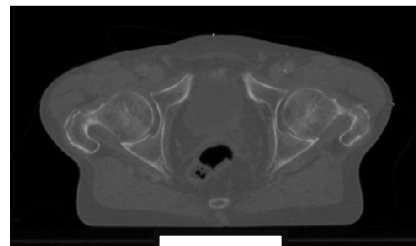
Exposing the “unseeable”



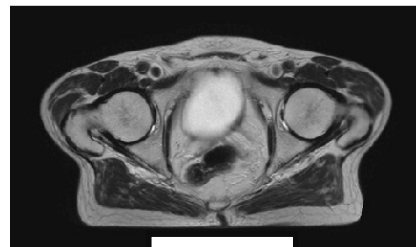
today



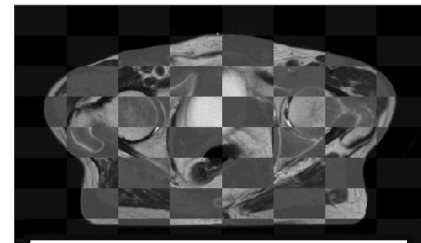
8 months ago



CT



MRI

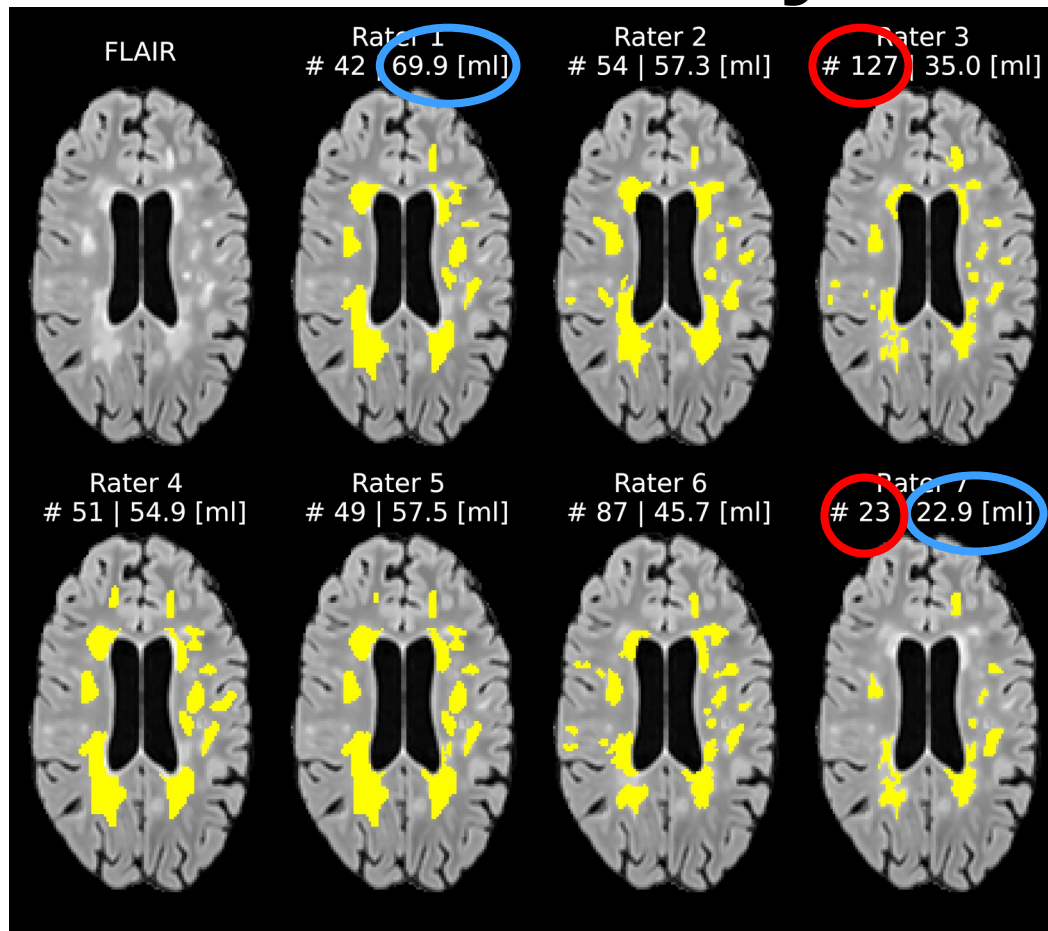


