Contribution ID: **18** Type: **not specified**

MC simulations and radiation transport in medical physics

Thursday 21 February 2013 10:40 (40 minutes)

We shall describe typical applications of Monte Carlo (MC) methods in the computation of radiation transport specifically in the domain of radiotherapy and associated applications to derive quantities of interest such as the deposited energy per unit mass (otherwise known as the dose in Gray [J/Kg]). The suitability of MC in radiation physics is favoured by the stochastic nature of the underlying physical interaction mechanisms involved, thereby requiring the iterative sampling of multiple particle type-dependent variables the most important of which are the particle energy, its position and direction of travel. The complexity of the problem of radiation transport within matter renders analytical solutions to the Boltzmann transport equation very difficult, owed to the assumptions required to limit the transport problem to only a few independent variables. The implementation of sampling by using random numbers, alongside known probability distribution functions of the basic interaction mechanisms would finally lead to a convergence of the result to the true value of the macroscopic quantity of interest under investigation, if sampling is performed over a significantly large number of events.

While the simulation of photon transport is less cumbersome, electron transport is very delicate especially at the boundaries between different media. Besides this, with regard to the multitude of catastrophic events involved in electron interactions, the computation time to achieve low statistical uncertainties may become very large. Typical techniques to circumvent lengthy tracking of electron events shall be described. An example is the condensed history technique entailing the grouping of a number of microscopic transport steps into one fictitious interaction step. To improve efficiency of calculations without compromising the results, typical variance reduction techniques such as range rejection, bremsstrahlung splitting and the Russian Roulette method shall be described. Furthermore, energy thresholds are set for both photons and electrons to values below which the particle is no longer tracked and its energy locally deposited. The proper choice of the cut-off energy significantly affects the simulation time and thereby the overall efficiency, keeping in mind that a significant interaction event may occur below this threshold, depending on the problem under consideration. The roles of the afore-mentioned techniques shall be highlighted in typical applications in medical radiation physics such as in the simulation of medical linear electron accelerators and dosimetric detector systems. Other MC applications in treatment planning techniques shall also be described, alongside some examples of commercial MC-based systems.

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