

# Mid-PhD Defense

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# Outline

## Introduction

- Cancer treatments
- Radiotherapy
- Multi-Leaf Collimator
- V-MAT Scheme
- IMRT Scheme
  - Step-and-Shoot
  - Sliding-windows
- Radiotherapy Workflow

## Problem Statement

- Optimization workflow
- FMO problem
  - Formulation
  - Optimization

## Early results

- Optimizers Review
- Meta-Optimization
- Dose Distances
- Dose Clustering

## Future work

- Reinforcement Learning
  - General Setup
  - Planned Network Architecture
  - Trick
  - Challenges

## Others

- Teaching
- Doctoral Training

## References

## Cancer treatments

Surgery



- +: Safe (little damage to healthy tissues)
- : Tumor needs to be localized & accessible

Chemotherapy



- : Heavy medicine on all the body
- +: Tumor does **not** need to be localized

## Cancer treatments

Surgery



+: Safe

-: Tumor needs to be localized

## Radiotherapy



+: Relatively safe (most tissues are spared)

-: Tumor needs to be (relatively) localized

Chemotherapy



Medicine on all the body

does not need to be localized

# Multi-Leaf Collimator



# V-MAT Irradiation Technique

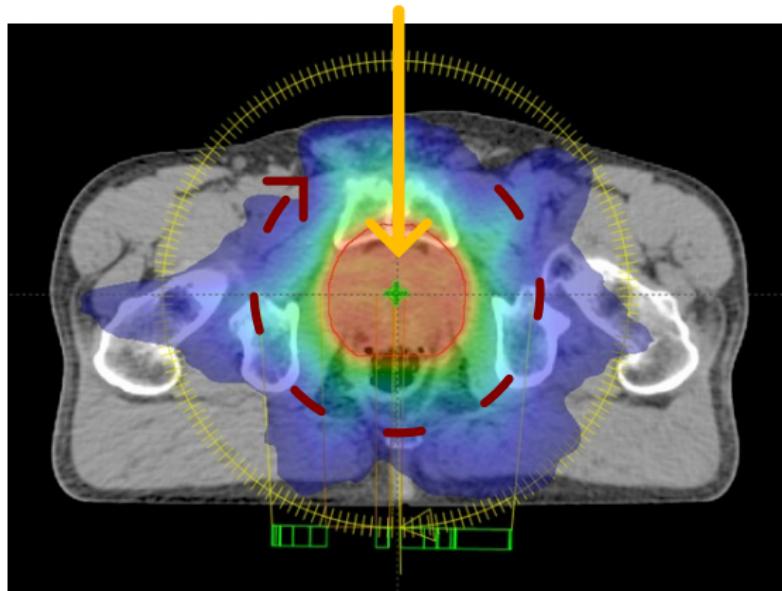


Figure: Typical V-Mat dose slice.

