Medical Image Analysis

NEBE-E4010

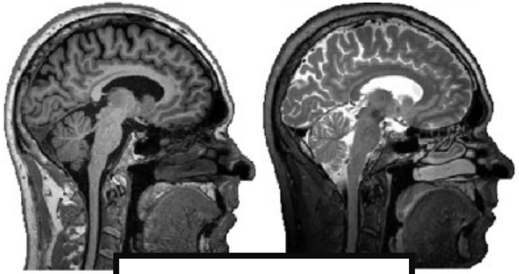
Aalto-yliopisto
Aalto-universitetet
Aalto University

Koen Van Leemput

Fall 2025

AI in medical imaging

scanner

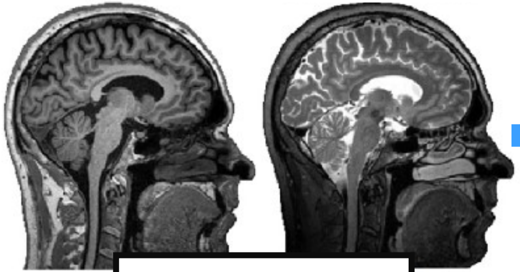


images

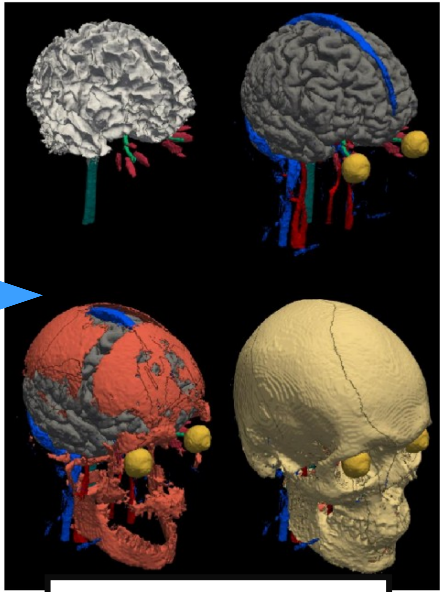
- acquire images faster
- visualize more details

AI in medical imaging

scanner



images



information

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

Exposing the “unseeable”

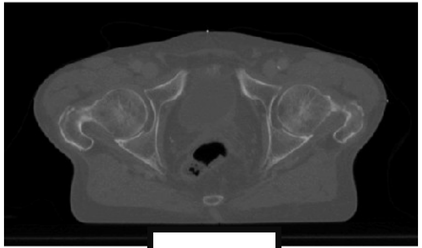
today

8 months ago

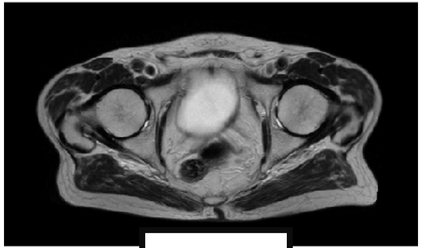
Exposing the “unseeable”

today

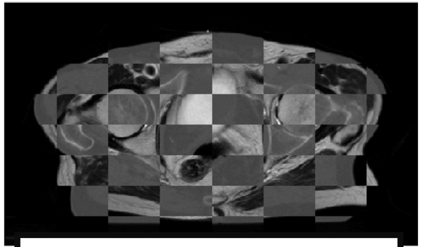
8 months ago



CT



MRI

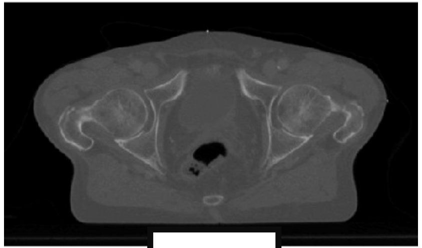


mosaic CT/MRI

Exposing the “unseeable”

