

基于 CUDA 的三维 Random Ray 多群中子输运求解器 及 GPU 加速机制研究

摘要

Random Ray Method 是一种将特征线法的确定性沿线积分与随机射线抽样相结合的中子输运数值方法，具有几何处理简单、天然适合大量独立射线并行推进等特点。针对三维非均匀反应堆物理问题中的射线追踪、源迭代和多群通量累积开销，本文研究基于 CUDA 的 Random Ray 多群中子输运求解思路。方法上采用裂变源幂迭代求解有效增殖因子 k_{eff} ，GPU 端将主要计算分解为按 cell-group、ray 和 ray-group 粒度组织的多个 kernel，将几何追踪、沿线衰减积分、标量通量统计和裂变源更新组织为适合 GPU 的并行计算流程。最后通过 Takeda 与 C5G7 基准问题验证方法的可行性和加速效果。

关键词

Random Ray Method；中子输运；CUDA；GPU 加速；多群方法；Takeda；C5G7

Abstract

The Random Ray Method is a neutron transport numerical method that combines the deterministic line integration of the characteristic line method with random ray sampling. It has the characteristics of simple geometric processing, low memory requirements, and is naturally suitable for the parallel advancement of a large number of independent rays. Aiming at the overhead of Ray tracing, source iteration and multi-group flux accumulation in three-dimensional non-uniform reactor physics problems, this paper studies the solution idea of Random Ray multi-group neutron transport based on CUDA. Methodologically, the fission source power iteration is adopted to solve the effective proliferation factor k_{eff} . At the GPU end, the main computation is decomposed into multiple kernels organized according to the granularity of cell-group, ray, and Ray-group. Organize geometric tracing, along-line attenuation integration, scalar flux statistics, and fission source updates into a parallel computing process suitable for GPUs. Finally, the feasibility and acceleration effect of the method are verified through the benchmark problems of Takeda and C5G7.

Keywords

Random Ray Method; neutron transport; CUDA; GPU acceleration; multigroup transport; Takeda; C5G7

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