Inverse problems and machine learning in medical physics

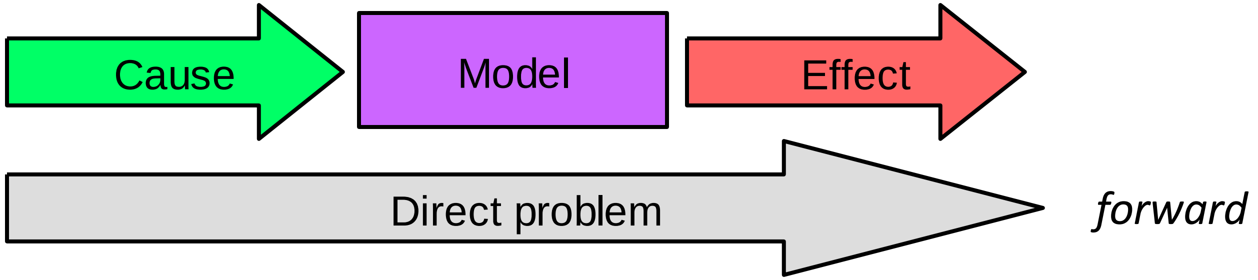
Introduction to the course

Dr. Chiara Gianoli
15/10/2024
chiara.gianoli@physik.uni-muenchen.de

Direct and inverse problems in medical physics

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

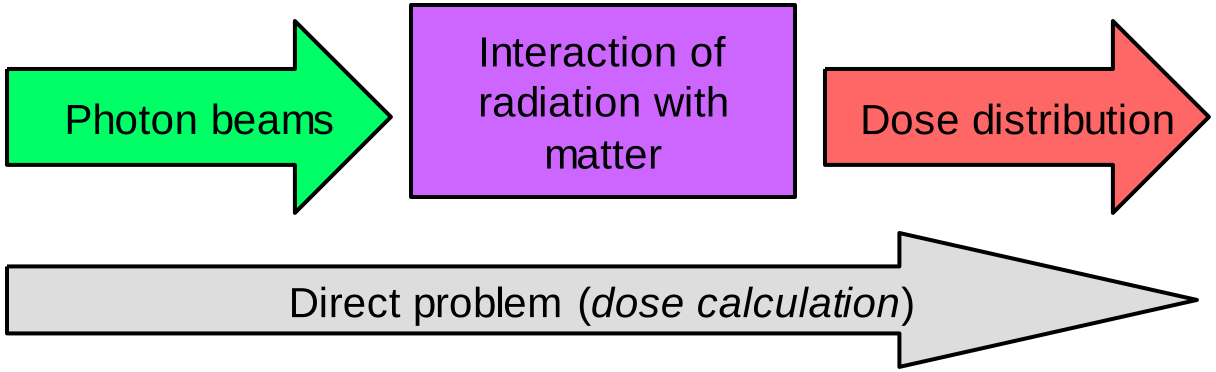
- Medical physics is a multidisciplinary field that includes computational science
- The computing power of machines is exploited to understand and solve complex problems of medical physics
- The direct problem is based on a mathematical model that links cause-effect of a certain phenomenon
    - The solution of the direct problem enables to explore the parameter space of the consequences (i.e., understand the problem by observing the consequences of the phenomenon)

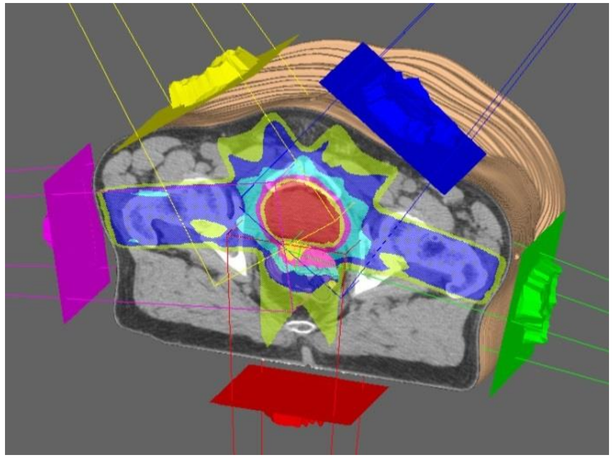


- The solution of the inverse problem requires the mathematical model of the direct problem that links cause-effect of a certain phenomenon to explore the parameter space of the causes (i.e., solve the problem by finding the causes of the phenomenon, when the causes are not directly observable)