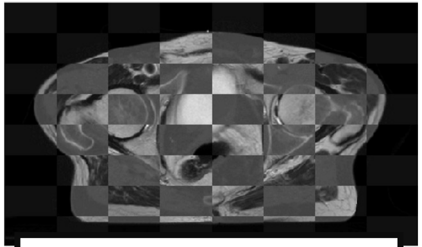
today

8 months ago



CT

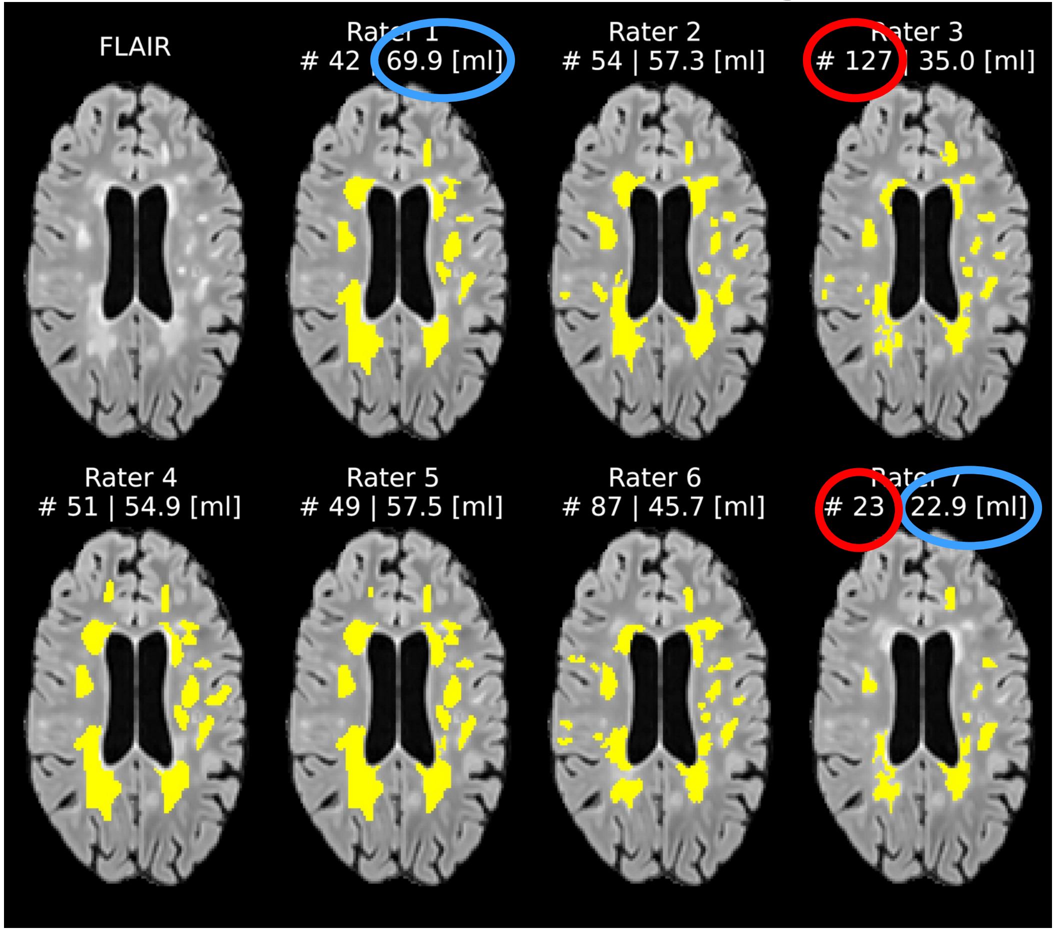
MRI



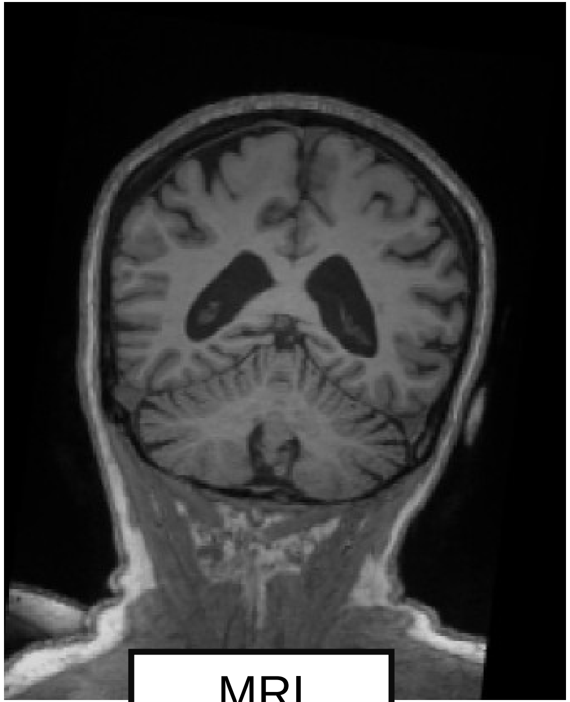
