Mike Kirby

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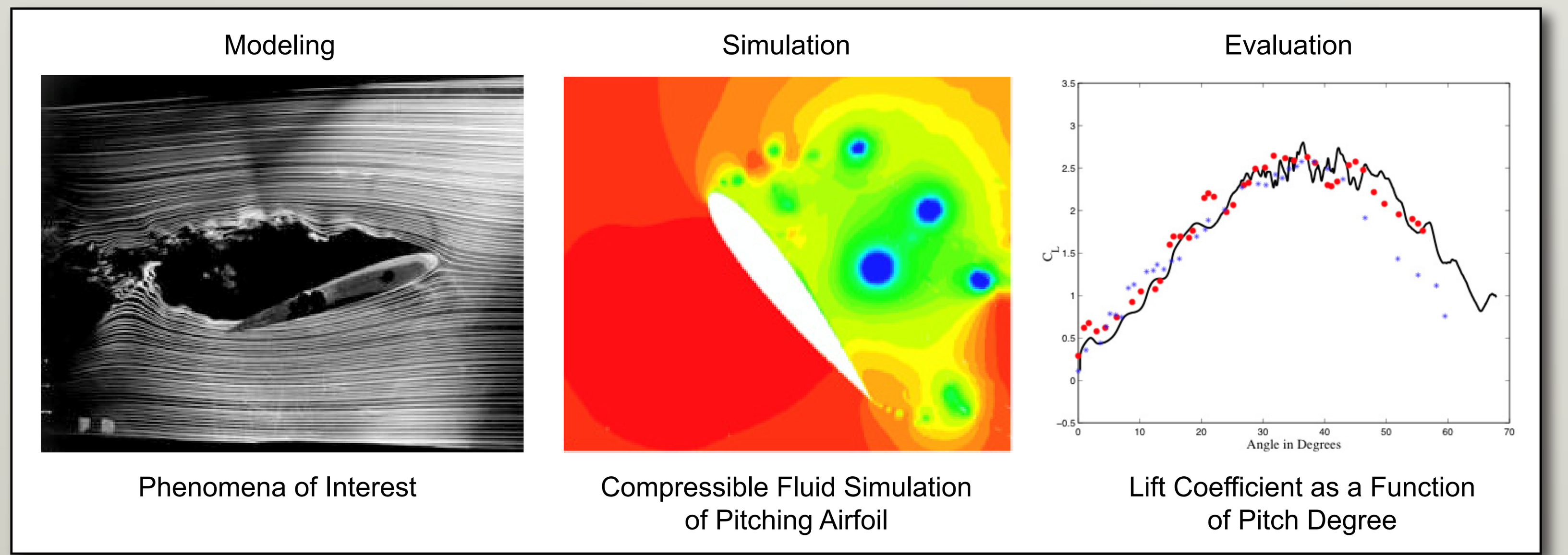
Kirby Research Group

The Scientific Computing and Visualization Research Group led by Professor Mike Kirby attempts to combine aspects of applied mathematics, computer science, and high-performance computing for solving engineering applications. Typically, mathematicians develop numerical methods constrained by a collection of assumptions that allow them to make concrete statements about their behavior. Engineers, however, often want to push the limits of these constraints and to use numerical methods beyond the initial regimes for which they were designed. Kirby's group seeks to bridge this gap—to investigate, design, and implement high-performance numerical algorithms about which some mathematical statements can concretely be made, while at the same time, employing them in regimes that are significant to the engineering community. Each project outlined below was initiated by a first-principles examination of the numerical methods that were employed, and each project negotiated the trade-off space between accuracy, fidelity, robustness, and efficiency, as dictated by the particular engineering requirements of the project.

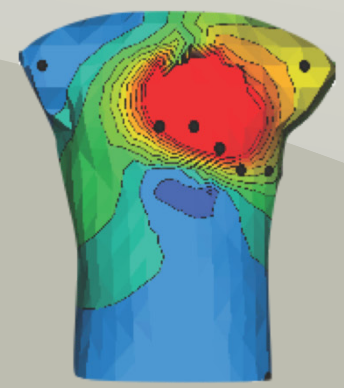


Phenomena of Interest | Compressible Fluid Simulation of Pitching Airfoil | Lift Coefficient as a Function of Pitch Degree