Direct and inverse problems in medical physics

- Dose calculation is a direct problem in medical physics, typically based on analytical or Monte Carlo models

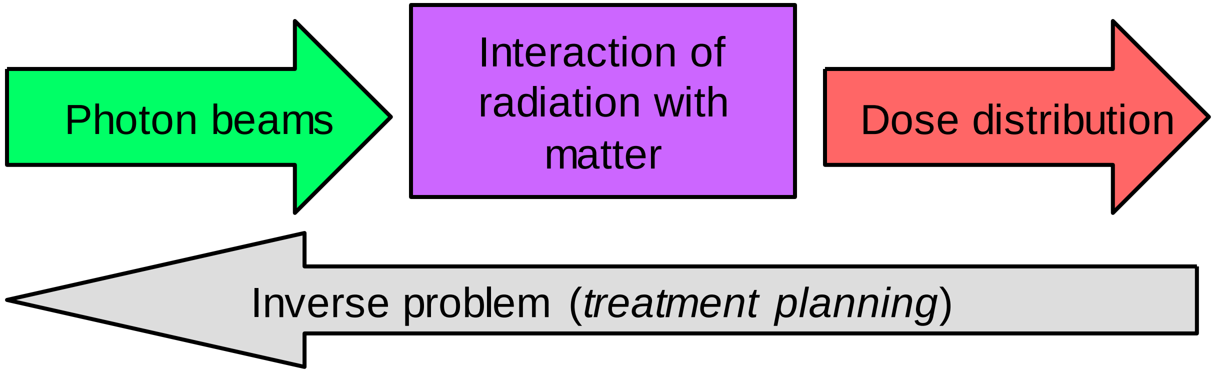


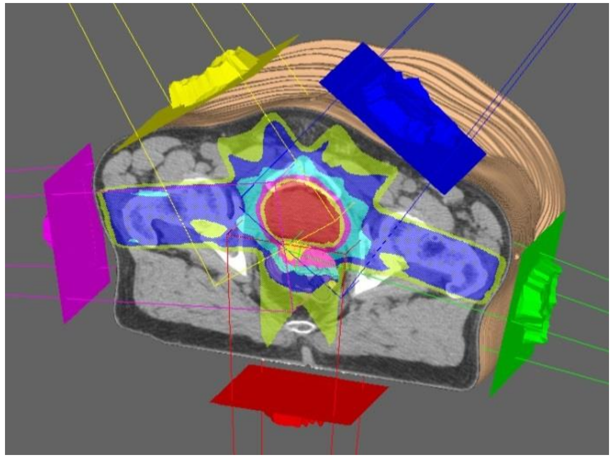


http://www.vmoc.com/wp-content/uploads/2013/04/IMRT-Dose.jpg

Direct and inverse problems in medical physics

- Treatment planning is the inverse problem based on the analytical or Monte Carlo models of the direct problem (i.e., dose calculation)

