Abstract

FW/CADIS-Ω: An Angle-Informed Hybrid Method for Neutron Transport

by

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The development of methods for deep-penetration radiation transport is of continued importance for radiation shielding, nonproliferation, nuclear threat reduction, and medical applications. As these applications become more ubiquitous, the need for transport methods that can accurately and reliably model the systems' behavior will persist. For these types of systems, hybrid methods are often the best choice to obtain a reliable answer in a short amount of time. Hybrid methods leverage the speed and uniform uncertainty distribution of a deterministic solution to bias Monte Carlo transport to reduce the variance in the solution. At present, the Consistent Adjoint-Driven Importance Sampling (CADIS) and Forward-Weighted CADIS (FW-CADIS) hybrid methods are the gold standard by which to model systems that have deeply-penetrating radiation. They use an adjoint scalar flux to generate variance reduction parameters for Monte Carlo. However, in problems where there exists strong anisotropy in the flux, CADIS and FW-CADIS are not as effective at reducing the problem variance as isotropic problems.

This dissertation covers the theoretical background, implementation of, and characterization of a set of angle-informed hybrid methods that can be applied to strongly anisotropic deep-penetration radiation transport problems. These methods use a forward-weighted adjoint angular flux to generate variance reduction parameters for Monte Carlo. As a result, they leverage both adjoint and contributon theory for variance reduction. They have been named CADIS-Ω and FW-CADIS-Ω.

To characterize CADIS-Ω, several characterization problems with flux anisotropies were devised. These problems contain different physical mechanisms by which flux anisotropy is induced. Additionally, a series of novel anisotropy metrics by which to quantify flux anisotropy are used to characterize the methods beyond standard Figure of Merit (FOM) and relative error metrics. As a result, a more thorough investigation into the effects of anisotropy and the degree of anisotropy on Monte Carlo convergence is possible.

The results from the characterization of CADIS-Ω show that it performs best in strongly anisotropic problems that have preferential particle flowpaths, but only if the flowpaths are not comprised of air. Further, the characterization of the method's sensitivity to determin-

istic angular discretization showed that CADIS-Ω has less sensitivity to discretization than CADIS for both quadrature order and P_N order. However, more variation in the results were observed in response to changing quadrature order than P_N order. Further, as a result of the forward-normalization in the Ω-methods, ray effect mitigation was observed in many of the characterization problems.

The characterization of the CADIS-Ω-method in this dissertation serves to outline a path forward for further hybrid methods development. In particular, the response that the Ω-method has with changes in quadrature order, P_N order, and on ray effect mitigation are strong indicators that the method is more resilient than its predecessors to strong anisotropies in the flux. With further method characterization, the full potential of the Ω-methods can be realized. The method can then be applied to geometrically complex, materially diverse problems and help to advance system modelling in deep-penetration radiation transport problems with strong anisotropies in the flux.