A Fast Dose and Fluence Optimization Engine Using Matrix Sparsity for Adaptive Radiotherapy

H Stephens[1], Q Wu[1], W Wang[1], J Zhang[1], C Wang[1], Y Sheng[1], Y Ge[2], Q Wu[1]
1 Duke University, Durham, NC
2 University of North Carolina at Charlotte, Charlotte, NC

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

Image guided radiation therapy allows for the real-time compensation and verification of treatment volume perturbations during radiotherapy with multiple fractions. These differences in the patient volume introduce variations within the dose distribution calculated in planning and the actual absorbed dose during treatment. Re-calculating the dose and re-optimizing the fluence can be time intensive, and a fast dose calculation that is both accurate and robust is needed in order to quickly re-optimize the fluence maps. Our goal was to design and implement a fast, coupled dose and fluence optimization engine to accomplish this end.

METHODS

- Given a finite-sized pencil beam model[1,2] the dose to a voxel v is found by

$$D(v) = \iiint A(v')f(v')k(v'-v)d^3v'$$

where $f(v')$ is the fluence at v' projected from the source.

- Letting $f(v') = \delta(v' - r_\beta)$, we can determine the dose to a voxel from a particular beamlet, $D_\beta(v)$.

- A mapping S, is constructed such that each voxel is mapped from the patient frame of reference to the beam frame of reference. Here heterogeneity corrections are applied such that,

$$S(v)\cdot\hat{z} = \int_0^1 \frac{\mu\big(\sigma + \alpha(v-\sigma)\big)}{\mu_o} d\alpha$$

where σ is the source origin.

- A dose matrix is then be constructed by,

$$H_v^\beta = D_\beta(S(v))$$

- We minimize a dose-volume cost function[3], $\Omega(f, H)$, by

$$f_{n+1} = f_n + \gamma\nabla\Omega(f,H)$$

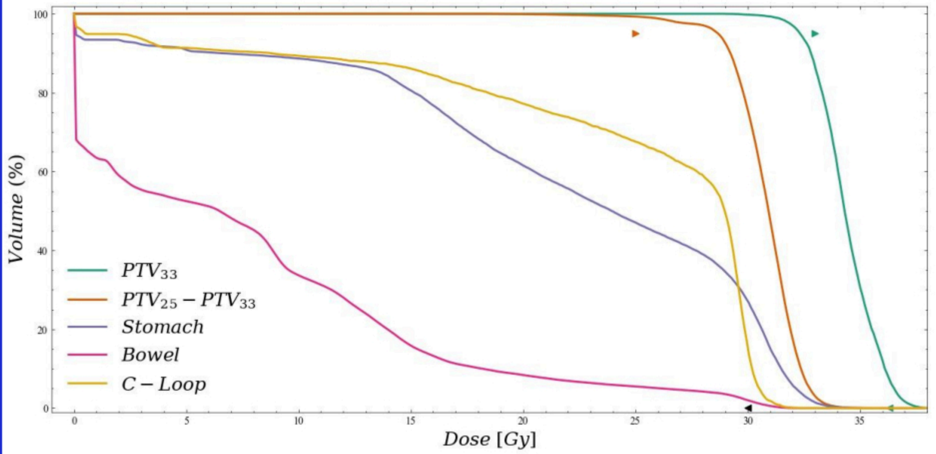
- H is an extremely spare matrix and taking advantage of storing and manipulating it in a Compressed sparse row (CSR) format greatly decreases computational cost.

- Our methods were tested on a Pancreas SBRT case with a 25 Gy prescription and a 33 Gy SIB.

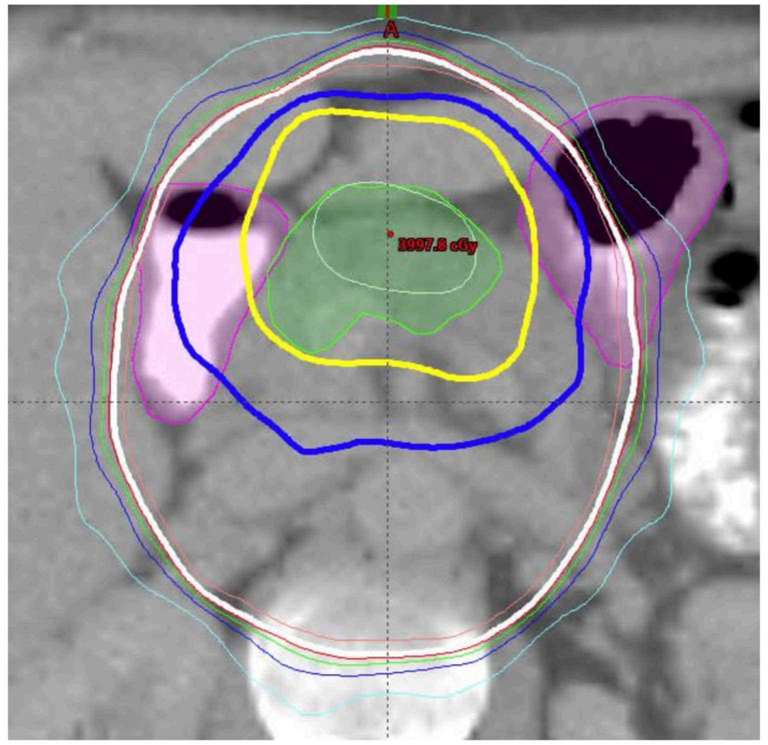
- 9 equally spaced beams with an energy of 6 MeV were used.

