PhD Thesis Presentation

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Title:	Accelerated Prompt Gamma estimation for clinical Proton Therapy simulations
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I. Purpose

There is interest in the particle therapy community to use prompt gammas (PG), a natural byproduct of particle treatment, for range verification and eventually dose control. However, PG production is a rare process and therefore estimating PGs exiting a patient during a proton treatment plan executed by a Monte Carlo (MC) simulation converges slowly. Recently, different approaches to accelerating the estimation of PG yield have been presented. Sterpin et al. (2015) described a fast analytic method which is still sensitive to heterogeneities. El Kanawati et al. (2015) described a variance reduction method (pgTLE) that accelerates the PG estimation by precomputing PG production probabilities as a function of energy and target materials, but has as drawback that the proposed method is limited to analytical phantoms.

II. Materials and Methods

We present a two-stage variance reduction method, named voxelized pgTLE (vpgTLE) that extends pgTLE to voxelized volumes. As a preliminary step, PG production probabilities are precomputed once and stored in a database. In stage one, we simulate the interactions between the treatment plan and the patient CT with low statistic MC to obtain the spatial and spectral distribution of the PGs. As primary particles are propagated throughout the patient CT, the PG yields are computed in each voxel from the initial database, as function of the current energy of the primary, the material in the voxel and the step length. The result is a voxelized image of PG yield, normalized to a single primary. The second stage uses this intermediate PG image as a source to generate and propagate the number of PGs throughout the rest of the scene geometry, e.g. into a detection device, corresponding to the number of primaries desired.

III. Results

We achieved a gain of around 10^3 (fig. 1) for a complete patient CT treatment plan with respect to analog MC, at a convergence level of 2% relative uncertainty in the 90% yield region. The method agrees with reference analog MC simulations to within 10^{-4}, with negligible bias. Gains per voxel range from 10^2 to 10^4.

Patient CT: Gain distribution and Convergence

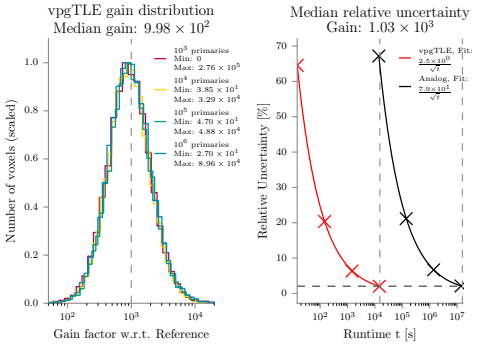

Figure 1: Patient CT. Left, the gain histogram is shown, for all vpgTLE primary-sets with respect to the reference. Right, the mean relative uncertainty is plotted as a function of runtime, for both the analog and vpgTLE methods. Each succesive point is generated with 10^3 - 10^6 primaries for vpgTLE, and with 10^6 - 10^9 primaries for analog MC. We take the ratio of the runtimes at the 2% level to obtain the gain.

IV. Conclusion

The presented generic PG yield estimator is drop-in usable with any geometry and beam configuration. We showed a gain of three orders of magnitude compared to analog MC. With a large number of voxels and materials, memory consumption may be a concern and we discuss the consequences and possible trade-offs. The method will be available as open source in the next release of Gate.

References

W El Kanawati, J M Létang, D Dauvergne, M Pinto, D Sarrut, É Testa, and N Freud. Monte Carlo simulation of prompt γ-ray emission in proton therapy using a specific track length estimator. *Physics in Medicine and Biology*, 60(20):8067–8086, 2015. ISSN 0031-9155. doi: 10.1088/0031-9155/60/20/8067.

E Sterpin, G Janssens, J Smeets, François Vander Stappen, D Prieels, Marlen Priegnitz, Irene Perali, and S Vynckier. Analytical computation of prompt gamma ray emission and detection for proton range verification. *Physics in Medicine and Biology*, 60(12):4915–4946, 2015. ISSN 0031-9155. doi: 10.1088/0031-9155/60/12/4915.