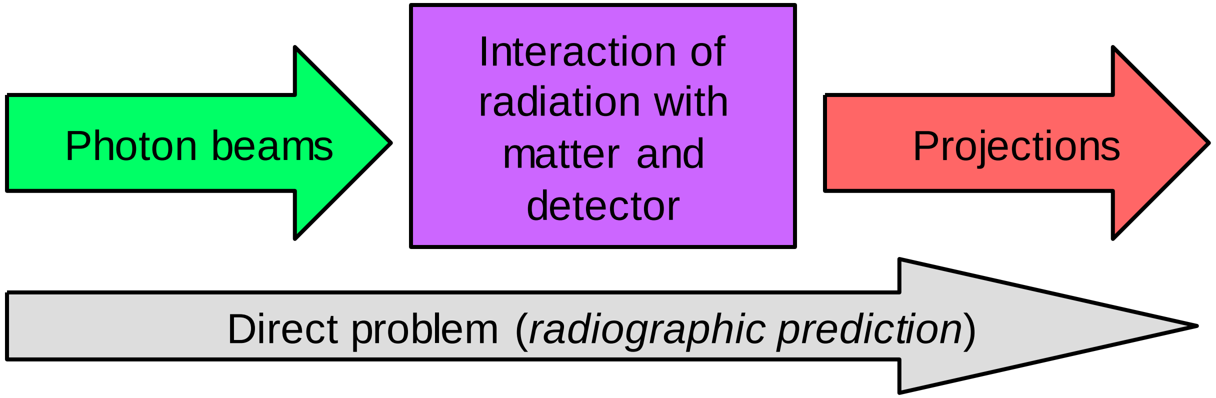




http://www.vmoc.com/wp-content/uploads/2013/04/IMRT-Dose.jpg

Examples in radiation oncology

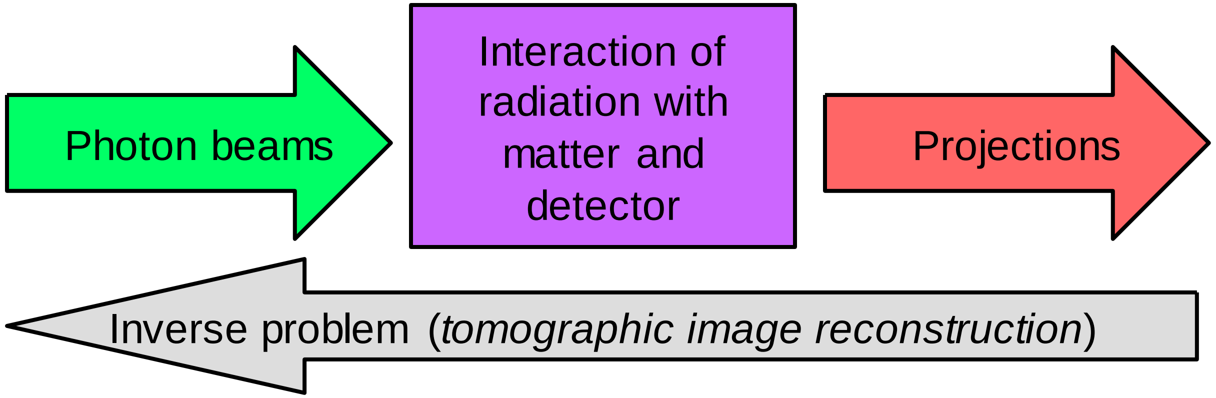
- Radiography prediction or calculation is a direct problem in medical physics, typically based on algebraic models



https://www.nature.com/articles/s41551-019-0466-4

Examples in radiation oncology

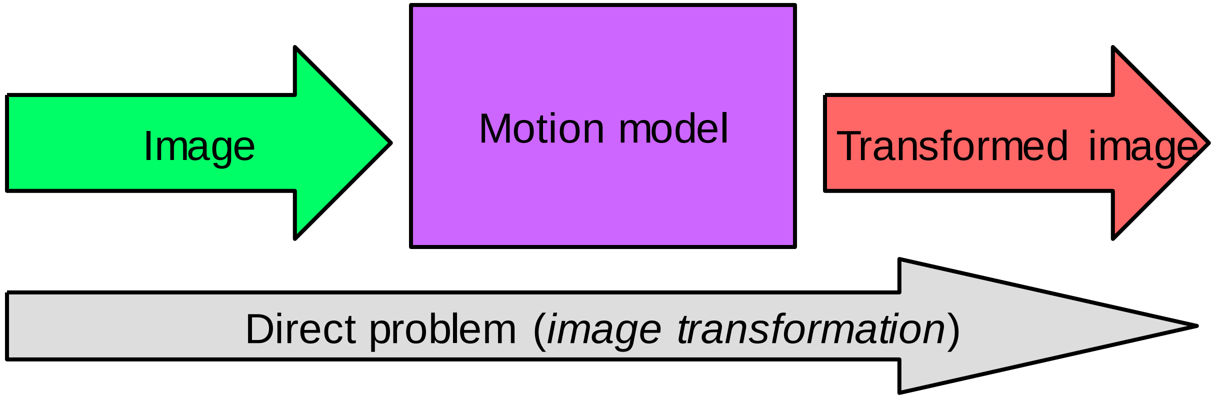
- Tomographic image reconstruction is the inverse problem based on the algebraic models of the direct problem (i.e., radiography prediction)

