Mid-PhD Defense

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Outline

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

Radiotherapy

Chemotherapy

+: Safe

-: Tumor needs to be loca

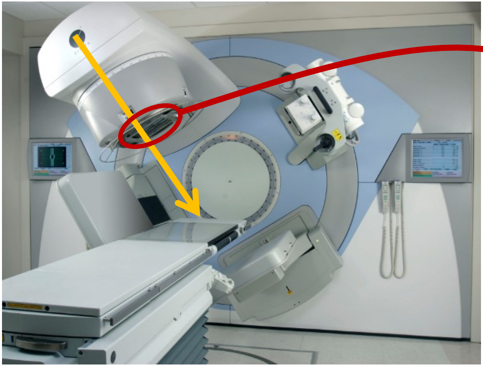
+: Relatively safe (most tissues are spared)

-: Tumor needs to be (relatively) localized

cine on all the body

s **not** need to be localized

Multi-Leaf Collimator



V-MAT Irradiation Technique

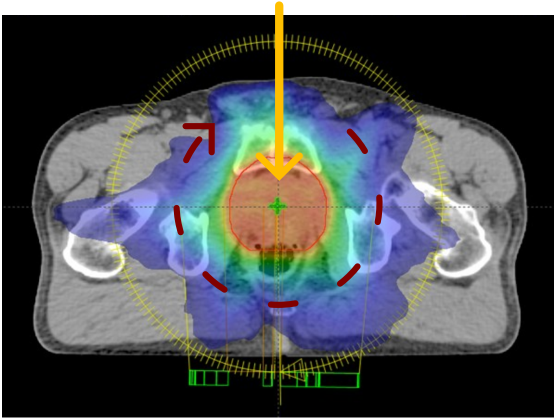


Figure: Typical V-Mat dose slice.

IMRT Irradiation Technique

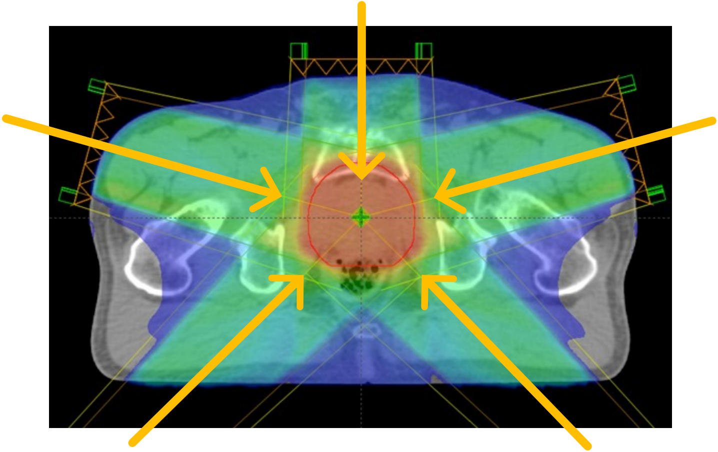


Figure: Typical 5 beams IMRT dose slice.

Step-and-Shoot (1/3)

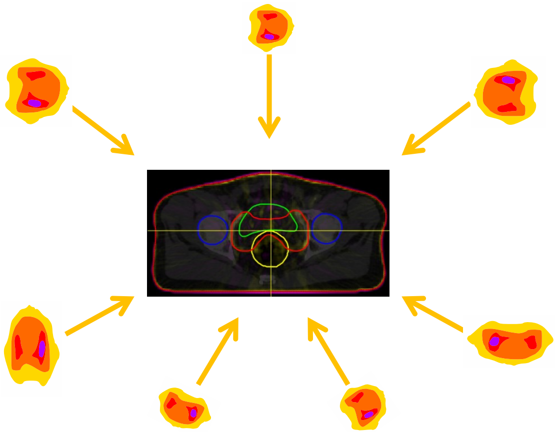


Figure: Optimal Continuous Fluence.

Step-and-Shoot (2/3)

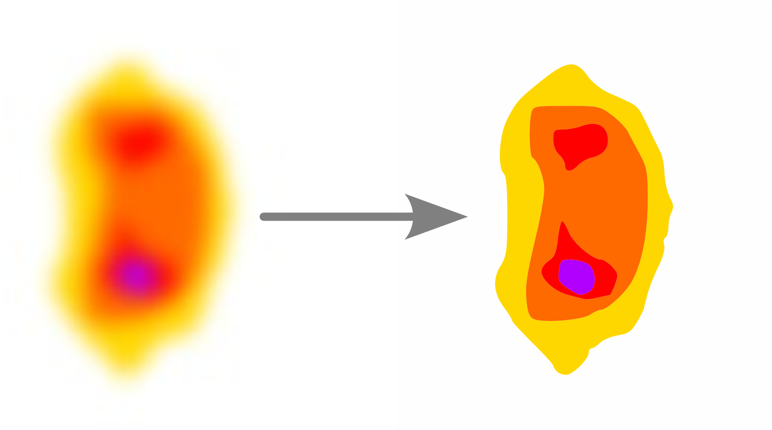


Figure: Discretizing the Fluence.