Quantifying Cardiac Position Sensitivity

Darrell Swenson, with Professor Rob Macleod

It is widely known that changes in heart position significantly affect body-surface potentials. While the electrocardiogram (ECG) is often employed as a diagnostic and monitoring tool for patients experiencing cardiac distress or disease, few studies have systematically evaluated the effects of heart displacement on the ECG. To carry out a comprehensive sensitivity analysis, we applied the generalized polynomial chaos-stochastic collocation method (gPC-SC) to a boundary-element formulation of the electrocardiographic forward problem. Results of the analysis identified regions on the body-surface where the potentials were especially sensitive to realistic heart motion.



ischemic epicardial potentials

RBF-Immersed Boundary Algorithms for the Simulation of Clotting

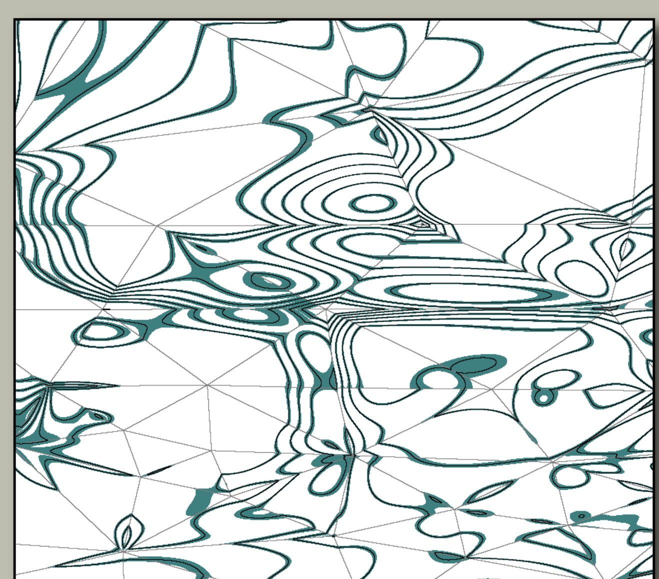
Varun Shankar

The Immersed Boundary Method (IBM) is a technique for simulating fluids and immersed, elastic solids in lockstep. In this study, we seek to extend and improve how the IBM models elastic solids. In this context, we investigate the use of Radial Basis Functions and explore their suitability for both geometric modeling and elastic-force modeling of platelets.

Accurate and Efficient Visualization of High-Order Finite Element Simulations

Blake Nelson

The majority of existing visualization techniques are optimized for data that is assumed to vary linearly between sample points. The data generated from high-order simulations, however, does not meet this requirement. Simulation scientists using this type of data must first convert their high-order data into low-order approximations before generating images, which introduces unnecessary error and inefficiency into the visualization pipeline. To avoid this, we are creating new visualization methods that use the high-order data directly and generate accurate, efficient visualizations.



Visualization of the ambiguous pixels when rendering contour lines.

Analysis and Visualization of Stochastic Simulation Solutions

Saquib Nazmus

This research focuses on problems in probabilistic uncertainty quantification and the visualization of simulation data generated from the solutions of stochastic partial differential equations. In our approach, we specifically aim to use the mathematical properties of generalized polynomial chaos (gPC) based solution fields to quantify and visualize the corresponding uncertainty through statistical and geometric means. We employ different algorithms to reconstruct isosurfaces from uncertain data, and compare the surfaces using different metrics to understand the variation between them. Currently, our work analyzes uncertain scalar fields, but we also aim to extend the methods to vector and tensor fields. The goal of this research is to create visualization methods that may convey an intuitive understanding of the underlying regions of uncertainty in simulation or experiment data, which is eventually a concern of the scientist or the engineer designing and evaluating the performance of a physical system.

