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Deep-Learning Acceleration of Proton Therapy Monte Carlo Simulations

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Proton therapy is a radiation treatment that targets tumoural masses more precisely than conventional radiotherapy. Simulations of clinical proton radiotherapy treatment plans and dose verification methods using Monte Carlo (MC) codes have been proven to be a valuable tool for basic research and clinical studies.

TOPAS, a CPU-based, open-source software tool, can be considered a golden standard of proton therapy MC simulators. Nevertheless, the main limitation of this tool is the time required to complete the simulation. Simulating a complete treatment plan, with the necessary statistics for adequate modeling, can take around five hours on a high-performance computer. If multiple treatment plan variations are to be generated for model training, the total simulation times become prohibitive.

To solve this problem, we propose to accelerate MC simulations in proton therapy with a deep learning (DL) model able to estimate high-statistics dose and activity images from low-statistics simulations. In this work, we simulated with TOPAS two treatment plans with 300 beams each: a high-statistics plan with 100k protons per beam and a low-statistics plan with 1k protons per beam. The DL model, based on the SwinUNETR architecture, was trained to predict the high-statistics beams from the low-statistics beams. It was trained for 50 epochs in one hour and was able to generate high-statistics activity images from low-statistics activity images with a mean squared error of 0.0016 and a gamma index (1mm, 3%) of 99.77%. For reference, the mean squared error and the gamma index between two high-statistics activity images, where only the simulation's random seed was modified, was 0.0008 and 99.91% respectively, which is close to the results obtained with our model.

These results show how DL methods can be used to reduce the computational time required for obtaining accurate proton therapy MC simulations. Even if new software tools are used to accelerate MC simulations (for instance, by using GPUs) our proposed approach could be also used in those cases to further accelerate the whole simulation workflow.

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