mosaic CT/MRI

Measuring more consistently

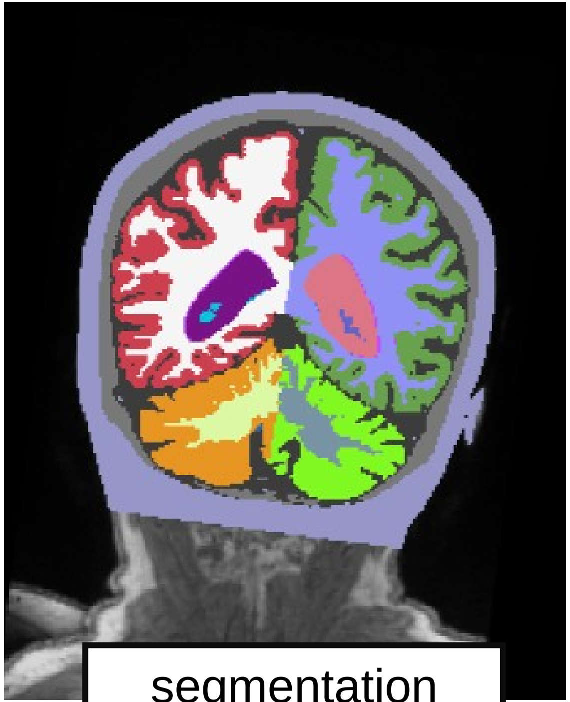
Quantifying lesions in multiple sclerosis (MS):
- number (#)
- volume (ml)