GPU Parallelization of Smoothness Increasing Accuracy Conserving Filters

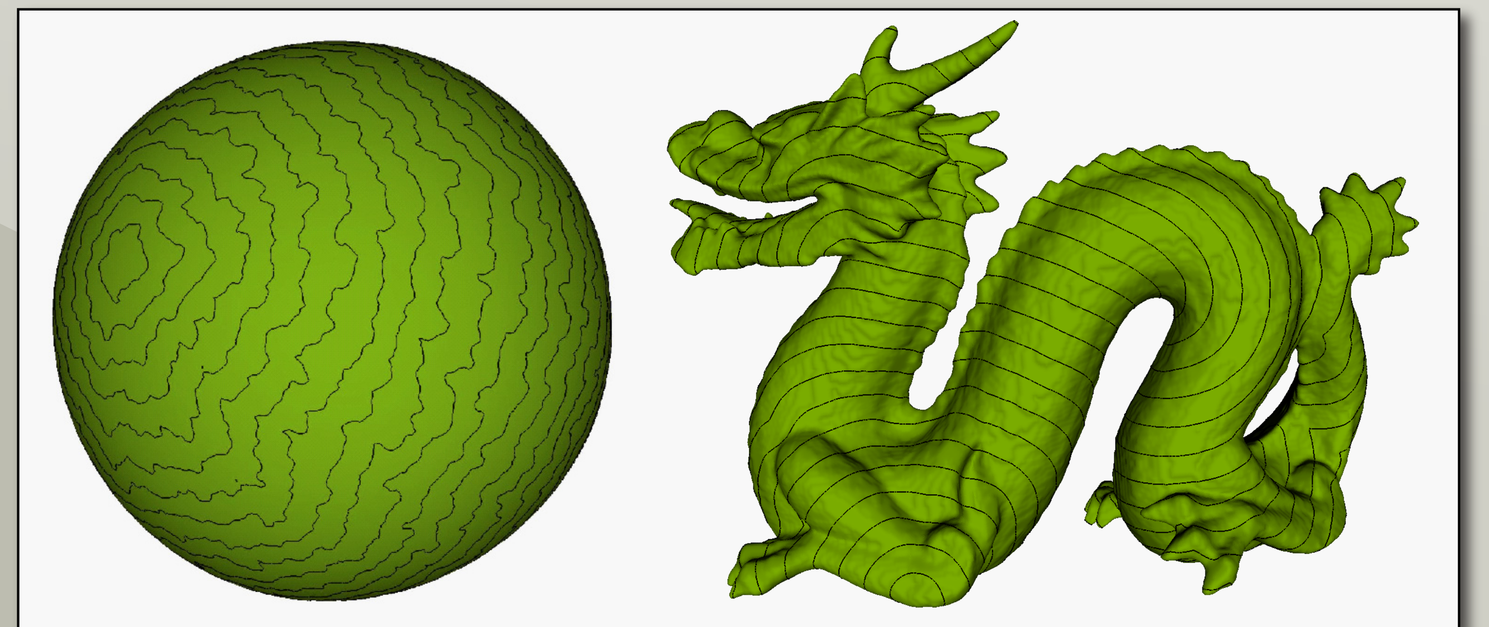
Jim King

This study explores GPU parallelization of post-processing for discontinuous Galerkin methods. Post-processing methods can be very computationally expensive for large meshes. However, they are also highly amenable to parallelization, allowing us to adapt them in an efficient way to the GPU. Smoothness-increasing, accuracy-conserving (SIAC) filters help smooth out the discontinuities between elements produced by the discontinuous Galerkin method. I have been developing post-processing algorithms which run on the GPU using NVIDIA's CUDA framework, and I'm adapting computing techniques to improves the speed of the post-processing methods. I hope to do further work on the parallelization of scientific computing problems and applications.

Eikonal Equation

Zhisong Fu, with Professors Ross Whitaker

In our recent paper, "A Fast Iterative Method for Solving the Eikonal Equation on Triangulated Surfaces" we presented an efficient, fine-grained parallel algorithm for solving the Eikonal equation (0.1) on triangular meshes. The Eikonal equation, and the broader class of Hamilton-Jacobi equations to which it belongs, ranges in application from geometric optics and seismology to biological modeling and geometric analysis. We extend the fast iterative method to solve Eikonal equations on triangulated domains on the CPU and on parallel architectures, including graphics processors. We also provide detailed descriptions of the implementations on a single CPU, a multicore CPU with shared memory, and SIMD architectures—all with comparative results against state-of-the-art Eikonal solvers.

