Deviational methods for Efficient Solution of the Boltzmann Equation

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We discuss recently-developed Monte Carlo methods for solving the Boltzmann equation in the context of complex multidimensional problems of engineering interest. These methods achieve considerable speedup compared to direct simulation Monte Carlo by simulating only the deviation from equilibrium. By removing the computational cost associated with removing the statistical uncertainty associated with equilibrium fluctuations, this control-variate variance-reduction approach can capture arbitrarily small deviations from equilibrium at a cost that is independent of the deviation from equilibrium. Moreover, by algebraically decomposing the distribution function into an analytical part that is known and a part described by particles, deviational methods represent a functional approach towards multiscale modeling, where the computational effort is automatically and adaptively focused on the regions where kinetic effects are important. Simulation methods based on algebraic decomposition have enabled us to simulate problems that are out of reach of other state-of-the-art Boltzmann solution methods.

We will conclude with a discussion of recent results from application of these methods to problems involving small-scale transport; examples include nanoscale gas flows as well as phonon transport in the context of nanoscale heat transfer in semiconducting materials.