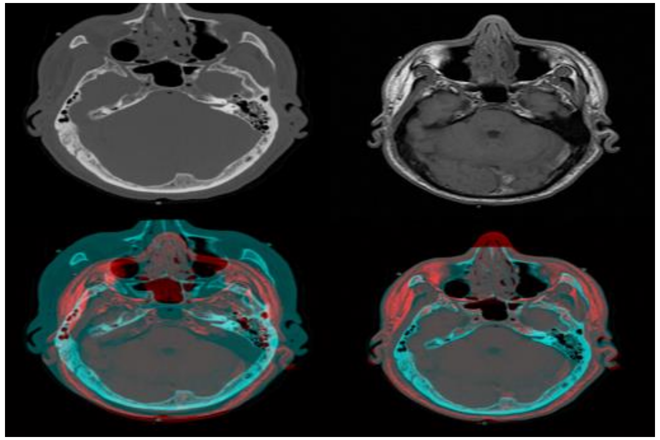


https://www.nature.com/articles/s41551-019-0466-4

Examples in radiation oncology

- Image transformation or deformation is a direct problem in medical physics, typically based on motion models

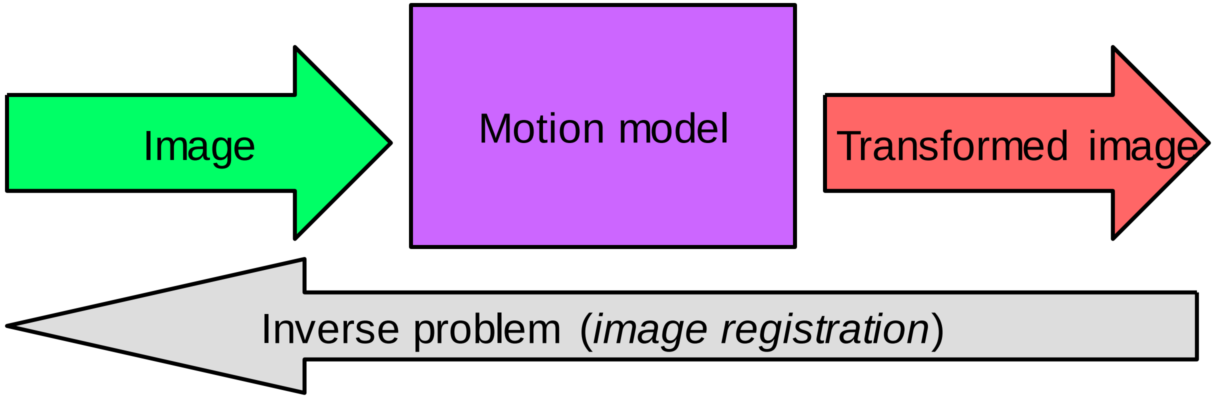


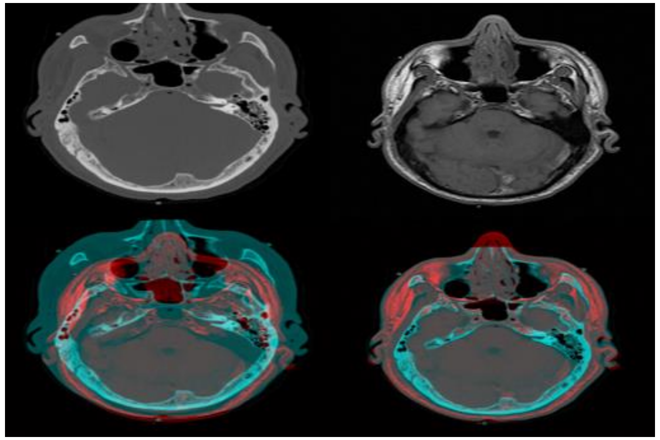


https://paperswithcode.com/task/image-registration

Examples in radiation oncology

- Image registration is the inverse problem based on the motion models of the direct problem (i.e., image transformation)