# IMRT Irradiation Technique

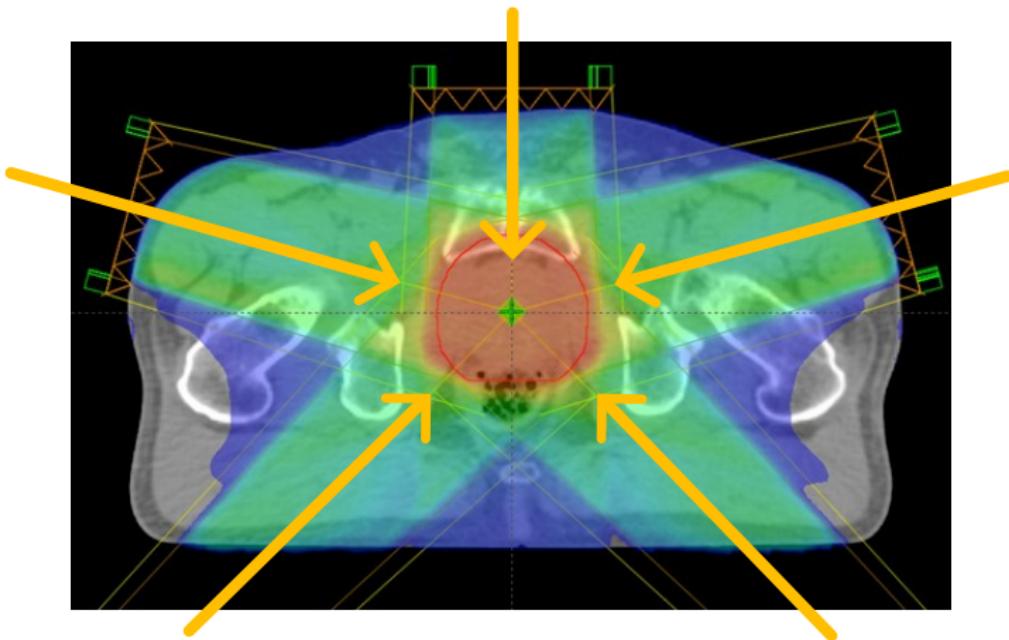
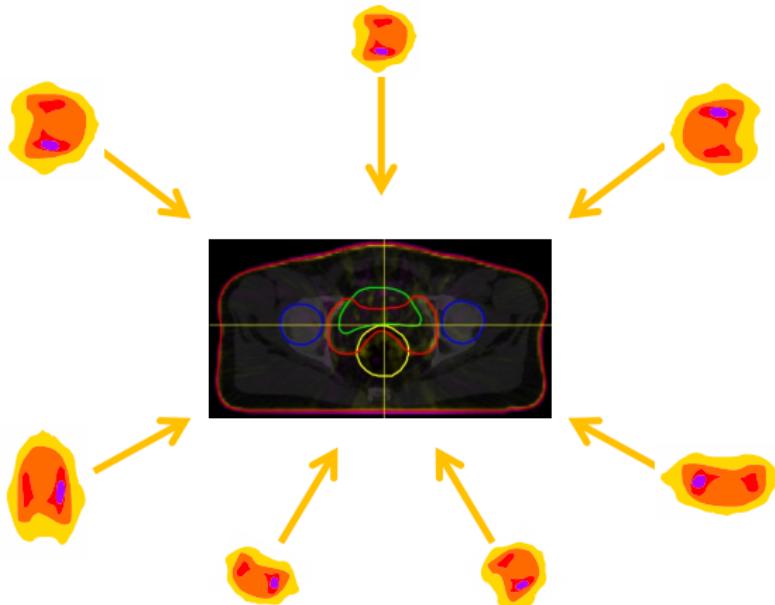


Figure: Typical 5 beams IMRT dose slice.

## Step-and-Shoot (1/3)



**Figure:** Optimal Continuous Fluence.

## Step-and-Shoot (2/3)

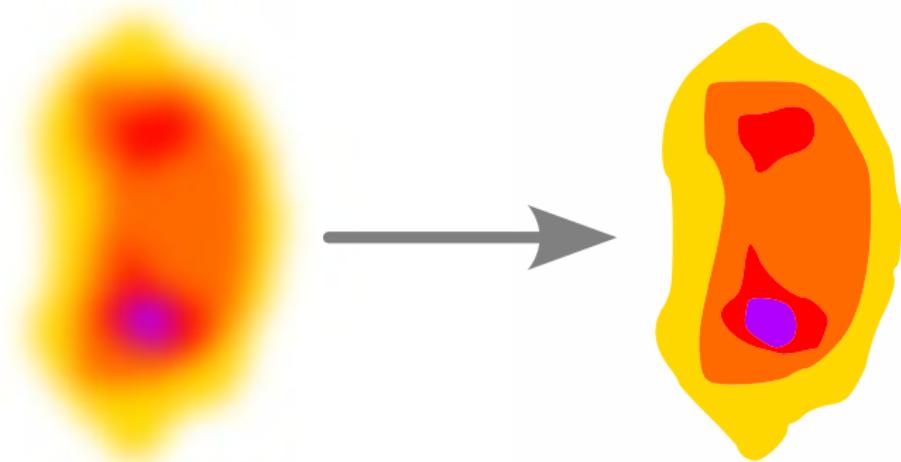


Figure: Discretizing the Fluence.

## Step-and-Shoot (3/3)

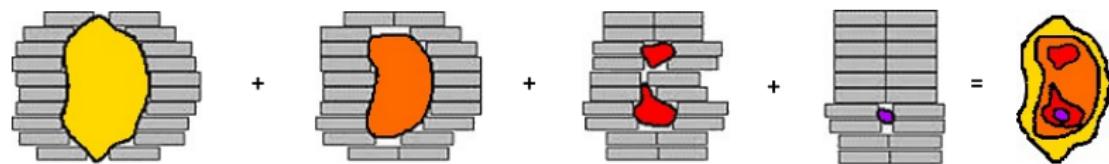


Figure: Delivering Discrete Fluence.