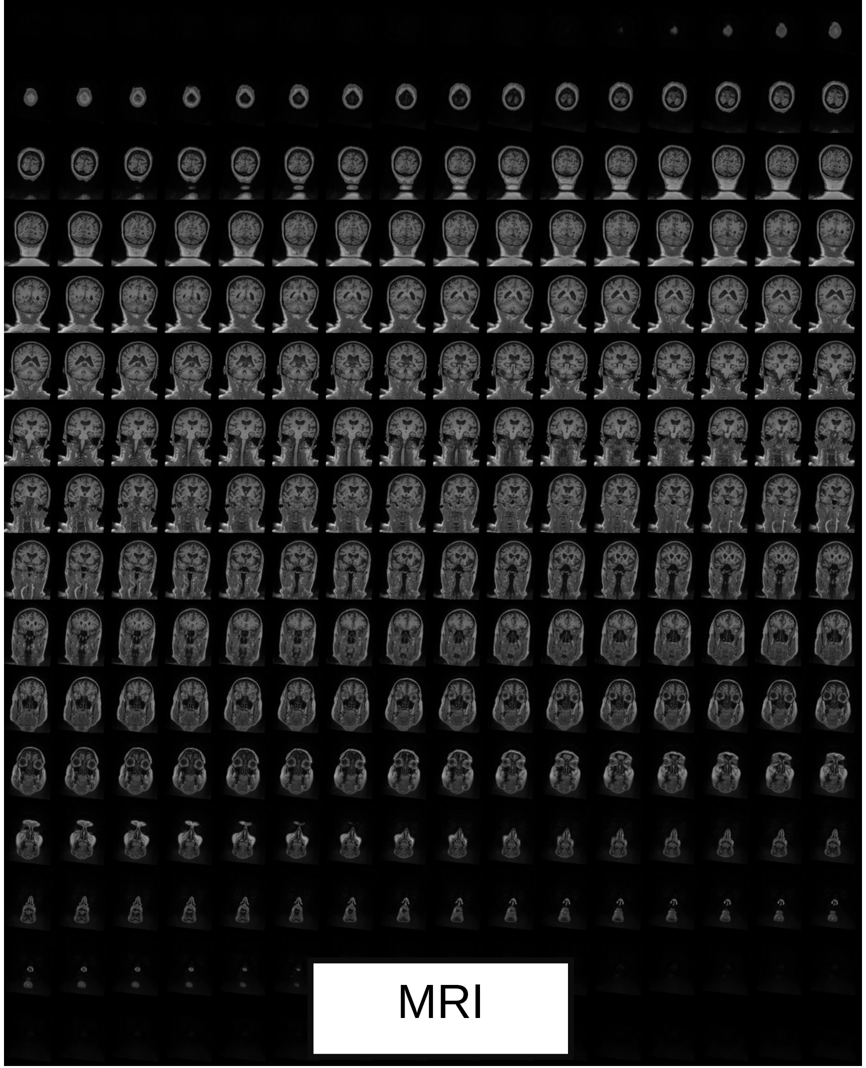
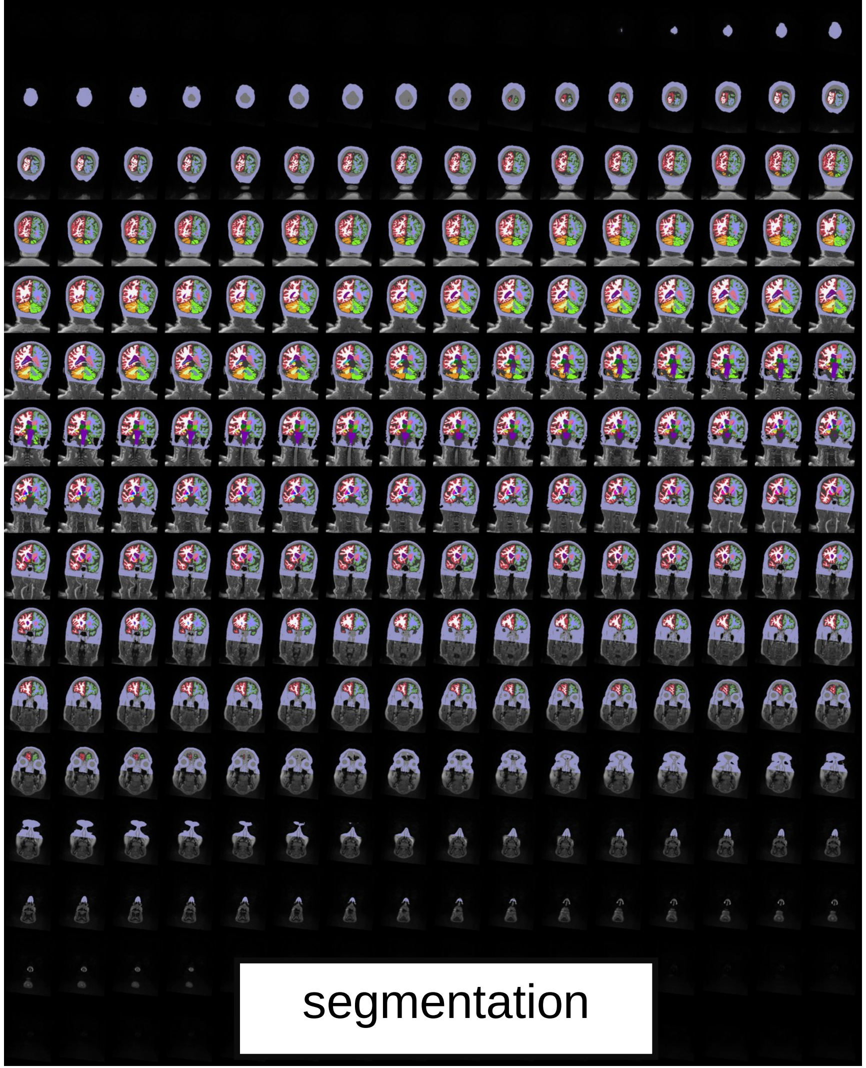
Analyzing images faster



MRI



segmentation


MRI

segmentation

Want to know more?