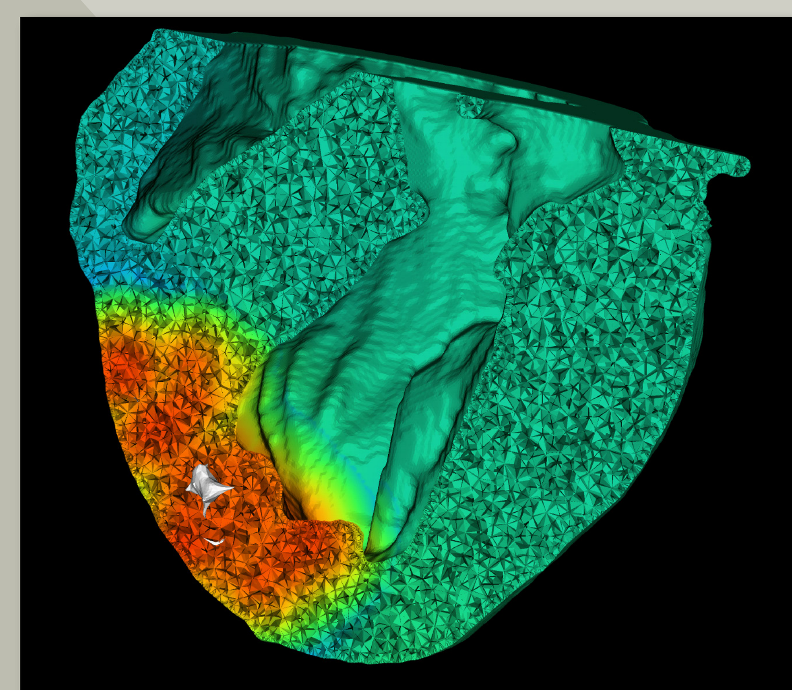


Level curves of the solutions. Left: Sphere mesh with the white noise speed function. Right: Stanford dragon with the constant speed function.

Noninvasive Diagnosis and Localization of Heart Diseases Using Body-Surface Electrocardiography

Dafang Wang, with Professors Rob Macleod and Chris Johnson

While electrocardiography (ECG) has long been established as a diagnostic tool, unprecedented gains in computing power and medical imaging technology have ushered ECG into an era of personalized healthcare. This research attempts to use body-surface ECG recordings to reconstruct the electrical activities within the heart and localize cardiac diseases such as myocardial ischemia. By combining advanced biophysical models, large-scale computer simulation, and patient-specific anatomies, this work will promote clinical diagnosis, intervention planning, and therapy delivery in modern healthcare.



Ischemic Heart Cross Section

Implementation and Comparative Study of CG and HDG Methods in 3D

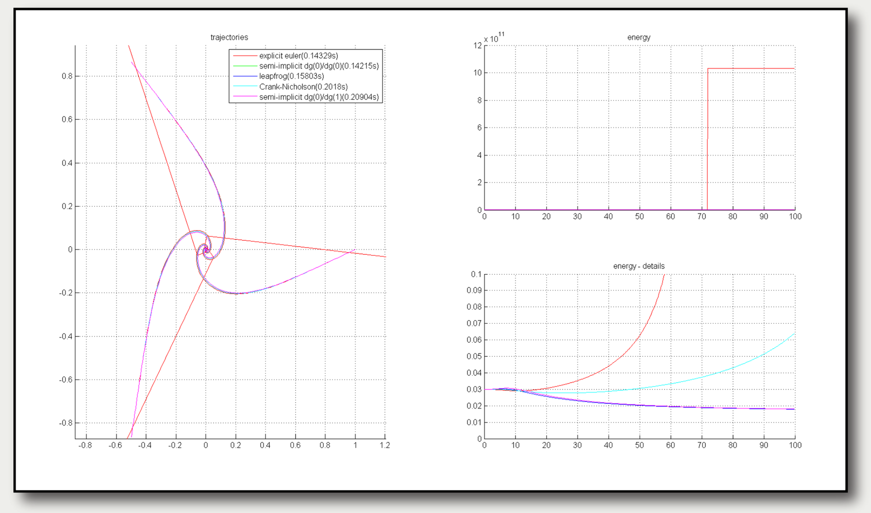
Sergey Yakovlev

Nektar++ is a publicly available, high-performance software library for performing high-order, finite-element discretizations of PDEs. This study investigates algorithmic and parallel-computing methods to equip Nektar++ to run three-dimensional, time-dependent continuous and discontinuous Galerkin simulations. This work is done in collaboration with the research group of Professor Spencer Sherwin at Imperial College London, UK.

Numerical Algorithms for Diffeomorphic Image Matching

Yungsung Kim, with Professor Sarang Joshi

In recent years, the data size of bio-medical images has grown exponentially. As a consequence, processing those images requires a memory area that far exceeds the capacity of conventional computing algorithms. This research explores various computing algorithms in the context of bio-medical and image-matching problems, identifies best suitable algorithms and their control parameters, and finally, economizes image processing to suit conventional memory capacities.