mosaic CT/MRI

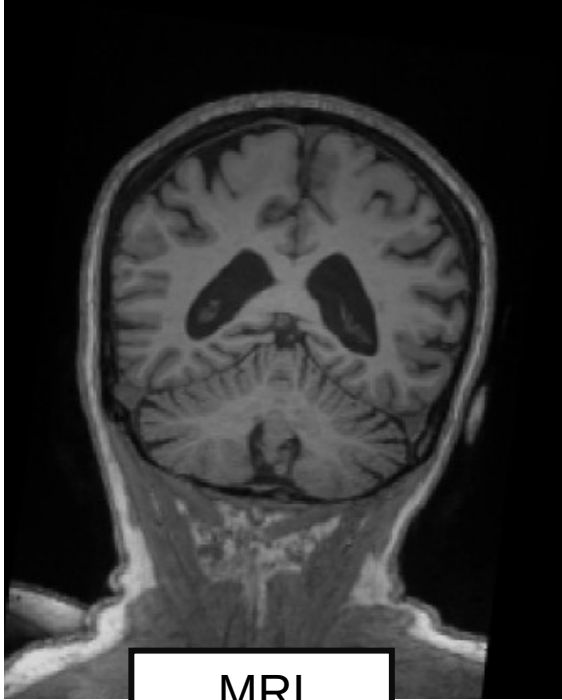
Measuring more consistently

Quantifying lesions in multiple sclerosis (MS):

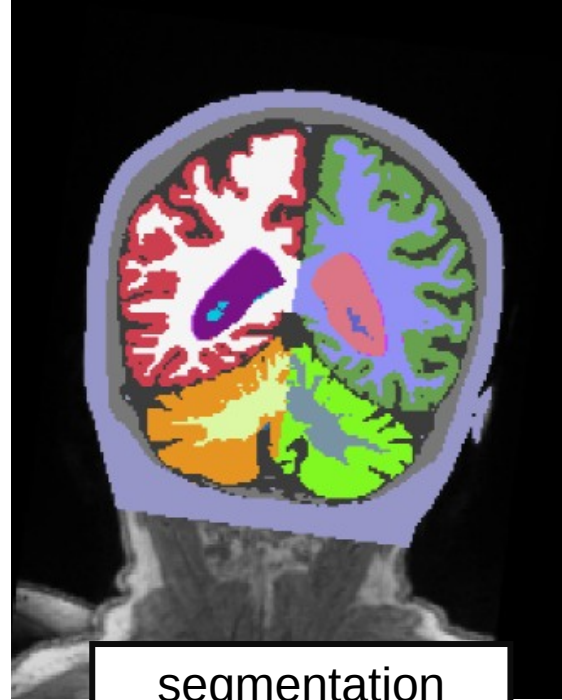
- number (#)
- volume (ml)