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

https://youtu.be/iiw4j-Frljo

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)
- ✔ Matias Vuokko, TA (Doctoral Researcher, Neuroscience and Biomedical Engineering)
- ✔ Amir Hassankhani, 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 29
- ✔ Exchange studies (SCI + ELEC): 11
- ✔ Master's Programme in Computer, Communication and Information Sciences 6

- ✔ Bachelor's Programme in Electrical Engineering 5
- ✔ Bachelor's Programme in Science and Technology 3
- ✔ Aalto Bachelor's Programme in Science and Technology 3
- ✔ Bachelor's Programme in Chemical Engineering 2

- ✔ JOO Studies (Engineering, manufacturing and construction), SCI 2
- ✔ Master's Programme in ICT Innovation 2
- ✔ Master's Programme in Engineering Physics 2
- ✔ Master's Programme in Health Technology Engineering 1
- ✔ Aalto Doctoral Programme in Science 1

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Physical attendance:
- is expected in the lectures and the exercise sessions
- your primary way to ask questions and get feedback
- (it’s possible to follow online, but not designed that way)

Teaching form

Lectures:

- ✔ Thursdays 12.15-14.00 (F239a)
- ✔ Lecture recordings are available
- ✔ One guest lecture (typically from industry)

go to MyCourses and select a group:
- otherwise you can't submit!
- exceptionally OK to have a 1-person "group" this week

Exercises:

- ✔ Thursdays 14.15-16.00 (Nanotalo 228)
- ✔ Python/NumPy + Jupyter notebooks
- ✔ Group-work **(2 students per group)**
- ✔ Five exercises in total, each split into an initial **"easy"** and a subsequent **"difficult"** part

simple grading by TAs

peer review by fellow students
+
feedback and final grading by TAs

Student participation:

- ✔ Students peer grade + present their fellow students' "difficult" exercise reports

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Student participation:

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today's exercise should be very easy for you
(if not, reconsider carefully taking this course!)

Logistics

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

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

https://mycourses.aalto.fi/

- ✔ Group selections
- ✔ Exercises (input data, report submissions, peer grading)

Zulip course chat

- ✔ Link in MyCourses
- ✔ Important announcements
- ✔ <u>*Secondary*</u> place to ask questions

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Week	Date	Activity	Location	Topic	
1	Thu 4 Sep	Lecture	F239a	Introduction; Image smoothing and interpolation	- chapter 1 in the book (html pdf) - slides: html pdf - lecture recording
	Thu 4 Sep	Exercise	Nanotalo 228	Smoothing and interpolation (first part)	submission deadline: Wed 10 Sep at 23:59
2	Thu 11 Sep	Lecture	F239a	Coordinate systems, linear spatial transformations, landmark-based registration	- sections 2.1-2.3 in the book (html pdf) - slides: html pdf - lecture recording
	Thu 11 Sep	Exercise	Nanotalo 228	Smoothing and interpolation (second part)	submission deadline: Wed 17 Sep at 23:59
3	Thu 18 Sep	Lecture	F239a	Intensity-based registration	- section 2.4 in the book, excluding Gauss-Newton optimization (html pdf) - slides: html pdf - lecture recording
	Thu 18 Sep	Exercise	Nanotalo 228	Linear registration (first part)	submission deadline: Wed 24 Sep at 23:59
4	Thu 25 Sep	Lecture	F239a	Student presentation: smoothing and interpolation exercise	
	Thu 25 Sep	Exercise	Nanotalo 228	Linear registration (second part)	submission deadline: Wed 1 Oct at 23:59
5	Thu 2 Oct	Lecture	F239a	Nonlinear registration	- sections 2.2.2 and 2.4 in the book, especially Gauss-Newton optimization (html pdf) - slides: html pdf - lecture recording
	Thu 2 Oct	Exercise	Nanotalo 228	Nonlinear registration (first part)	submission deadline: Wed 8 Oct at 23:59
6	Thu 9 Oct	Lecture	F239a	Student presentation: Linear registration exercise; Model-based segmentation I	- sections 3.1-3.3 in the book (html pdf) - probability refresher: html pdf - slides: html pdf - lecture recording