## Sliding-Windows (1/3)



Figure: Continuous Fluence to Bixel Fluence.

## Sliding-Windows (2/3)

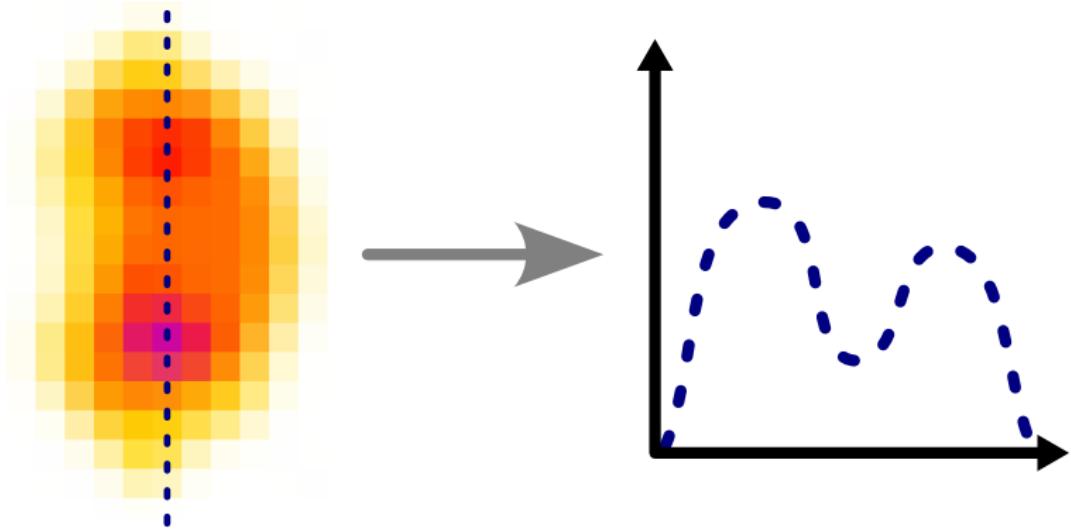


Figure: Bixel Fluence to Row/Column Curves.

## Sliding-Windows (3/3)

Convert rows/columns fluence curves to leafs motions.



(<https://mics-lab.github.io/PresentationJuin2023MICS/demo>)

# Radiotherapy Workflow



# Radiotherapy Workflow



# Automatic Dose Optimization for Radiotherapy



# Problem Formulation

## IMRT

Bixel values:

$$x_{i,j}^{\theta} \geq 0, \text{ for } \theta \in \Theta \text{ and } 1 \leq i \leq 20, 1 \leq j \leq \text{nb\_leafs\_involved}$$

usually concatenated to a single bixels-value vector  $\mathbf{x}$ .

Dose calculation:

$$\mathbf{y} = L\mathbf{x} \text{ with } L \text{ (pre-calculated) dose-influence (DI) matrix}$$

# Problem Formulation

## IMRT (bis)

Objective for *maximum* constraint  $c$  on structure  $s$ , dose  $d$ :

$$f_c(\mathbf{y}) = \frac{1}{|\mathcal{V}_s|} \sum_{v \in \mathcal{V}_s} (\mathbf{y}_v - d)_+^2$$

(reverse sign for minimal constraint).

Final objective:

$$f(\mathbf{y}) = \sum_{c \in \mathcal{C}} w_c f_c(\mathbf{y})$$

with  $w_c$  the weight of constraint  $c$ .

# Problem Optimization

## Optimizer review



Figure: Typical prostate case.

<https://arxiv.org/abs/2305.18014>

# Problem Optimization

## Optimizer review (bis)



Figure: Typical prostate case.

