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Unsteady Three-Dimensional Adaptive Spatial-Temporal Multi-Scale Direct Simulation Monte Carlo Solver to Simulate Rarefied Gas Flows in Micro/Nano Devices

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Abstract : We present an efficient, three-dimensional parallel multi-scale Direct Simulation Monte Carlo (DSMC) algorithm for the simulation of unsteady rarefied gas flows in micro/nanosystems. The algorithm employs a novel spatiotemporal adaptivity scheme. The scheme performs a fully dynamic multi-level grid adaption based on the gradients of flow macro-parameters and an automatic temporal adaptation. The computational domain consists of a hierarchical octree-based Cartesian grid representation of the flow domain and a triangular mesh for the solid object surfaces. The hybrid mesh, combined with the spatiotemporal adaptivity scheme, allows for increased flexibility and efficient data management, rendering the framework suitable for efficient particle-tracing and dynamic grid refinement and coarsening. The parallel algorithm is optimized to run DSMC simulations of strongly unsteady, non-equilibrium flows over multiple cores. The presented method is validated by comparing with benchmark studies and then employed to improve the design of micro-scale hotwire thermal sensors in rarefied gas flows.

Keywords : DSMC, oct-tree hierarchical grid, ray tracing, spatial-temporal adaptivity scheme, unsteady rarefied gas flows
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