

ACCELERATION OF MONTE CARLO RAY TRACING IN PARTICIPATING MEDIA USING GRAPHICS PROCESSING UNITS AND BOUNDING VOLUME HIERARCHIES

Nicolas Tricard¹ and Xinyu Zhao^{1*}

¹University of Connecticut, 191 Auditorium Rd, Storrs, CT 06269, USA

Thermal radiation contributes significantly to the dynamics and heat transfer within combustion systems and must be included in combustion simulations for a comprehensive prediction of flame properties. Monte Carlo Ray tracing (MCRT) is the most robust and accurate model of radiation but is very computationally expensive due to its prohibitive ray tracing procedure. Therefore, enhanced computational approaches are considered in this study to accelerate MCRT using inspirations from the field of computer graphics. Specifically, Graphics Processing Units (GPUs) and Bounding Volume Hierarchies (BVHs) are used to improve MCRT performance within on-node and distributed memory environments.

This poster first presents work in the development of a GPU and BVH accelerated MCRT solver. The solver is connected to the OpenFOAM open-sourced CFD platform to enable transient simulations of coupled combustion-radiation calculations. A line-by-line non-gray model is used for accurate spectral emission and absorption profiles of high temperature CO₂, H₂O, CO, and soot. Distributed-memory capabilities are enabled using the Message Passing Interface (MPI). On-node parallelization is enabled using the Kokkos C++ library for performance-portability across CPUs and GPUs. The ArborX geometric search library is applied for a BVH implementation.

A method for improved scalability using BVHs is then proposed, where rays are first distributed across all intersected domain-decompose MPI-rank regions and then traced at multiple points along their path lengths simultaneously. The adjusted formulation of reverse Monte-Carlo and step-by-step approach to enable this feature are presented. ArborX implements the multi-rank BVH construction and traversal functionality and provides functionality to MPI send and receive rays in bulk with Kokkos-acceleration.

The model is applied to two geometries. Solver performances are presented for a 1-D plane-parallel participating medium and a direct numerical simulation of a small pool fire. Verifications show excellent agreement between the solvers with respect to analytical solutions and established radiation models for both 1-D and 3-D geometries with non-gray modeling. Single-timestep on-node frozen-field analyses show GPUs accelerate MCRT up to almost 400 times over serial calculations. When radiation is applied across multiple nodes, the Bounding Volume Hierarchy (BVH) is shown to compare excellently against reverse MC without the BVH. Runtime comparisons with BVH and without BVH acceleration are also shown, and the benefits and limitations of the BVH approach are compared alongside existing methods for acceleration of MCRT in distributed-memory environments.

* Corresponding Author: xinyu.zhao@uconn.edu.