<https://arxiv.org/abs/2305.18014>

# Meta-Optimization

## Usual optimization

$$\min_{\mathbf{x}} f(\mathbf{x}, w) \text{ s.t. } \mathbf{x} > 0$$

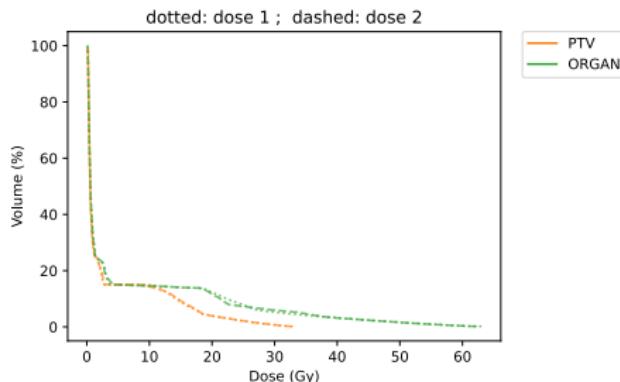
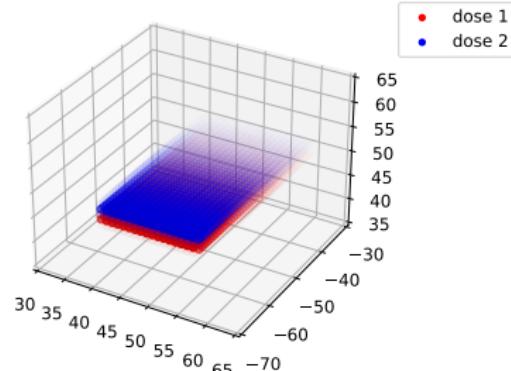
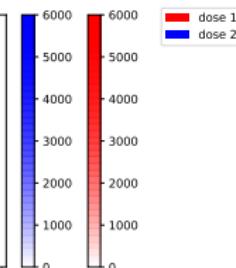
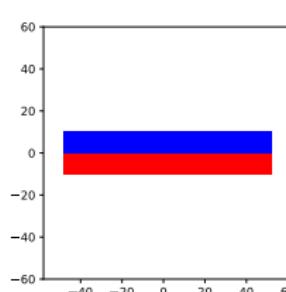
... and fine-tune  $w$  until the dose is clinically acceptable.

## Meta optimization

$$\min_w \left\{ \min_{\mathbf{x}} f(\mathbf{x}, w) \text{ s.t. } \mathbf{x} > 0 \right\}$$

... still need to fine-tune the parameters (learning rate, momentum, etc...) of the meta-optimizer.

# Dose Distances



**Figure:** Example of two doses that have the same clinical effect (measured from the DVHs), but very different voxel-wise dose values.

# Dose Clustering



(a) (Circular Layout)



(b) (Spring Layout)

