Discrete Diffusion Monte Carlo for Radiation-Transport Simulations on Adaptive-Refinement Meshes

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Discrete Diffusion Monte Carlo (DDMC) is a technique for increasing the efficiency of Monte Carlo simulations in diffusive media. Monte Carlo simulation is a well-established method for modeling energy transfer by x-ray radiation transport in applications such as astrophysics and inertial confinement fusion, but can be computationally inefficient in problems with diffusive regions. In this regime, particle histories will consist of many steps due to the small distance between collisions and lack of absorption, a situation that results in an inefficient radiation-transport calculation.

In DDMC, particles take discrete steps between spatial cells according to a spatially discretized diffusion equation. Since each discrete step replaces many smaller Monte Carlo steps, DDMC is more efficient than standard Monte Carlo in diffusive media. In practice, DDMC is combined with standard Monte Carlo in nondiffusive regions to form a hybrid method.

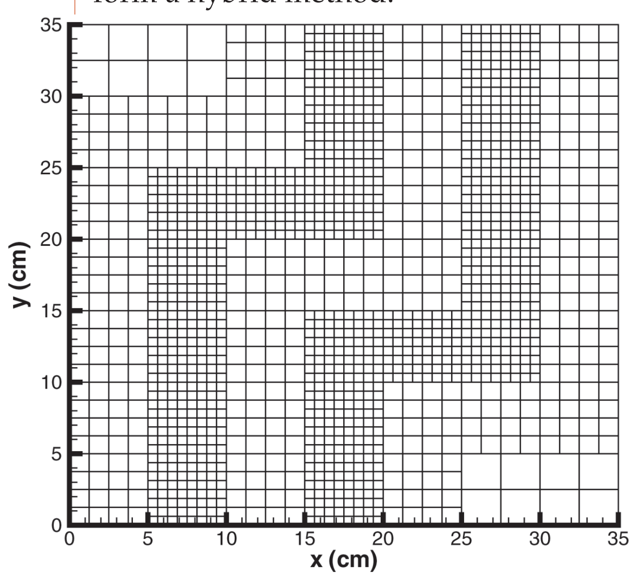

Fig. 1.
Computational mesh.

In previous work, we have developed techniques for interfacing DDMC and Monte Carlo simulations [1,2] and presented a hybrid Monte Carlo-DDMC method for nonlinear, time-dependent problems [3]. Recently, we have developed a DDMC technique for adaptive-refinement meshes [4], a type of mesh in which spatial cells may have multiple neighboring cells across each face. Adaptive-refinement meshes are commonly used in Eulerian hydrodynamics calculations, so extending our DDMC methodology to these meshes is important for coupled radiation-hydrodynamics simulations.

We compare our DDMC technique for adaptive-refinement meshes to both standard Monte Carlo and Random Walk (RW), another hybrid Monte Carlo-diffusion method in which particles take macrosteps over spheres according to an analytic diffusion solution [5]. We consider a test problem consisting of a purely scattering region with an embedded duct. The computational mesh for this problem is given in Fig. 1. We form a hybrid method by employing DDMC in the purely scattering region and standard Monte Carlo in the duct. In addition, we use two values of the minimum sphere radius, λ, with RW.

A contour plot of the scalar flux for this problem is given in Fig. 2. In Fig. 3, we plot the scalar flux resulting from these calculations as a function of x for fixed y. From this figure with see that the hybrid and $\lambda = 20$ solutions agree well with standard Monte Carlo, while the $\lambda = 5$ scalar flux is systematically too low.

In addition, the hybrid simulation was almost 500 times faster than standard Monte Carlo and over 300 times faster than the most efficient (but inaccurate) RW calculation. Thus, our new DDMC method for adaptive-refinement meshes is more computationally efficient than standard Monte Carlo and RW while yielding accurate solutions.

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[1] J.D. Densmore, *Ann. Nucl. Energy* **33**, 343 (2006).
[2] G. Davidson, et al., *Trans. Am. Nucl. Soc.* **94,** 517 (2006).
[3] J.D. Densmore, et al., *J. Comput. Phys.* **222**, 485 (2007).
[4] J.D. Densmore, et al., *Trans. Am. Nucl. Soc.* **95**, 541 (2006).
[5] J.A. Fleck, Jr., and E.H. Canfield, *J. Comput. Phys.* **54**, 508 (1984).

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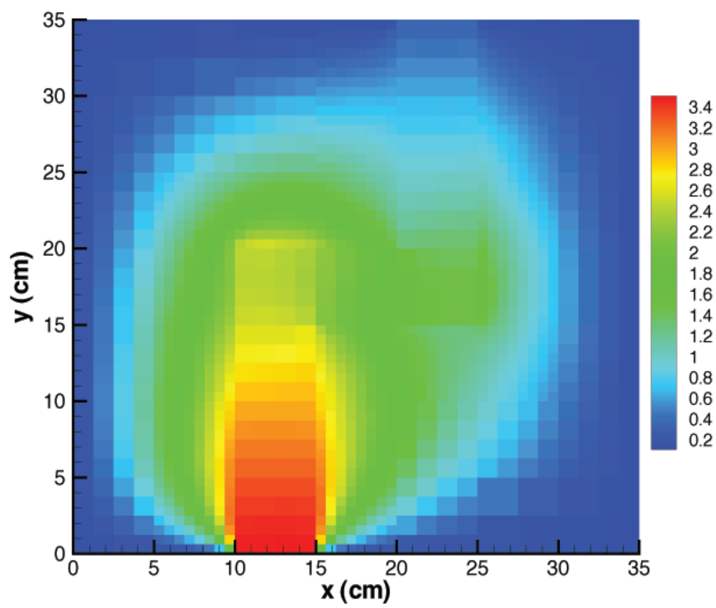

Fig. 2.
Contour plot of scalar flux (cm^{-2} - s^{-1}).

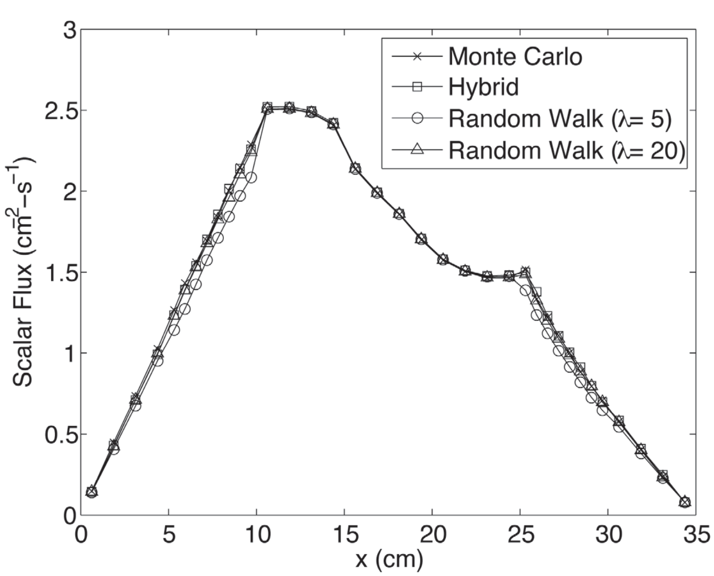

Fig. 3.
Scalar flux at y = 15.3125 cm. This value of y corresponds to the row of cells just after the duct makes a turn to the right.