Rapid and accurate dose computation and optimization for IMPT

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Abstract

The speed of IMPT dose optimization is the key factor limiting the rate of treatment plan generation. Long optimization times have the effect of forcing dosimetrists to compromise due to time limitations and potentially select lower quality plans. The speed of dose optimization is determined both by the optimization algorithm itself and by the underlying dose computation algorithm.

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Background: The speed of IMPT dose optimization is the key factor limiting the rate of treatment plan generation. Long optimization times have the effect of forcing dosimetrists to compromise due to time limitations and potentially select lower quality plans. The speed of dose optimization is determined both by the optimization algorithm itself and by the underlying dose computation algorithm.

Method: To overcome limitations in the speed of dose optimization we have developed a novel dose computation algorithm, the Outer Product Algorithm (OPA), which produces highly accurate dose distributions with extraordinary speed. We have coupled OPA to a novel gradient-free quadratic optimization algorithm, Parallel Quadratic Programming (PQP), which uses multiplicative updates and incorporates hard constraints.

Results: The OPA, implemented for GPU, is capable of computing 3D dose distributions for clinical treatment plans, e.g. $(512\ \mathrm{mm})^3$ patient CT with $1\ \mathrm{mm}^3$ voxels and $\sim 10^5$ treatment spots, in ~10 ms with a maximum dose error of <10% and a 3mm/3% Gamma match of >98% for liver and lung tumors in comparison to the dose from the TOPAS Geant4 application. PQP leverages this high dose computation speed to enable full multi-port optimization to converge in a few seconds.

Conclusion: The high speed IMPT dose optimization provided by the combination of OPA for dose computation and PQP for optimization enables the nearly real-time response of a TPS to user input. This enables a dosimetrist to try many different treatment scenarios and potentially produces better plans with greater tumor control and OAR sparing.