Step-and-Shoot (3/3)

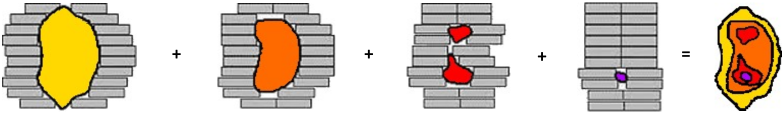


Figure: Delivering Discrete Fluence.

Sliding-Windows (1/3)

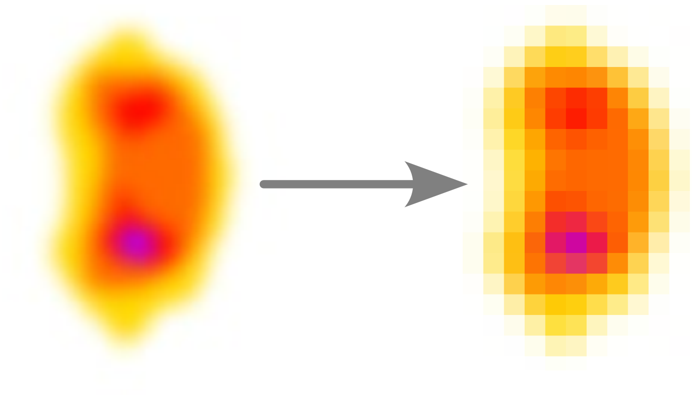


Figure: Continuous Fluence to Bixel Fluence.

Sliding-Windows (2/3)

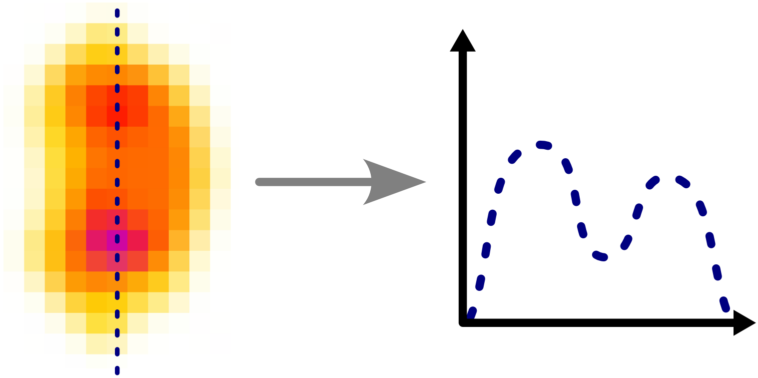


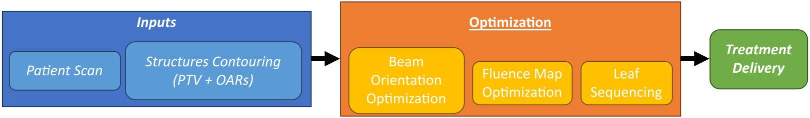
Figure: Bixel Fluence to Row/Column Curves.

Sliding-Windows (3/3)

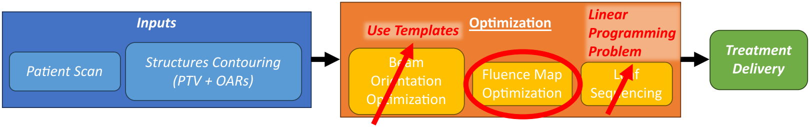
Convert rows/columns fluence curves to leafs motions.

