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1. Introduction

Implicit Monte Carlo [1] (IMC) has been shown to be very expensive when used to evaluate a radiation field in opaque media. Implicit Monte Carlo Diffusion (IMD) [2], which evaluates a spatial discretized diffusion equation using a Monte Carlo algorithm, can be used to reduce the cost of evaluating the radiation field in opaque media [2,3]. Hybrid Implicit Monte Carlo Diffusion (HIMCD) couples the IMC and IMD algorithms together to evaluate simulations with both optically thin and thick material. This work investigates the presence of teleportation error [4] in frequency-dependent HIMCD simulations. We show that the teleportation error that occurs from scattering between optically thick and optically thin opacity groups can be mitigated by source tilting. This teleportation error is present in both our HIMCD method and the similar frequency-dependent Hybrid Discrete Diffusion Monte Carlo (DDMC) [5].

2. Hybrid Implicit Monte Carlo Diffusion

The HIMCD method separates a simulation into two domains: an optically thin transport domain and an optically thick diffusion domain. The transport domain is evaluated using the frequency-dependent IMC transport equation that can be written as:

$$\frac{1}{c}\frac{dI_\nu}{dt} + \bar{\Omega}\cdot\bar{\nabla}I_\nu = \frac{1}{4\pi}\kappa_\nu f B(\nu,T) - \kappa_\nu I_\nu + \frac{\kappa_\nu b(\nu,T)}{\kappa_p 4\pi}\int_0^\infty\int_0^{4\pi}\kappa_{\nu'}(1-f)I_{\nu'}d\bar{\Omega}'d\nu' \qquad (1)$$

The radiation field in the diffusion domain is defined by the semi-implicit diffusion equation:

$$\frac{dE_\nu}{dt} + c\bar{\nabla}\cdot\frac{1}{3\kappa_\nu}\bar{\nabla}E_\nu = \kappa_\nu f B(\nu,T) - c\kappa_\nu E_\nu + \frac{\kappa_\nu b(\nu,T)}{\kappa_p}\int_0^\infty \kappa_{\nu'}(1-f)cE_{\nu'}d\nu', \qquad (2)$$

The radiation field is coupled to the conservation of material energy equation.

In HIMCD the diffusion and transport domains are evaluated simultaneously using the Monte Carlo (MC) method. This is done by allowing MC particles to explicitly transition between the diffusion and transport domains given the boundary conditions that defines the interface between them. There are three different types of boundary conditions used in frequency-dependent HIMCD: boundaries between the diffusion and transport frequency groups, spatial boundaries between material interfaces of optically thick and thin material, and temporal boundaries that account for radiation energy that is reclassified as diffusion or transport energy because of changes in the material properties. Crossing from the IMC domain to the IMD domain only requires that the MC particle be tracked differently in the diffusion domain. Crossing from the diffusion domain to the transport domain is more complicated, because it requires that we sample the missing spatial and temporal distribution required by the IMC method. Each diffusion transport boundary condition requires a different type of sampling. Sampling for the spatial and temporal boundary conditions is trivial: spatial boundaries are sampled as an isotropic face source into the transport domain at the

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interface, temporal boundaries are sampled with an isotropic direction and an equally distribution in space and time. We have found that equally distributing the MC particles in space that are scattered from the diffusion domain to the transport domain, as was done in the work of Densmore et al.[5], causes teleportation error to accumulate in the simulation.

3. Mitigating Teleportation Error

The spatial distribution of the diffusion-transport scattering events is sampled in one of two ways in this work: either an equal distribution in in space, or a source tilting distribution [6] that takes into account the spatial gradient of the emission source. The source tilting distribution sampling helps mitigate the teleportation error in regions of the simulation with strong temperature gradients. This is because it better emulates the distribution of the true scattering events, as compared to an equal distribution in space. This tilting scheme is typically used for thermal emission source distributions in optically thick material. Figure 1 shows that HIMCD with tilting matches well with the IMC result, significantly reduces the teleportation error that occurs in the HIMCD method without tilting.

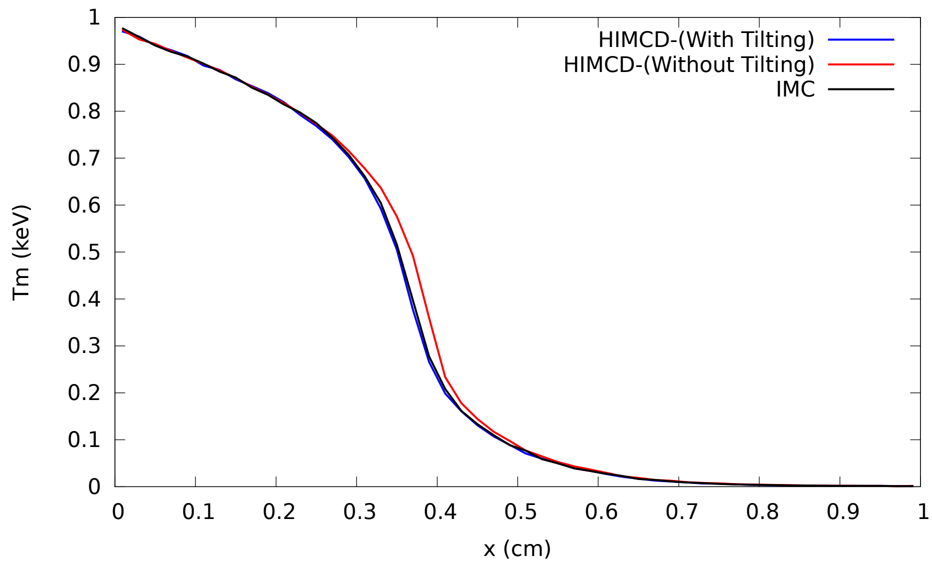

Figure 1: The material temperature for HIMCD with and without source tilting versus IMC at $t = 1.0$ [ns]. This is a semi-infinite medium problem with an initial material temperature of 1 [eV] and a black body face source at $x = 0$ [cm] with a temperature of 1 [keV]. The opacity is frequency and temperature dependent, $\kappa_\nu = 1000(h\nu)^{-3}(kT)^{-0.5}$ [1/cm], and the specific heat is constant $C_v = 0.1$ [GJ/keV/cm^3] [5].

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