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Adaptive multilevel splitting for Monte Carlo particle transport

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Abstract. In the Monte Carlo simulation of particle transport, and especially for shielding applications, variance reduction techniques are widely used to help simulate realisations of rare events and reduce the relative errors on the estimated scores for a given computation time. Adaptive Multilevel Splitting (AMS) is one of these variance reduction techniques that has recently appeared in the literature. In the present paper, we propose an alternative version of the AMS algorithm, adapted for the first time to the field of particle transport. Within this context, it can be used to build an unbiased estimator of any quantity associated with particle tracks, such as flux, reaction rates or even non-Boltzmann tallies like pulse-height tallies and other spectra. Furthermore, the efficiency of the AMS algorithm is shown not to be very sensitive to variations of its input parameters, which makes it capable of significant variance reduction without requiring extended user effort.

1 Introduction

The challenge in using Monte Carlo particle transport simulations for shielding applications is to minimize the computation time required to attain a reasonable variance on the quantity of interest, called *score*.

The basic approach of variance reduction techniques is to modify the simulation behaviour so as to increase rare events occurrence while keeping an unbiased estimator of the score.

In this view, *multilevel splitting techniques* were introduced to the field of particle transport by Kahn and Harris [1]. The principle of these techniques is to increase the number of simulated particles when approaching areas of interest of the geometry. Practically, the simulated space is divided into regions of importance delimited by so-called splitting levels, and the particles that pass from a less important to a more important region are duplicated. Each of the duplicated particles is given half the weight of the original to ensure that the simulation remains unbiased. Thus, more computation time is spent to simulate interesting particles rather than new particles from the source.

The downside of these techniques is that they require a fair knowledge of the system in order to accurately define the importance regions. More recently, a new method called Adaptive Multilevel Splitting (or AMS) has been proposed by Cérou and Guyader [2], and studied in a more general setting by Bréhier et al. [3]. This method also aims to duplicate the interesting particles of the simulation, but does not use an a priori definition of importance regions. Instead, the splitting levels are determined on the fly, following a selection mechanism based on the classification of the simulated particle histories.

One of the most interesting features of AMS, which will be illustrated in this work through various numerical simulations, is that it yields very robust results even if the importance function only reflects a poor knowledge of the system. The efficiency of the AMS in Monte Carlo simulations and its properties makes it attractive for computational physics problems that require precise rare event simulation. To this end, AMS was successfully extended to the simulation of path-dependent quantities and applied to molecular dynamics simulations by Aristoff et al. for the resampling of reactive paths [4].

In this paper, we aim to apply the AMS algorithm to Monte Carlo particle transport and demonstrate its efficiency for rare event simulations. In Section 2, we will describe a mathematical version of the AMS algorithm specifically designed to fit the requirements of particle transport. We introduce in Section 3 the context of the study, which is neutral particle transport with the Monte Carlo method. The core of this work is presented in Section 4, in which we introduce for the first time a practical implementation of AMS within a Monte Carlo particle transport simulation. This version of the AMS algorithm was implemented in the development version of the Monte Carlo particle transport code TRIPOLI-4®. In

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