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

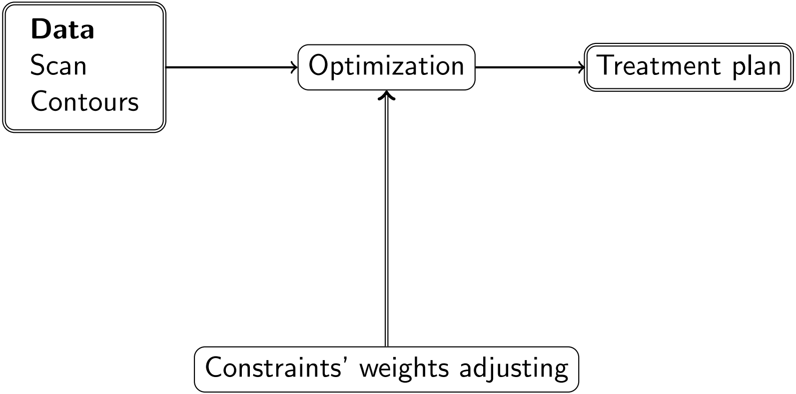
Radiotherapy Workflow



Radiotherapy Workflow



Automatic Dose Optimization for Radiotherapy



Problem Formulation
IMRT

Bixel values:

$$x^{\theta}_{i,j} \geq 0, \text{ for } \theta \in \Theta \text{ and } 1 \leq i,j \leq 20^{1}$$

usually concatenated to a single bixels-value vector x.

Dose calculation:

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

[1] 20x20 is a typical bixel discretization

Problem Formulation

IMRT (bis)

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

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

(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

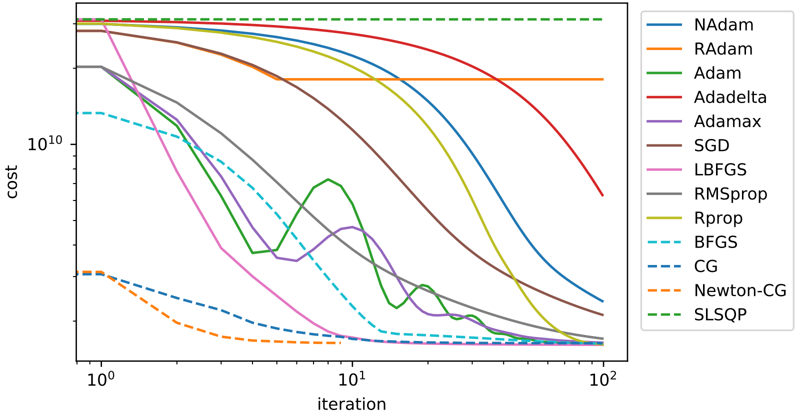


Figure: Typical prostate case.

https://arxiv.org/abs/2305.18014

Problem Optimization

Optimizer review (bis)

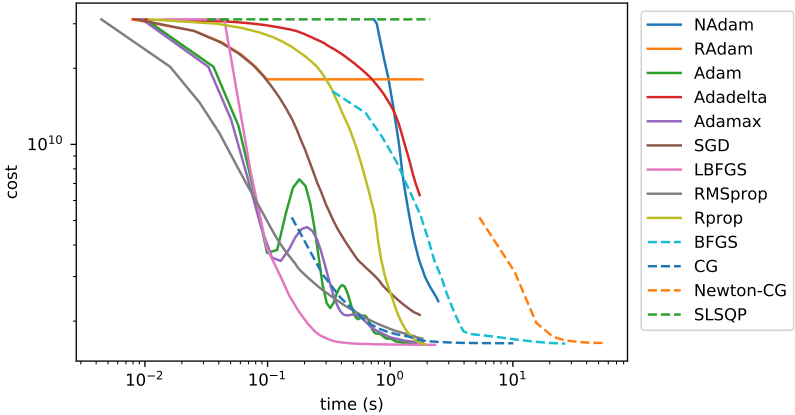


Figure: Typical prostate case.

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

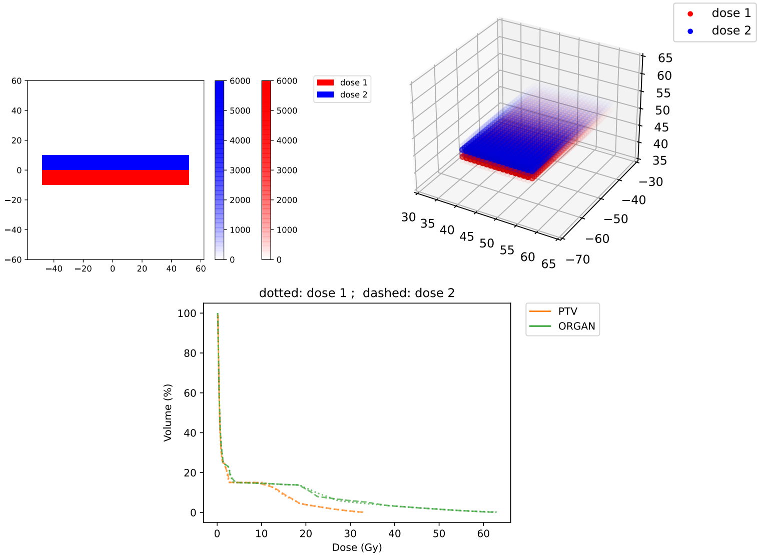
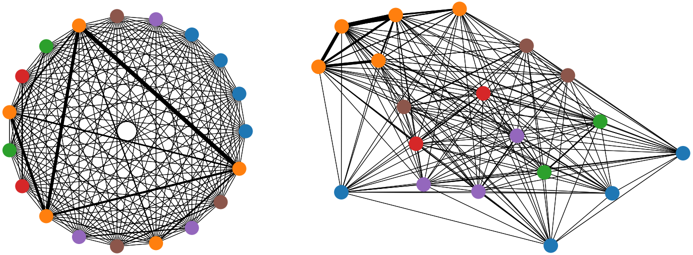


