Vortragsankündigung

An Adaptive Multiscale Wavelet Framework for Modeling and Simulation of Fluid Dynamics Flows

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Abstract

Today there are a number of problems in engineering and science, which share a single common computational challenge: the ability to solve and/or model accurately and efficiently a wide range of spatial and temporal scales. Numerical simulation of such problems requires either the use of highly adaptive physics based numerical algorithms, the use of reduced models that capture "important" physics of the problem at a lower cost, or the combination of both approaches. In this talk we present a unified mathematical and computational framework that can be used for efficient modeling and simulation of multiscale phenomena. The talk consists of two closely connected parts.

In the first part of the talk I will discuss four approaches we have been developing for solving nonlinear partial differential equations adaptively. Each method uses the adaptive wavelet collocation method (AWCM) based on bi-orthogonal lifted interpolating wavelets to construct a computational grid adapted to the solution. The wavelet decomposition naturally provides a set of nested multi-scale grids adapted to the solution, and we take advantage of this property in developing our methods. In the first two methods we implement a traditional time marching scheme for parabolic and hyperbolic partial differential equations, but use AWCM to adapt the computational grid to the solution at each time step. When hyperbolic equations are solved an additional wavelet-based procedure for shock capturing is used. With this procedure the mesh is refined in the vicinity of the shock up to a-priori specified resolution and the shock is smoothed out using localized numerical viscosity. The third method simply uses the multi-scale wavelet decomposition as the basis for an adaptive multilevel method for nonlinear elliptic equations. Finally, the preliminary results for adaptive simultaneous space–time method are presented. In this case, both the space-time grid adapts locally to the solution, and the final solution is obtained simultaneously in the entire space–time domain of interest. In the presentation each method are briefly outlined and some examples are provided.

The second part of the talk will deal with modeling and simulation of turbulent flows. First we present some preliminary evidence that the conventional estimates for cubic dependence of the computation cost of fully developed turbulent flows simulations on Reynolds number is

naive and too conservative. The actual computation cost could be substantially lower if numerical algorithms capable to take advantage of both spatial and temporal intermittency are utilized. This suggests that even DNS simulations of high Reynolds number flows might more realistic than previously thought. In addition, the "relatively" small number of degrees of freedom required for the numerical simulation of turbulent flows encourages the search for reduced mathematical models. Two of such models are discussed: Stochastic Vortex Simulation (CVS) and Stochastic Coherent Adaptive Large Eddy Simulation (SCALES). Both of these approaches come from the realization of the deficiency of the current large eddy simulation (LES) approach, which, at best, relies on a zonal grid adaptation strategy to attempt to minimize the computational cost. This mesh is typically flow dependent and chosen in a somewhat subjective manner. While an improvement over the use of regular grids, classical LES methods fail to resolve the high wavenumber components of spatially intermittent coherent eddies that typify turbulent flows, thus, neglecting valuable physical information. At the same time, the flow is over-resolved in regions between the coherent eddies, consequently wasting computational resources. The SCALES approach addresses the shortcomings of LES by using a dynamic grid adaptation strategy that is able to resolve and track the most energetic coherent structures in a turbulent flow field. This corresponds to a dynamically adaptive local filter width. Unlike CVS, which is able to recover low order statistics with no subgrid scale stress model, the higher compression used in SCALES necessitates to model the effect of the unresolved subgrid scale (SGS) stresses. These SGS stresses are approximated using novel localized dynamic models of both eddy and non-eddy viscosity types. A number of numerical experiments for decaying and forced homogeneous turbulence are presented and the results are compared with pseudo-spectral reference solutions. The agreement holds not only in terms of global statistical quantities but also in terms of spectral distribution of energy and, more importantly, enstrophy all the way down to the dissipative scales.

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