Figure: Doses Network

edges width  $\propto$  edge weight  $\propto 1/\text{distance}$

node's color reflects community attribution

# Dose Clustering



Figure: Dose-Volume Histogram

# Dose Clustering

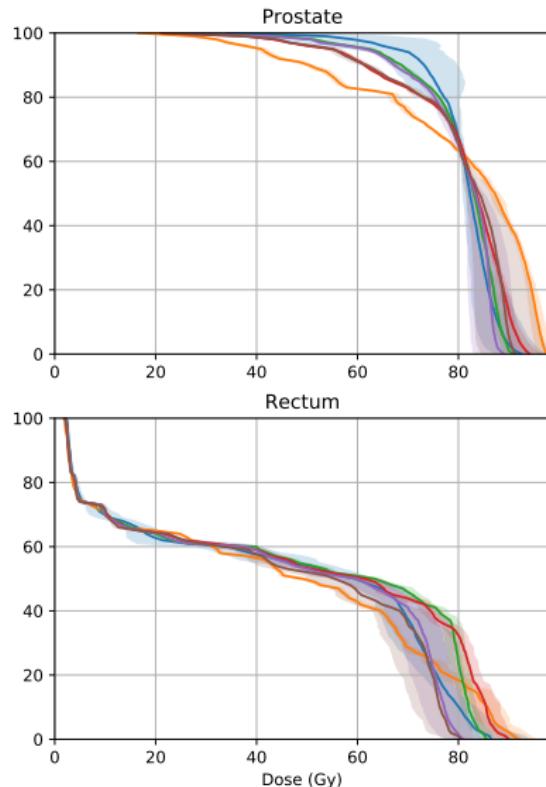
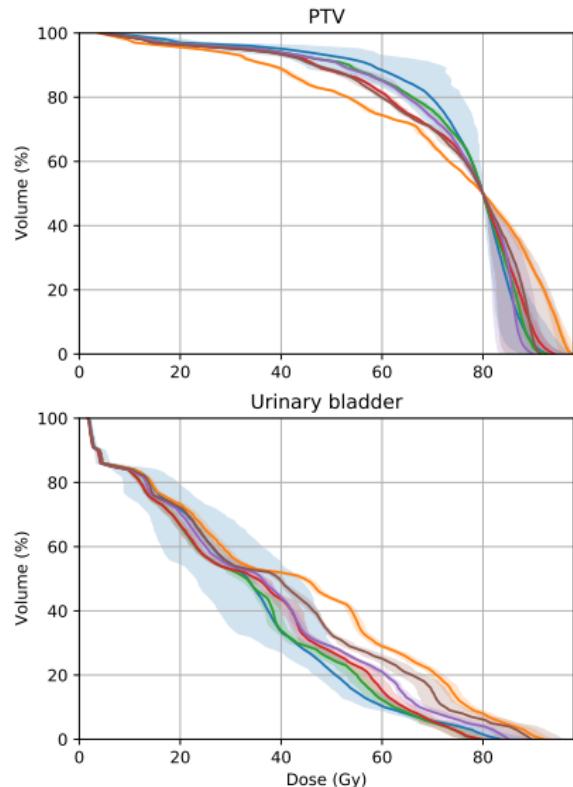
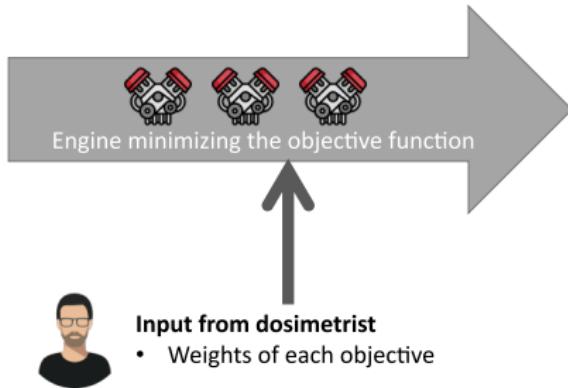


Figure: Dose-Volume Histogram Standard Deviation per Community

# Current Workflow

## Patient data

- CT scan
- OARs & PTVs contours
- doctors' objectives



## Treatment plan

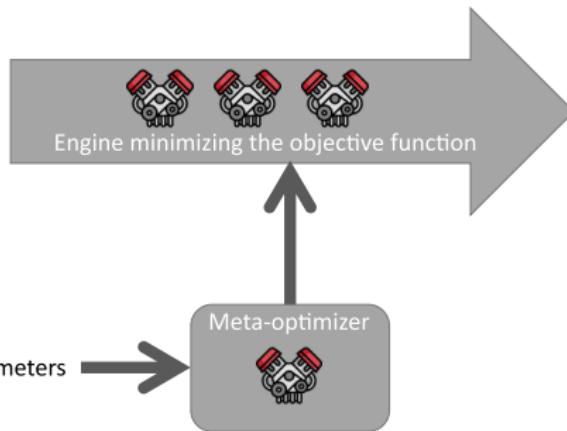
- Fluences
- Leaf movements
- Dose per organ