Figure: Example of two doses that have the same clinical effect (measured from the DVHs), but very different voxel-wise dose values.

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

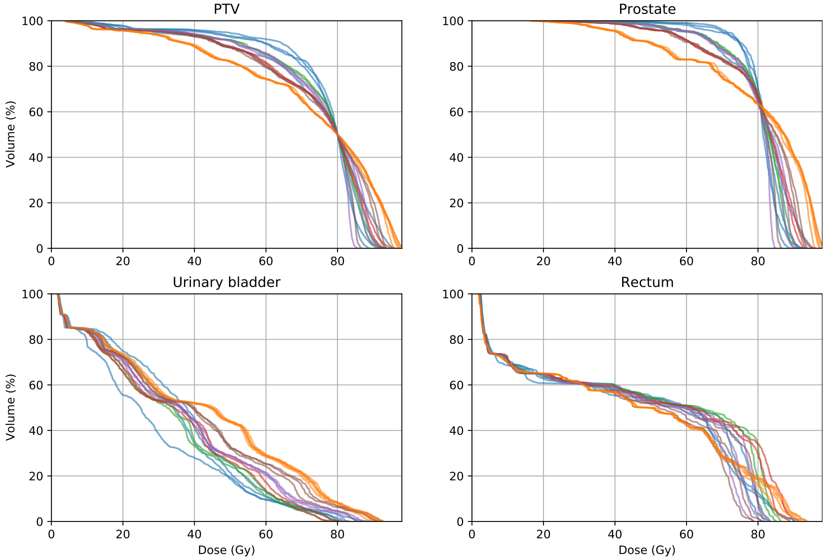


Figure: Dose-Volume Histogram

Dose Clustering

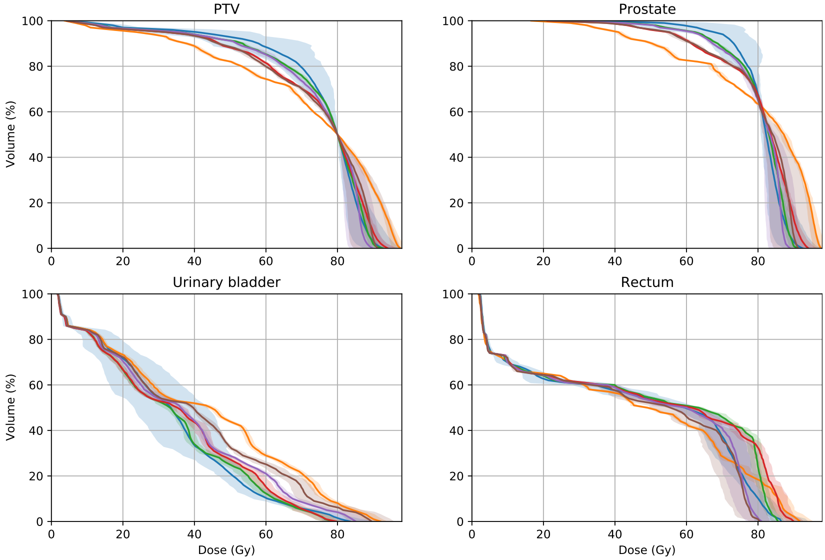
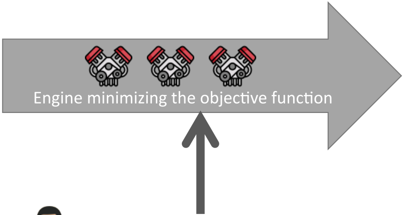


