Artificial intelligence guided positioning of active voxels in particle therapy treatment planning

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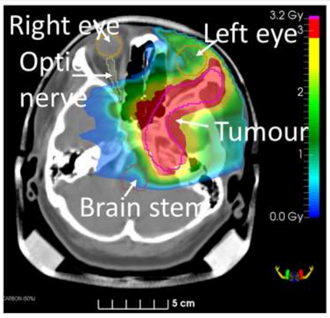
Introduction and Motivation

Ion beam therapy is a highly effective cancer treatment. The physical properties of ion beams permit to concentrate dose in the target, while sparing healthy tissue.
This high precision also makes it vulnerable to uncertainties such as shifts in the patient position or changes in their anatomy. Robust optimization involves uncertainty scenarios in the plan generation, but requires high computational effort. In this study, we aim to employ CNN architecture to reduce the problem size of ion beam plan generation. AI will select the subset of volume elements in target and normal tissue that is most relevant for a high quality plan.



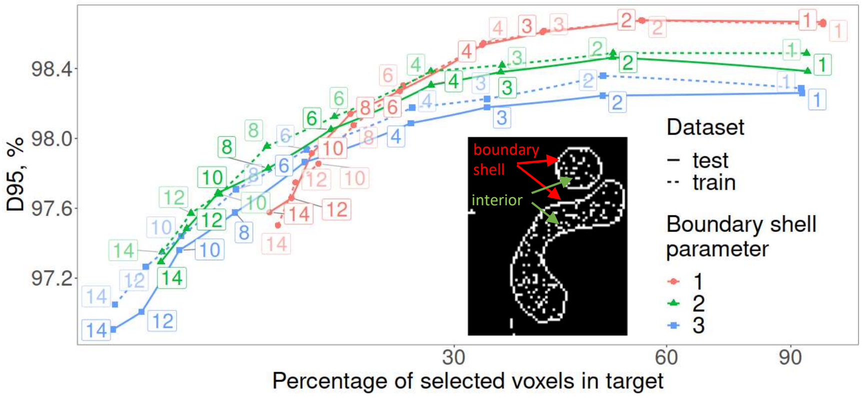
CT image of a sample patient with a tumor close to the left eye and brainstem, treated at GSI with carbon ions in 2008.
The tumor receives full target dose, while large regions of the skull are not irradiated at all.

Previous method [1]

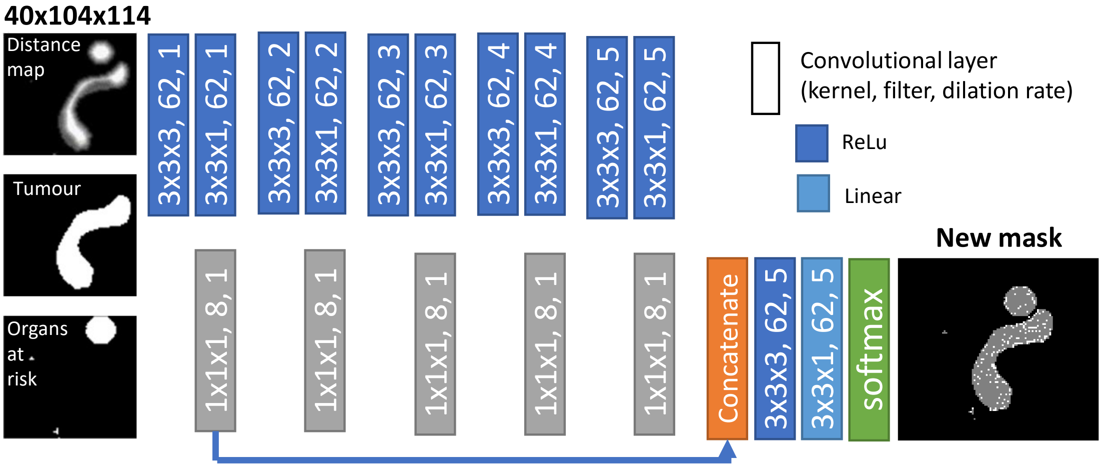
Empirical studies showed the efficiency of a subsampling method, where the boundary shell (2mm) is more important for the optimization process than interior volume. The voxels are randomly sampled from the boundary shell and interior with probability set by a user:

$$Px = 1/x \cdot 100\%$$

The subsampling considerably reduces the computational load and time needed for plan optimization. The change of parameters influences the dose quality, as shown with evaluating target coverage D95 (over a range of sampling parameters).



Current method



Goal

To keep dose in 95% of the target volume over 95% of the prescribed dose (3 Gy).

Dataset

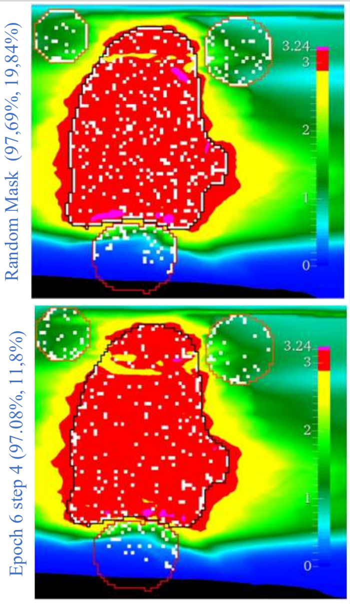
50 head and neck cancer patients' data produced at GSI [2] was used for the evaluation of the model (train dataset (30 patients), test dataset (20 patients)).

Method

The system was pretrained on random mask for 5 epochs and trained with our loss function for the following 15 epochs.

Result

3 independent runs of the experiment showed a stable result over the epochs without an overfitting effect.
The system generates a mask, which contains in median 10-15% of the target voxels and keeps the dose coverage goal in most epochs for more than 75% of the patients.
The algorithm delivers the result, which could substitute a manual setting of the optimal random parameter for both the shell boundary and interior volume.



Outlook

The system showed promising results for the posited requirements. It needs some tuning such as a motivation not only to reduce the number of selected voxels keeping the constraints, but to increase the dose coverage with better positioning of the selected voxels as well.
The system should be tested on the robust plan optimization, where the RAM requirements are higher than for the non-robust optimization.

Literature

[1] M. Wolf, K. Anderle, M. Prall, and C. Graeff, "Random voxel subsampling enables large scale robust optimization in heavy ion therapy," in *50. Jahrestagung der Deutschen Gesellschaft für Medizinische Physik (DGMP) e. V.*, 2019, pp. 252–253
[2] D. Schardt, T. Elsässer, and D. Schulz-Ertner, "Heavy-ion tumor therapy: Physical and radiobiological benefits," *Rev. Mod. Phys.*, vol. 82, no. 1, pp. 383–425, 2010, doi: 10.1103/RevModPhys.82.383.