Python/NumPy, Jupyter Notebooks

- ✔ Python: https://lectures.scientific-python.org/
- ✔ Jupyiter Notebooks: https://www.dataquest.io/blog/jupyter-notebook-tutorial/

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

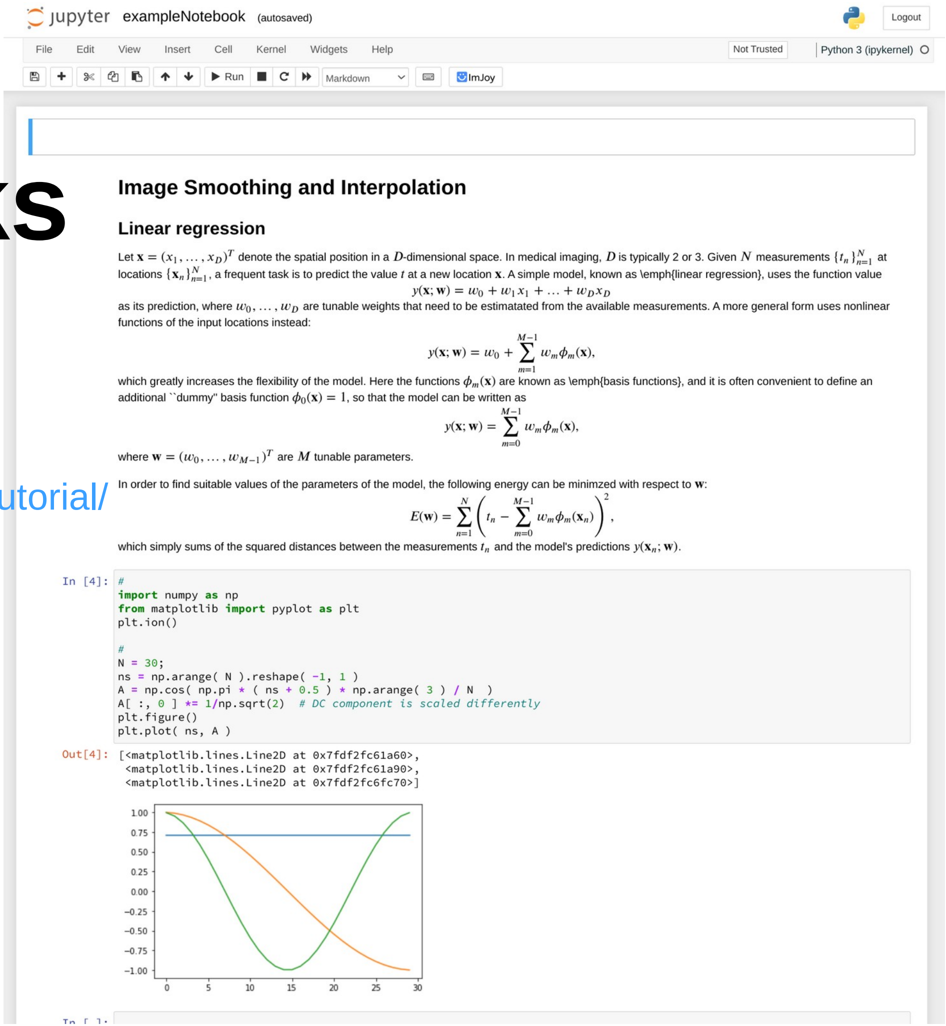

Image Smoothing and Interpolation

Linear regression

Let $\mathbf{x} = (x_1, \ldots, x_D)^T$ 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 \emph{linear regression}, uses the function value

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

as its prediction, where $w_0, \ldots, w_D$ are tunable weights that need to be estimatated 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 \emph{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 $\mathbf{w} = (w_0, \ldots, w_{M-1})^T$ are M tunable parameters.

In order to find suitable values of the parameters of the model, the following energy can be minimzed 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 )
```

Out[4]:

```
[<matplotlib.lines.Line2D at 0x7fdf2fc61a60>,
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 <matplotlib.lines.Line2D at 0x7fdf2fc6fc70>]
```


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