Figure: Dose-Volume Histogram Standard Deviation per Community

Current Workflow

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

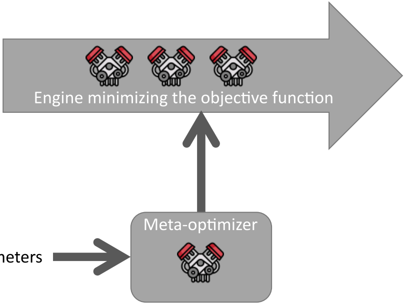


Treatment plan
- Fluences
- Leaf movements
- Dose per organ

Input from dosimetrist
- Weights of each objective

1^{st} Automatization try *“baseline”*

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

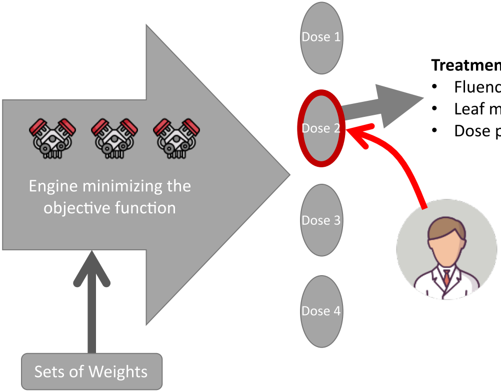


Treatment plan
- Fluences
- Leaf movements
- Dose per organ

Fine tuning of hyper parameters

1^{st} (bis) Automatization try

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

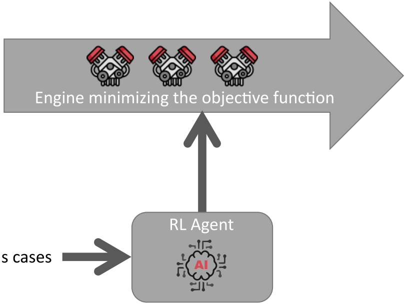


Treatment plan
- Fluences
- Leaf movements
- Dose per organ

2^{nd} Automatization try *(work in progress)*

Patient data

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



Treatment plan

- Fluences
- Leaf movements
- Dose per organ

Learning based on previous cases

Reinforcement Learning Setup

Teaching

Lectures:

- Mathematics Refresher Course for DSBA (M2 students) 2021
- Deep Learning for HSB (3$^{\text{rd}}$ year students) 2023

TDs:

- Coding Weeks (1$^{\text{st}}$ year) 2021
- Optimization (1$^{\text{st}}$ year) 2021
- Visual recognition (3$^{\text{rd}}$ year) 2022
- Coding Weeks (1$^{\text{st}}$ year) 2022
- Algorithm and Complexity (2$^{\text{nd}}$ 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**

References I

Paul Dubois.
Radiotherapy dosimetry: A review on open-source optimizer, 2023.

Gary A. Ezzell, James M. Galvin, Daniel Low, Jatinder R. Palta, Isaac Rosen, Michael B. Sharpe, Ping Xia, Ying Xiao, Lei Xing, and Cedric X. Yu.
Guidance document on delivery, treatment planning, and clinical implementation of imrt: Report of the imrt subcommittee of the aapm radiation therapy committee.
Medical Physics, 30(8):2089–2115, 2003.

Thomas P. Kole, Osarhieme Aghayere, Jason Kwah, Ellen D. Yorke, and Karyn A. Goodman.
Comparison of heart and coronary artery doses associated with intensity-modulated radiotherapy versus three-dimensional conformal radiotherapy for distal esophageal cancer.

References II

*International Journal of Radiation Oncology*Biology*Physics*, 83(5):1580–1586, 2012.

Dinesh Kumar Mynampati, Ravindra Yaparpalvi, Linda Hong, Hsiang-Chi Kuo, and Dennis Mah.
Application of aapm tg 119 to volumetric arc therapy (vmat).
Journal of Applied Clinical Medical Physics, 13(5):108–116, 2012.

David Palma, Emily Vollans, Kerry James, Sandy Nakano, Vitali Moiseenko, Richard Shaffer, Michael McKenzie, James Morris, and Karl Otto.
Volumetric modulated arc therapy for delivery of prostate radiotherapy: Comparison with intensity-modulated radiotherapy and three-dimensional conformal radiotherapy.
*International Journal of Radiation Oncology*Biology*Physics*, 72(4):996–1001, 2008.

References III

Bortfeld Thomas.
The number of beams in imrt—theoretical investigations and implications for single-arc imrt.
Physics in Medicine & Biology, 55:83 – 97, 2009.

Lynn J. Verhey.
Comparison of three-dimensional conformal radiation therapy and intensity-modulated radiation therapy systems.
Seminars in Radiation Oncology, 9(1):78–98, 1999.
Radiation Therapy Treatment Optimization.

S Webb.
The physical basis of imrt and inverse planning.
The British Journal of Radiology, 76(910):678–689, 2003.
PMID: 14512327.