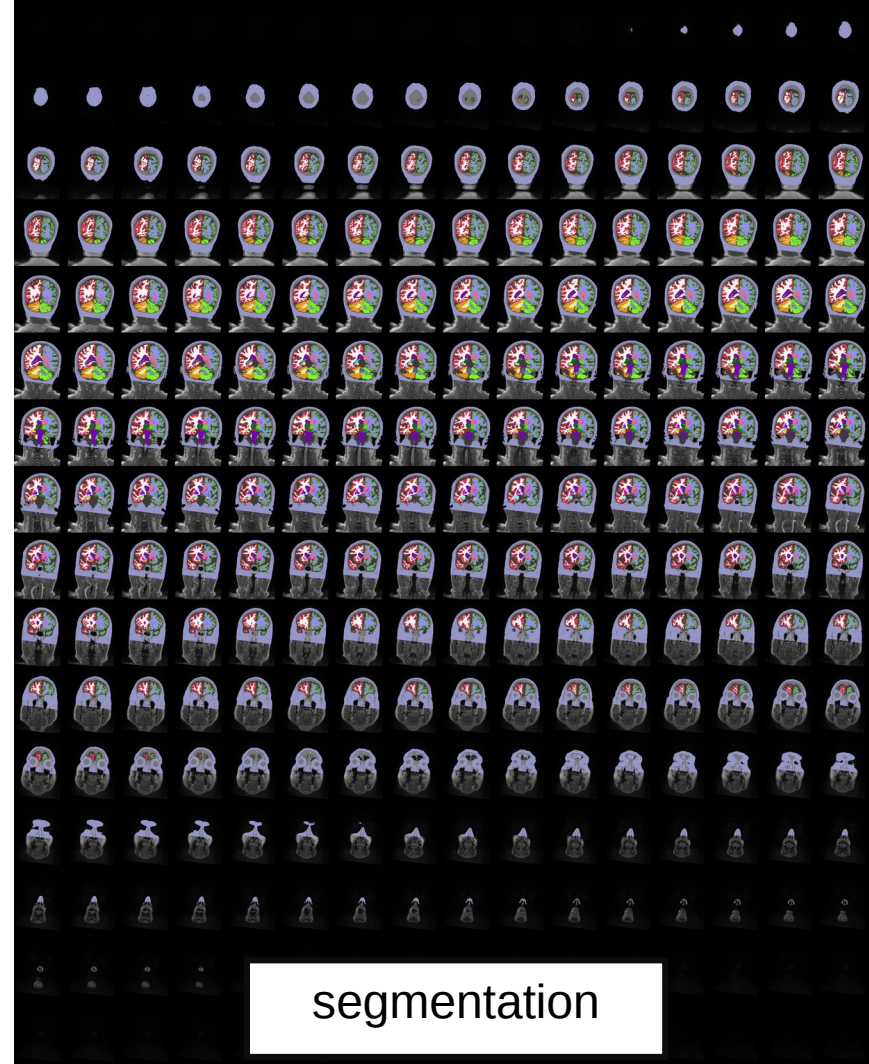
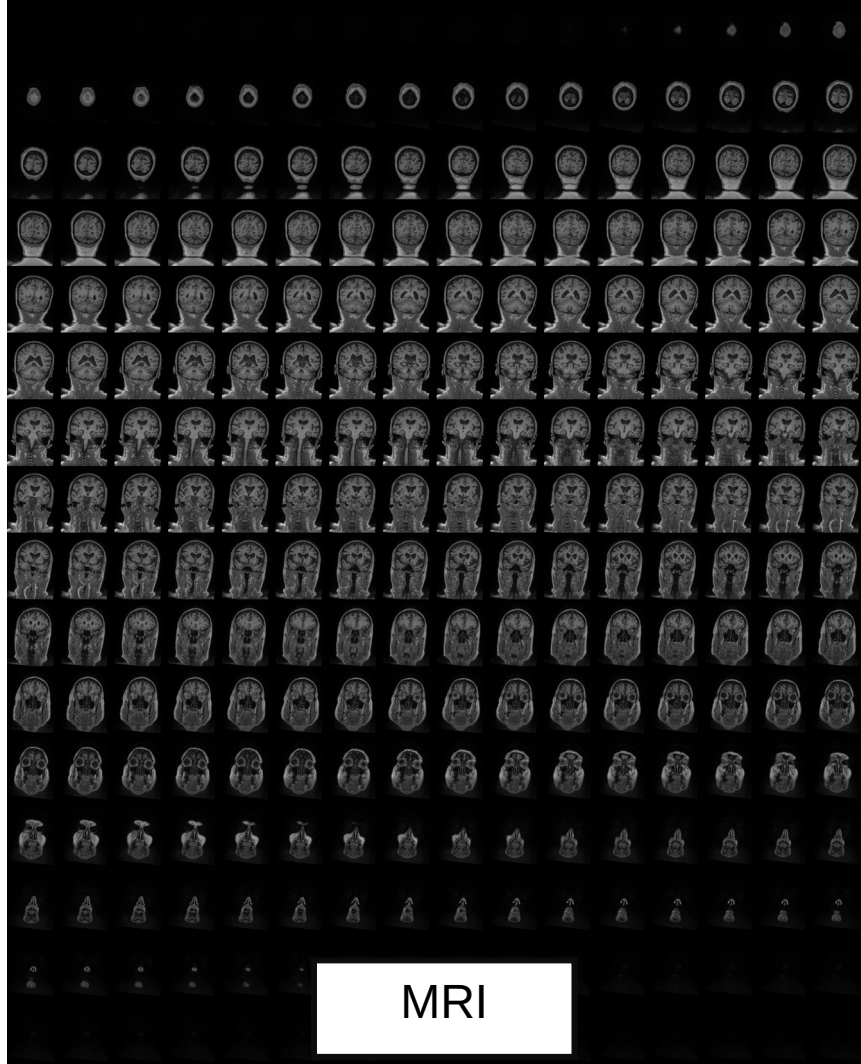
Analyzing images faster