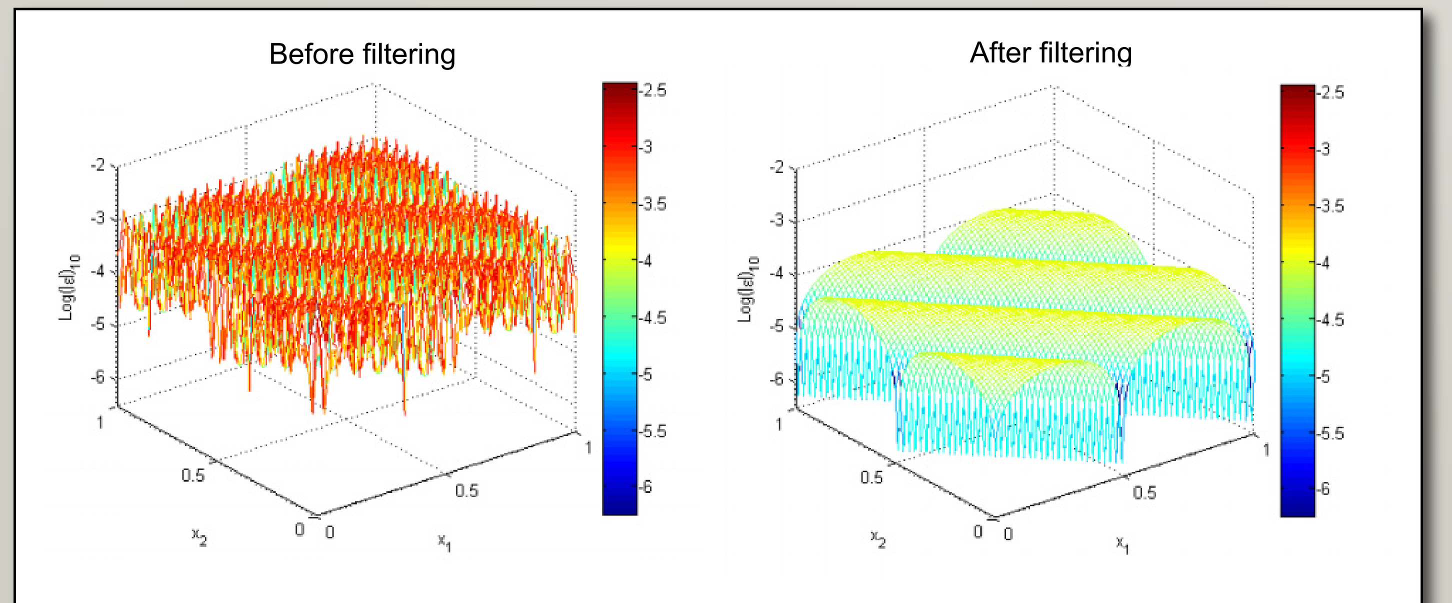


Trajectories (left plot): plots numerical solutions of a Hamiltonian system which has three particles (landmarks). energy (both right plots): plots energy-conservation characteristics of each numerical methods.

Filtering for Visualization

Hanieh Mirzaee

This research focuses on smoothness-increasing, accuracy-conserving (SIAC) methods for filtering discontinuous Galerkin (DG) solutions. The discontinuous Galerkin method maintains heightened levels of interest within the simulation community due to its discretization flexibility. SIAC filters eliminate discontinuities in DG solutions and economize data for visualization purposes. The goal is to develop techniques to reduce the computational costs of integrations in SIAC filters. Additionally, these techniques are used in higher dimensions that employ complicated mesh structures and in the calculation of iso-surfaces.



Point-wise errors in log scale for constant coefficient advection equation over a structured DG triangular mesh.

Collaborations and Funding

- Development of High-Order Finite Element Code Nektar++, Spencer Sherwin, Imperial College, London UK
- Visualization of High-Order Finite Element Methods, Robert Haimes, Massachusetts Institute of Technology, Funded by ARO
- Smoothness-Increasing Accuracy-Conserving (SIAC) Filters for Post-Processing Unstructured Discontinuous Galerkin Fields, Jennifer Ryan, Delft Institute of Technology, The Netherlands. Funded by AFOSR
- Multiscale Computational Modeling of Blood Clotting, Aaron Fogelson, University of Utah, Funded by NIH
- Unconventional and Renewable Energy Research Utilizing Advanced Computing Simulations, Chris Johnson, Martin Berzins and Ross Whitaker, University of Utah, Funded by DOE-NETL
- Analysis and Visualization of Stochastic Simulation Solutions, Dongbin Xiu, Purdue University, Funded by NSF

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