https://paperswithcode.com/task/image-registration

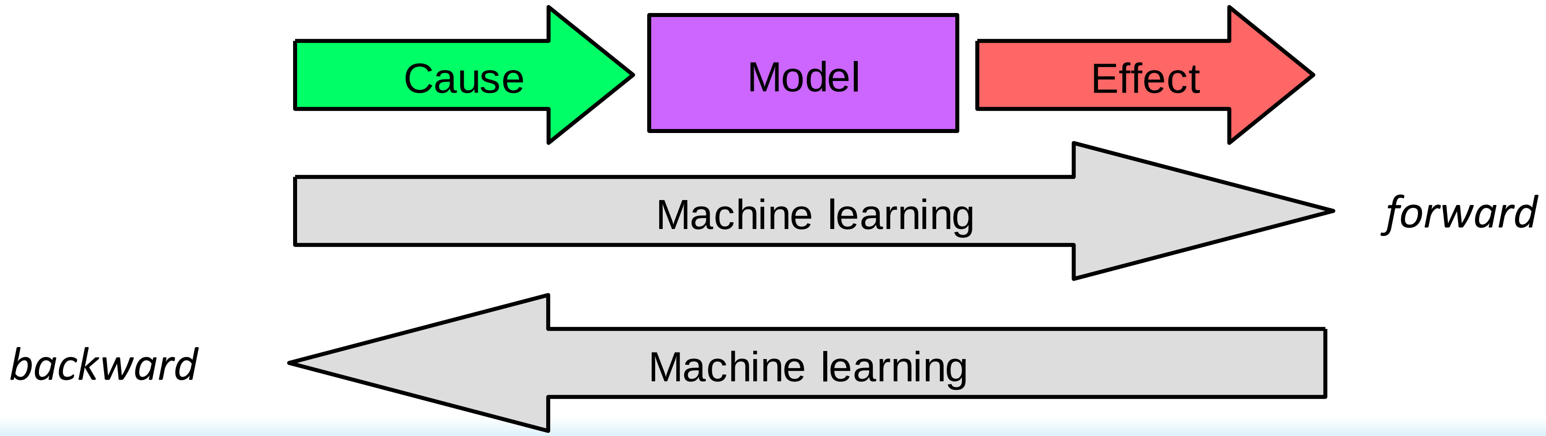
Inverse problems and machine learning in medical physics

- Machine learning is based on numerical optimization (of the parameters of the functions that describe the neural network…)

- The numerical optimization aims at finding the model that links cause-effect or effect-cause

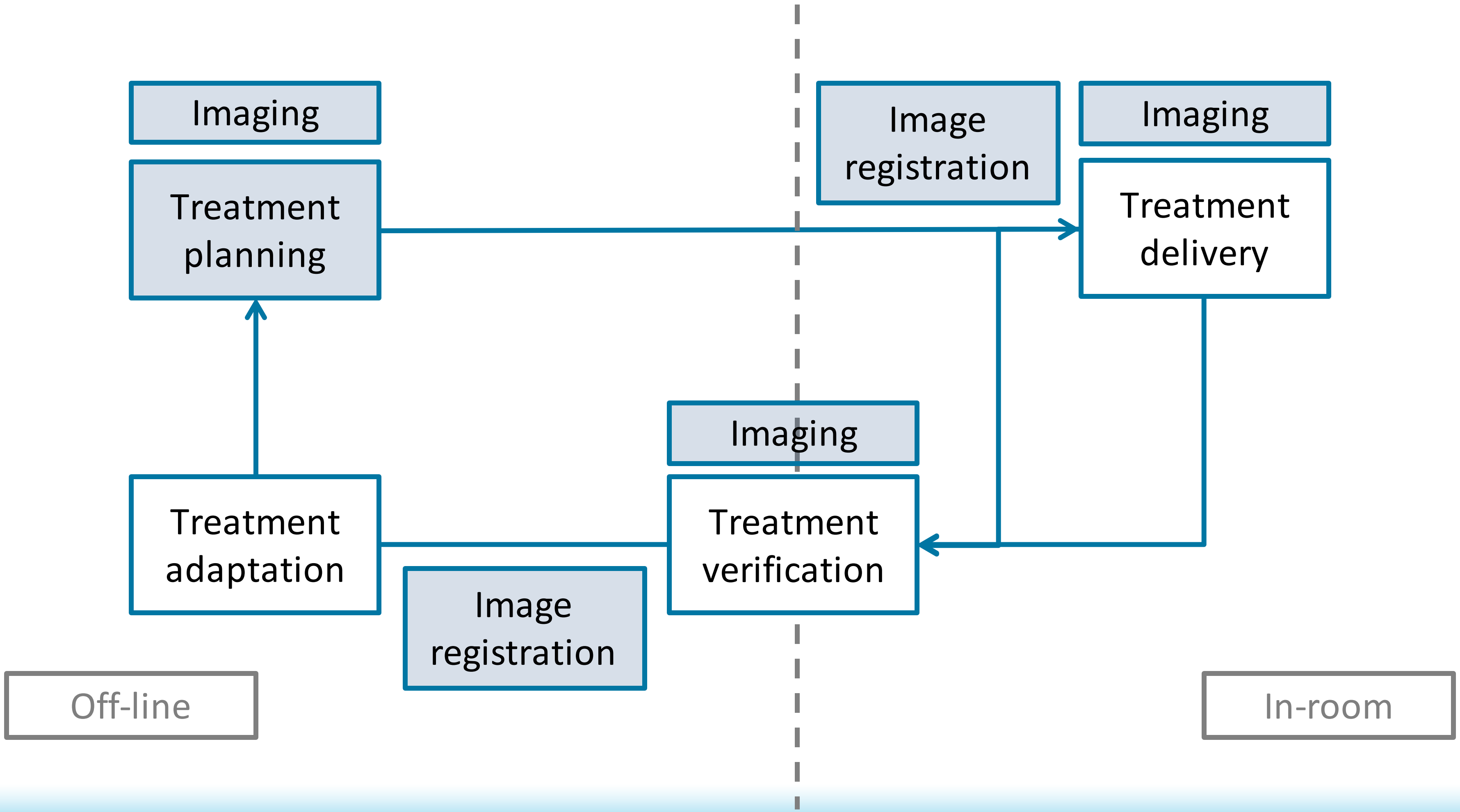
  - to solve the direct problem when the causes are the inputs and the consequences are the targets/outputs

