Analysis of Correlated Coupling of Monte Carlo Forward and Adjoint Histories

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Abstract—In Monte Carlo correlated coupling, forward and adjoint particle histories are initiated in exactly opposite directions at an arbitrarily placed surface between a physical source and a physical detector. It is shown that this coupling calculation can become more efficient than standard forward calculations. In many cases, the basic form of correlated coupling is less efficient than standard forward calculations. This inherent inefficiency can be overcome by applying a black absorber perturbation to either the forward or the adjoint problem and by processing the product of batch averages as one statistical entity. The usage of the black absorber is based on the invariance of the response flow integral with a material perturbation in either the physical detector side volume in the forward problem or the physical source side volume in the adjoint problem. The batch-average product processing makes use of a quadratic increase of the nonzero coupled-score probability. All the developments have been done in such a way that improved efficiency schemes available in widely distributed Monte Carlo codes can be applied to both the forward and adjoint simulations. Also, the physical meaning of the black absorber perturbation is interpreted based on surface crossing and is numerically validated. In addition, the immediate reflection at the intermediate surface with a controlled direction change is investigated within the invariance framework. This approach can be advantageous for a void streaming problem.

I. INTRODUCTION

Multiple Monte Carlo (MC) calculations are executed, for example, in recursive Monte Carlo1 and some coupling methods.2 Such calculations require a spatial surface placed at an arbitrary position where MC simulations are coupled or recursively continued. Neutron penetration through complicated geometries and/or streaming channels is an application area for these MC methods. On the other hand, it is often difficult to quantify the propagation of the statistical error to the next-stage calculation.

Cramer proposed correlated coupling3 to overcome the error propagation feature in MC calculations based on a response flow integral (RFI) (the surface integral of the product of directional cosine and forward and adjoint fluxes). In his method, a pair of forward and adjoint histories starting in exactly opposite directions are uniformly and isotropically initiated at an intermediate surface between a physical source and detector. Since this initial-state (source) sampling does not depend on the result of the calculation at the previous stage, there is in principle no statistical error propagation due to the coupling procedure. Moreover, no space-angle-energy discretization is introduced in that procedure. On the other hand, the entire coupled history yields a zero score when