# 1<sup>st</sup> Automatization try “baseline”

## Patient data

- CT scan
- OARs & PTVs contours
- doctors' objectives

Fine tuning of hyper parameters



## Treatment plan

- Fluences
- Leaf movements
- Dose per organ

# 1<sup>st</sup> (bis) Automatization try

## Patient data

- CT scan
- OARs & PTVs contours
- doctors' objectives

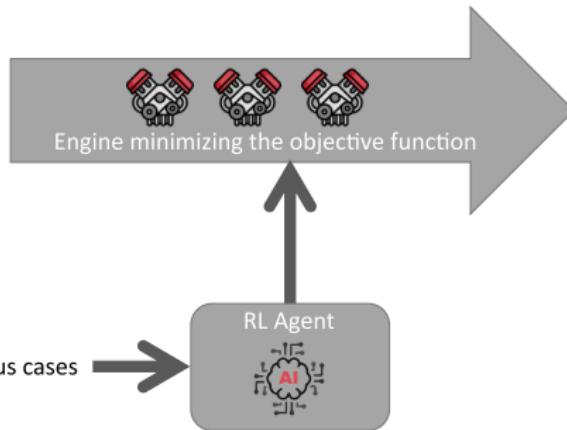


## 2<sup>nd</sup> Automatization try (*work in progress*)

### Patient data

- CT scan
- OARs & PTVs contours
- doctors' objectives

Learning based on previous cases



### Treatment plan

- Fluences
- Leaf movements
- Dose per organ

# Reinforcement Learning Setup

**Agent** A network.

**Environment** The current dose/weights, the CT scan, structures contours.

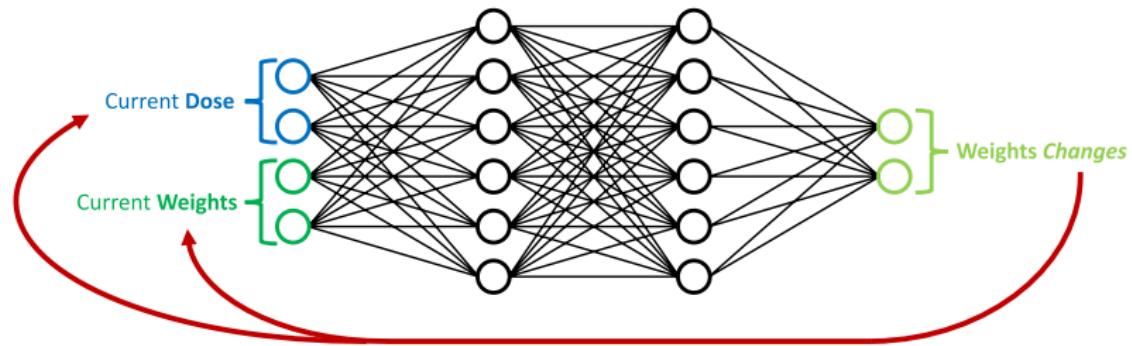
**State** The agent will only access the the current dose/weights.

**Action** Changing the set of weights.

**Reward** The (DVH) distance between the current dose and the one that was actually used.

**Policy** The value changes of the sets of weights.

# Planned Network Architecture



## Trick: encode the dose to smaller space

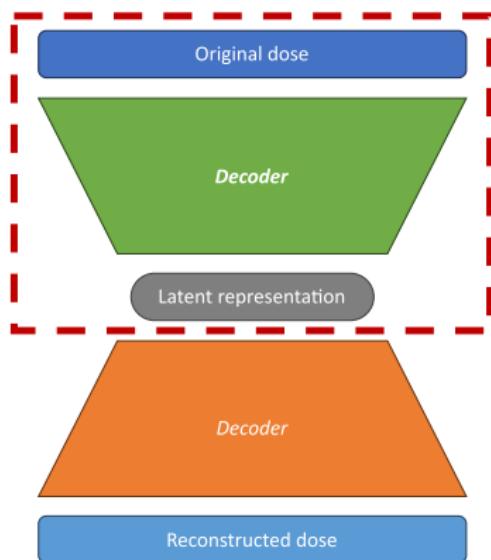


Figure: Dose Auto-Encoder Architecture

# Challenges

- ▶ Normalizing the body scan size
- ▶ Normalizing the structures per anatomy
- ▶ Normalizing the constraints per anatomy
- ▶ Training on large data
- ▶ Weights sensitivity

# Teaching

## Lectures:

- ▶ Mathematics Refresher Course for DSBA (M2 students) 2021
- ▶ Deep Learning for HSB (3<sup>rd</sup> year students) 2023

## TDs:

- ▶ Coding Weeks (1<sup>st</sup> year) 2021
- ▶ Optimization (1<sup>st</sup> year) 2021
- ▶ Visual recognition (3<sup>rd</sup> year) 2022
- ▶ Coding Weeks (1<sup>st</sup> year) 2022
- ▶ Algorithm and Complexity (2<sup>nd</sup> year) 2022/2023

# Doctoral Training

- ▶ ED INTERFACES - Journée de Rentrée 2022 (12 janvier 2023)
- ▶ Math On Mars (06 mai 2022) Info@lèze
- ▶ Asymmetric Cryptography (23 septembre 2022) Info@lèze
- ▶ Genetic Algorithms (10 juin 2022) Info@lèze
- ▶ Math With Jupyter (18 décembre 2021) Info@lèze
- ▶ Writing skills in Science ADVANCED [Eng] (10 mai 2022)
- ▶ AI 4 Health (10 janvier 2022 - 14 janvier 2022)

Total participation: **109/125** heures; 7 modules

Total des Crédits/Points de Thèse: **22/25**

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