  - to solve the inverse problem when the consequences are the inputs and the causes are the targets/outputs with no explicit knowledge of the model of the direct problem



Topics of the lectures

- Lectures cover topics in radiation oncology where inverse problems play fundamental role



Lectures and tutorials

- Both lectures and tutorials (by Ines Butz) are given in presence (*Kleiner Physiksaal*)
  - During tutorials, step by step and "real time" coding in Python is displayed (participation with personal laptop is suggested)
- Slides of the lectures and supporting material of the tutorials are uploaded on the course website (generally one day in advance)
- A remote access to the lectures and tutorials is available upon request (Chiara.Gianoli@physik.uni-muenchen.de)
- No recording of the lectures and tutorials

Exercises

- The exercises are not mandatory
- The exercise are assigned to bridge theory and practice of the course (and to get a bonus in the exam…)
- The aim of the tutorials is to support the implementation of the exercises
- The exercises consist in the implementation of a numerical optimization algorithm and a neural network for tomographic image reconstruction
  - The “preparatory” algorithms can be similar to those presented in the tutorials
  - The “core” algorithm is not the one presented in the tutorials
- The code can be implemented in Python, Octave (Matlab) or c++ (with libraries, and previous experience)

Exam

- The written exam is made by open questions (1 or 2) and multiple choice questions (9 or 10) with different weights
  - Open questions can consider pseudo-codes but no coding
  - Multiple choice question can consider calculations (a calculator is allowed but not necessarily needed…)
- The date of the exam is democratically decided via on line poll

Outline of the lectures

15.10.2024	Introduction to the course	Lecture
22.10.2024	Fundamentals of tomographic imaging - Analytical image reconstruction	Lecture
29.10.2024	Numerical image reconstruction - Transmission and emission imaging in radiation oncology	Lecture
5.11.2024	*Introduction and imaging fundamentals in Python*	*Tutorial*
12.11.2024	Imaging in ion beam therapy – Ion imaging	Lecture
19.11.2024	Tomographic image reconstruction for ion imaging	Lecture
26.11.2024	*Tomographic image reconstruction algorithm in Python*	*Tutorial*
3.12.2024	Introduction to machine learning	Lecture
10.12.2024	*Introduction and machine learning fundamentals in Python*	*Tutorial*
17.12.2024	*Machine learning applications in Python*	*Tutorial*
7.1.2025	Machine learning for tomographic image reconstruction or “deep reconstruction”	Lecture
14.1.2025	Treatment planning - Machine learning in treatment planning	Lecture
21.1.2025	Image registration - Machine learning for image registration	Lecture
28.1.2025	Artificial intelligence in adaptive radiation therapy	Lecture
4.2.2025	Robotics in radiation therapy	Lecture
to be decided	Exam and handing in of the exercise	