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
- ✓ **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 discriminative methods (neural nets)
- ✓ **Weigh** the advantages and limitations of generative vs. discriminative techniques in medical image analysis

A “do” course

Who are we?

- ✓ Koen Van Leemput, teacher (Professor, Neuroscience and Biomedical Engineering)
- ✓ Ida Granö, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)
- ✓ Matias Vuokko, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)
- ✓ Amir Hassankhani, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)



Who are **you**?

- ✓ Life Science Technologies: 21
- ✓ Exchange studies: 10
- ✓ Electrical Engineering: 6
- ✓ Aalto Doctoral Programme in Science: 4
- ✓ Science and Technology: 2
- ✓ Chemical Engineering: 1
- ✓ Engineering: 1
- ✓ Computer, Communication and Information Sciences: 1
- ✓ Chemical Technology: 1
- ✓ Non-degree Studies (Arts and Culture): 1

Physical attendance:

- not “required” in lectures or exercise sessions
- but but...

Teaching form

Lectures:

- ✓ Mondays 12.15-14.00
- ✓ Lecture recordings will be made available
- ✓ Two guest lectures: Aino Nieminen (Disior) and Eero Salli (HUS Radiology)

Exercises:

- ✓ Thursdays 12.15-14.00
- ✓ Python + Jupyter notebooks
- ✓ Group-work (max. 3 students per group)
- ✓ 2 weeks to submit a group report (6 reports in total)
- ✓ Peer grading using FeedbackFruits

Student presentations:

- ✓ Students present their fellow students' exercise reports
- ✓ Instead of the lectures on 21 Oct and 25 Nov

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Course grading:

- peer grading quality (10%)
- teachers' final score on reports (80%)
- student presentation (10%)

Logistics

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

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

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

- ✓ Announcements
- ✓ Discussion fora
- ✓ Exercises (input data, report submissions, peer grading)

Week	Date	Activity	Location	Topic	
1	Mon 2 Sep	Lecture	F239a	Introduction to the course	- slides: pdf - jupyter notebook example
2	Mon 9 Sep	Lecture	F239a	Image smoothing and interpolation	- chapter 1 in the book (html pdf) - slides: html pdf
	Thu 12 Sep	Exercise	F239a	Smoothing and interpolation	- submission deadline: Wed 25 Sep at 23:59
3	Mon 16 Sep	Lecture	F239a	Coordinate systems, linear spatial transformations, landmark-based registration	- sections 2.1-2.3 in the book (html pdf) - slides: html pdf
	Thu 19 Sep	Exercise	F239a	Landmark-based registration	- submission deadline: Wed 2 Oct at 23:59
4	Mon 23 Sep	Lecture	F239a	Intensity-based registration	- section 2.4 in the book, excluding Gauss-Newton optimization (html pdf) - slides: html pdf
	Thu 26 Sep	Exercise	F239a	Mutual Information-based registration	- submission deadline: Wed 9 Oct: at 23:59
5	Mon 30 Sep	Lecture	F239a	Nonlinear registration	- sections 2.2.2 and 2.4 in the book, especially Gauss-Newton optimization (html pdf) - slides: html pdf
	Thu 3 Oct	Exercise	F239a	Mutual Information-based registration (cont.)	- submission deadline: Wed 9 Oct: at 23:59
6	Mon 7 Oct	Lecture	F239a	Model-based segmentation I	- sections 3.1-3.3 in the book (html pdf) - probability refresher: html pdf - slides: html pdf
7	Mon 21 Oct	Lecture	F239a	Student presentations of the first three exercises	
	Thu 24 Oct	Exercise	Y202a	Nonlinear registration	- submission deadline: Wed 6 Nov at 23:59
8	Mon 28 Oct	Lecture	F239a	Model-based segmentation II	- sections 3.4-3.5 in the book (html pdf) - slides: html pdf

