Student Projects in Radiation Transport Methods, Summer 2006

Todd Urbatsch, Ed., CCS-2

The Transport Methods Group, CCS-4, has had a strong summer student program, typically hosting about one student per two to three technical staff members. The CCS-4 mentors have fostered productive and enlightening summers with well-defined work plans. These work plans are designed to engage the student in novel research that is publishable and will positively impact the science behind our programmatic efforts. Prior to the formation of the Computer, Computational, and Statistical Sciences (CCS) Division in October 2000, the Transport Method Group was X-6, which was formed from an X-6/T-1 merger in the early 1980s. In January 2007, CCS-4 merged with CCS-2 (Continuum Dynamics) to form the Computational Physics and Methods Group. To commemorate the final Transport Methods Group summer student class, we briefly summarize the projects from the summer of 2006.

"Neutrino Streaming Under Weak Gravitational Fields," Alex Maslowski, Graduate Research Assistant (GRA), Texas A&M University, DOE Nuclear Engineering Health Physics Fellow
Mentor: Kent Budge

Neutrino particles act as the main energy transport agents in supernovae. The influence of gravitational fields on neutrino transport is nontrivial, and yet its effect remains uncertain. Thus, we derived a cylindrical coordinate streaming operator that accounts for the effects of a weak gravitational field. A second-order (post-Newtonian) approximation to the General Relativity induced curvature was applied. Based on the post-Newtonian metric, the Christoffel symbols were computed and the corresponding geodesic particle trajectories were solved. Using the Lindquist approach for nonorthonormal coordinate systems, we derived a post-Newtonian-order Boltzmann operator for massless particles in cylindrical coordinates. We also derived the respective energy gravitational shift. The energy gravitational shift was implemented into the Capsaicin Project's Macho neutrino transport software package.

"Implementing and Testing the Piecewise Linear Finite Element Method in Capsaicin," Teresa Bailey, GRA, Texas A&M University, DOE Computational Science Fellow
Mentor: Kelly Thompson (currently with Transpire, Inc.)

We have derived Stone and Adams' Piecewise Linear Discontinuous Finite Element Method (PWL) for the 2-D RZ transport equation. We implemented and tested it in the Capsaicin Project software. The PWL method is uniquely suited to discretize differential equations on arbitrary polyhedral meshes, whereas methods such as the bilinear discontinuous finite element method (BLD) has been applied only to triangular and quadrilateral grids. We used an asymptotic analysis to determine successful PWL lumping schemes. The convergence rate of PWL on quadrilateral grids for both the transport and diffusive regimes is similar to BLD.

"Krylov Acceleration for Transport in Binary Statistical Media," Erin D. Fichtl, GRA, University of New Mexico
Mentor: Jim Warsa

Radiation transport methods for stochastic mixtures using the Levermore, Pomraning, Vanderhaegen coupled equations are slow to converge as one or both materials approach the diffusion and/or atomic mix limits. We propose a three-part acceleration scheme to accelerate convergence. Firstly, we divide the iteration into a series of "inner" material and species iterations to attenuate the atomic mix and diffusion error modes separately. Secondly, we apply atomic mix synthetic acceleration to the inner material iteration and S_2 synthetic acceleration to the inner species iteration. Finally, we wrap a Krylov iterative solver around each inner and outer iteration. Utilizing a spectral analysis, we compare the effectiveness and efficiency of our new two-step scheme to the basic one-step scheme.

"Interface Reconstruction in PARTISN," Michael Reed, GRA, Texas A&M University
Mentor: Randy Baker

Orthogonal meshes greatly simplify numerical discretizations, but they often introduce significant meshing errors into the problem. Traditionally, the mesh is refined until such meshing errors are acceptable, but this can be prohibitively expensive in 2-D and 3-D. Alternatively, we reconstruct material interfaces at the subcell level and consider such interfaces in the governing equations. We have derived and implemented a diamond difference interface reconstruction technique for the discrete ordinates code PARTISN in multidimensional Cartesian and curvilinear geometries. The reduction in error has been shown to be equivalent to half an order of mesh refinement.

"Fourier Analysis of Parallel, Inexact Block-Jacobi Splitting in 2-D Geometry," Massimiliano Rosa, GRA, Pennsylvania State University
Mentor: Jae Chang

A Fourier analysis is proposed for the steady state one-group transport problem solved with Richardson Iteration (Source Iteration) using the parallel block-Jacobi (PBJ) algorithm, Bilinear Discontinuous Finite Element Method (BLDFEM) discretization in 2-D XY geometry, and assuming isotropic scattering. Our novel Fourier analysis considers four computational cells and the interfaces of four adjacent computational subdomains and has proven to be effective in capturing the peculiar features of the PBJ algorithm. The results agree with observed behavior in the Capsaicin Project's 2-D code, Anaheim. Convergence of the PBJ algorithm can degrade and lead to stagnation of GMRES for thin problems. However, our analysis shows that Modified Transport Synthetic Acceleration is an effective preconditioner in the optically thin case.

"Cell Global-Local Discontinuous Finite Element Spatial Discretizations for Radiation Transport," Rick Gleicher, GRA, University of New Mexico
Mentor: Jim Warsa

We propose the Cell Global-Local Discontinuous Finite Element (CGOLD) method for radiation transport on highly unstructured meshes. During a standard discrete ordinates transport sweep across spatial cells, each cell is divided into subelements. Each subelement interpolates the initial scalar flux from the cell and then the cell's subelements are swept in the current discrete ordinate direction. The subelement's angular fluxes are obtained and projected back onto the cell. The transport sweep continues and new cell scalar fluxes, obtained from the accumulation of projected angular fluxes, are iterated to convergence. In 1-D, the CGOLD method is shown to be third-order accurate and to have the diffusion limit.

"Extending Quadruple Range Quadrature," Eric Baker, Undergraduate Student (UGS), Oregon State University
Mentor: Jon Dahl

The quadruple-range and octant-range quadratures developed by I.K. Abu-Shumays, require fewer angular directions to achieve the same degree of accuracy as other quadratures. However, their maximum attainable accuracy has been limited by the extent of the angular discretization with which they have been computed. We have developed the capability to produce the quadruple-range and octant-range quadratures and, in so doing, we have verified the previously published values.

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