RESULTS

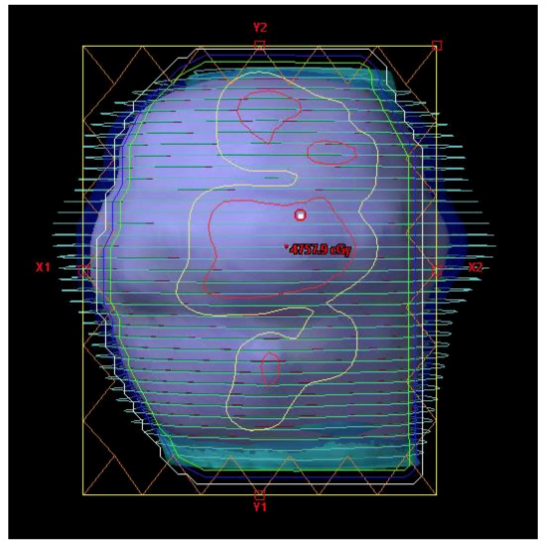
Resulting DVH for target and GI constraints with a NTO ring constraint outside the PTV25



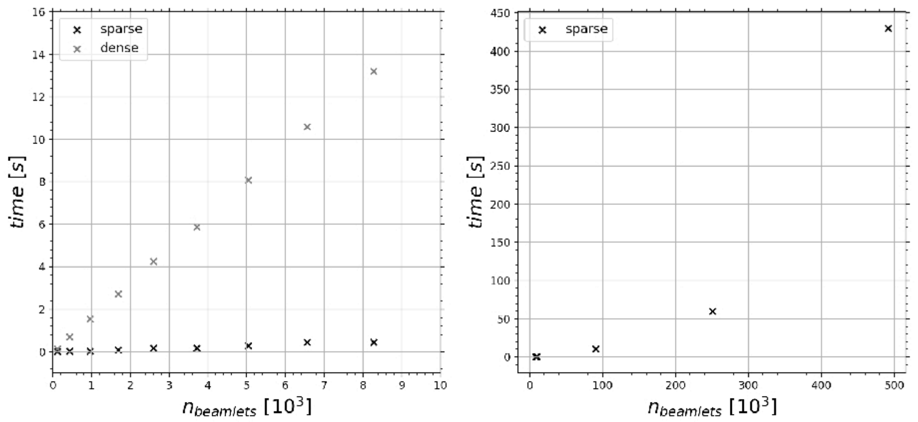
Iso-dose lines from importing optimized fluence map into eclipse showing the conformality of the optimized dose distribution.



Beam's eye view of single field showing how the optimizer conforms to the PTV25 as well as creating hotspots for the PTV33.



Speed comparison of a dense dose calculation compared to the sparse calculation for different number of beamlets.



CONCLUSIONS

- The optimization algorithm provided a sufficient dose distribution that both covered the targets while sparing some critical organs.
- This being the initial implementation, more sophisticated methods needs to be introduced into the optimizer to account for fluence smoothing and to produce shaper gradients around the targets.
- Introducing sparsity into the framework greatly reduced computational cost. A full dose calculation can be performed in a manner of seconds for a single beam as well as multiple beams with parallel techniques.
- This work shows promise in the goal of producing a fast, efficient, self-contained IMRT optimizer.

ACKNOWLEDGEMENTS

- This work was supported by an NIH grant (#R01CA201212). The majority of the code was written in the Julia programming as well as Python.

REFERENCES

1. Jeleń U, Söhn M, Alber M. A finite size pencil beam for IMRT dose optimization. *Phys Med Biol*. 2005;50(8):1747-1766. doi:10.1088/0031-9155/50/8/009

2. Jeleń U, Alber M. A finite size pencil beam algorithm for IMRT dose optimization: density corrections. *Phys Med Biol*. 2007;52(3):617-633. doi:10.1088/0031-9155/52/3/006

3. Wu Q, Mohan R. Algorithms and functionality of an intensity modulated radiotherapy optimization system. *Med Phys*. 2000;27(4):701-711. doi:10.1118/1.598932

CONTACT INFORMATION

hunter.stephens@duke.edu