Python and Jupyter Notebooks

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

Jupyter exampleNotebook (autosaved) Logout

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

Run Markdown InJoy

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 `lemph`(linear regression), uses the function value

$$y(\mathbf{x}; \mathbf{w}) = u_0 + u_1 x_1 + \dots + u_D x_D$$

as its prediction, where u_0, \dots, u_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:

$$y(\mathbf{x}; \mathbf{w}) = u_0 + \sum_{m=1}^{M-1} u_m \phi_m(\mathbf{x}),$$

which greatly increases the flexibility of the model. Here the functions $\phi_m(\mathbf{x})$ are known as `lemph`(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

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

where $\mathbf{w} = (u_0, \dots, u_{M-1})^T$ 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} :

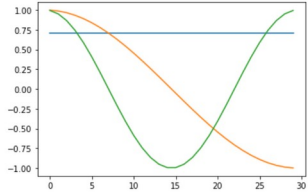
$$E(\mathbf{w}) = \sum_{n=1}^N \left(t_n - \sum_{m=0}^{M-1} u_m \phi_m(\mathbf{x}_n) \right)^2,$$

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)
```

Out[4]: [matplotlib.lines.Line2D at 0x7fdf2fc61a60],
[matplotlib.lines.Line2D at 0x7fdf2fc61a90],
[matplotlib.lines.Line2D at 0x7fdf2fc6fc70]



Jupyter notebooks at Aalto

<https://jupyter.cs.aalto.fi/>

Server Options

- Python: General use (JupyterLab) v6.1.4
- Python: General use (classic notebook) v6.1.4
- R: General use (JupyterLab) v5.0.25-jh401
- Julia: General use (JupyterLab) v5.0.16-jh401
- (testing) Python: General use (JupyterLab) v6.0.0
- Old version (JupyterLab) v5.0.0



Jupyter notebooks at Aalto

<https://jupyter.cs.aalto.fi/>

 jupyterhub

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<input type="checkbox"/>	..		seconds ago	
<input type="checkbox"/>	 eventTest.ipynb		a day ago	44.8 kB
<input type="checkbox"/>	 interactiveViewerBackend.ipynb		12 hours ago	660 kB
<input type="checkbox"/>	 testje.ipynb		a day ago	2.44 MB
<input type="checkbox"/>	 Untitled.ipynb		3 months ago	3.83 kB
<input type="checkbox"/>	 Untitled1.ipynb		a day ago	2.1 kB
<input type="checkbox"/>	 Untitled2.ipynb		a day ago	2.93 kB
<input type="checkbox"/>	 Untitled3.ipynb		12 hours ago	438 kB
<input type="checkbox"/>	 IXI002-Guys-0828-T1.nii.gz		a day ago	6.94 MB

Jupyter notebooks at Aalto



<https://jupyter.cs.aalto.fi/>

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Files Running Clusters Assignments Nbextensions

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New



0		/ notebooks		Name	
<input type="checkbox"/>	..				
<input type="checkbox"/>	eventTest.ipynb				
<input type="checkbox"/>	interactiveViewerBackend.ipynb				
<input type="checkbox"/>	testje.ipynb				
<input type="checkbox"/>	Untitled.ipynb				
<input type="checkbox"/>	Untitled1.ipynb				a day ago 2.1 kB
<input type="checkbox"/>	Untitled2.ipynb				a day ago 2.93 kB
<input type="checkbox"/>	Untitled3.ipynb				12 hours ago 438 kB
<input type="checkbox"/>	IXI002-Guys-0828-T1.nii.gz				a day ago 6.94 MB

Notebook:

- Bash
- Python 3

Other:

- Text File
- Folder
- Terminal



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