2007-08 Program on Random Media Opening Workshop
September 23-26, 2007

SPEAKER ABSTRACTS

Liliana Borcea
Rice University
Department of Computational and Applied Mathematics
borcea@caam.rice.edu

"Imaging in Random Media and Optimal Waveform Design"

In array imaging, we wish to find strong reflectors in a medium, given measurements of the time traces of the scattered echoes at a remote array of receivers. I will discuss array imaging in cluttered media, modeled with random processes, in regimes with significant multipathing of the waves by the inhomogeneities in the clutter. In such regimes, the echoes measured at the array are noisy and exhibit a lot of delay spread. This makes imaging difficult and the usual technique give unreliable, statistically unstable results. I will present a coherent interferometric imaging approach for random media, which exploits systematically the spatial and temporal coherence in the data to obtain statistically stable images. I will discuss the resolution of this method and its statistical stability and I will illustrate its performance with numerical simulations. I will also discuss optimal waveform design for image enhancement in random media.

John Cushman
Purdue University
Department of Mathematics and Department of Earth and Atmospheric Sciences
jcushman@purdue.edu

"A Universal Field Equation for Dispersion: Turbulence, Porous Media, Nano-films and Microbial Dynamics"

Nearly fifty years ago Zwanzig posited that a wave-vector and frequency dependent 2nd-order diffusion tensor, tensor-producted with the Fourier-mode of the gradient of concentration, was the appropriate constitutive law for diffusion when the space time-scales are pre-asymptotic. Here we present a generalization of his pioneering idea, along with the appropriate background analysis, and apply the concept to four disparate topics on disparate scales. MD and MC simulations are employed with the theory to examine

phase transitions and stick-slip phenomena in confined nano-films, 3d-PTV experiments are employed with the theory to look at pre-asymptotic dispersion in porous media, a Levy-velocity process is used to study Richardson and related atmospheric super-diffusions, and renormalized Levy-trajectories are used to model microbe motility. Each of these, as well as many other dispersive processes, obeys the same form of a field equation.

Karen Daniels
North Carolina State University
Department of Physics
karen_daniels@ncsu.edu

"Sound Propagation and Force Chains in Granular Materials"

One prominent feature of granular materials is the highly nonuniform distribution of internal forces, in which a small fraction of the particles carry a large fraction of the total force, arranged in roughly colinear structures. To understand which signatures of this "force chain" network are present in acoustic signals, we perform experiments in 2D arrays of photoelastic particles and examine the spatio-temporal dynamics due to sound waves. Because a photoelastic disk viewed through crossed polarizers has a brightness pattern indicative of its stress state, such aggregations allow measurement of the forces and positions for all particles. In our experiments, we send discrete pulses through granular packings, and simultaneously make optical measurements of the changes in the force chain network using a digital high speed camera and use biaxial accelerometers of similar size and mass to the photoelastic particles to provide the amplitude and speed of the response. We examine the influence of the force chain network on the propagation properties, and the differences in signals parallel and perpendicular to the direction of the driver motion. We observe differences in the speed, amplitude, and detailed response, with faster/stronger signals occurring along stronger force chains. In addition, we make time-reversed measurements within the material.

Weinan E
Princeton University
Department of Mathematics
weinan@math.princeton.edu

Abstract: TBA

Bjorn Engquist
University of Texas-Austin
Department of Mathematics
engquist@math.utexas.edu

Interface tracking in connection to multiscale processes Invited Abstract: We will consider interface dynamics driven by local microscale processes and compare adaptive mesh refinement to heterogeneous multiscale approximations. In the latter case the microscale simulation is done selectively in space and time and coupled to a numerical interface tracking method. Applications to combustion and epitaxial growth will be discussed.

Lisa Fauci
Tulane University
Department of Mathematics
fauci@tulane.edu

"Interface Problems Inspired by the Biofluidmechanics of Reproduction"

Complex fluid-structure interactions are central to mammalian fertilization. Motile spermatozoa, muscular contractions of the uterus and oviduct, as well as ciliary beating generate forces that drive fluid motion. At the same time, the dynamic shapes of these biostructures are determined by the fluid mechanics. In many of these systems, the fluid exhibits non-Newtonian characteristics. While much progress has been made in the development of mathematical models and numerical methods for fluid-structure interactions in a Newtonian fluid, much work needs to be done in the case of complex fluids. In this talk we will give an overview of the classical work in fluid dynamics that has been applied to reproduction. We will also present recent computational models, based upon an immersed boundary framework, that promise to provide insight into these complex, coupled dynamical systems.

John Fricks
Penn State University
Department of Statistics
fricks@stat.psu.edu

"Diffusion of Particles in Biofluids"

High speed microscopy has enabled experimentalists to track individual microscopic particles in complex biofluids. While traditional rheology can give insights into the bulk properties of these fluids, it may not be sufficient for understanding the diffusion of the microscopic particle in the biofluid including the interaction between the surface of the particle and the fluid. These microscopy experiments attempt to understand diffusion through the paths of individual particles. As an example of such diffusion, an experiment will be introduced in which microbeads are tracked in human lung mucus (in vitro) from both healthy patients and patients with cystic fibrosis with the goal of understanding the diffusion of microscopic pathogens. The dynamics of a bead is modeled using the generalized Langevin equations. A maximum likelihood method to estimate parameters for a certain class of generalized Langevin equations will be presented along with an improved stochastic simulation method for this class of models.

Tom Hou
California Institute of Technology
Department of Applied and Computational Mathematics
hou@acm.caltech.edu

"On the Stabilizing Effect of Convection in 3D Incompressible Flows"

Convection and incompressibility are two important characteristics of incompressible Euler or Navier-Stokes equations. In 3D flows, the convection term is responsible for generating the vortex stretching term, which leads to large growth of vorticity and possibly a finite time blowup of the solution. Here we reveal a surprising nonlinear stabilizing effect that the convection term plays in regularizing the solution. Our study shows that the convection term tends to generate a locally anisotropic structure or flattening of the solution in the region of maximum vorticity, which could

weaken or even deplete the nonlinearity, thus prevent a finite time blowup of the solution. We also discuss the difference of the stability properties between the full 3D incompressible flow and the interfacial flow. The implication of the stochastic formulation of the 3D incompressible Navier-Stokes equations is also addressed.

Sam Kou
Harvard University
Department of Statistics
kou@stat.harvard.edu

"Fractional Gaussian Noise, Subdiffusion and Stochastic Networks in Biophysics"

In recent years, single-molecule experiments have emerged as a powerful means to study biophysical/biochemical processes; many new insights are obtained from this single-molecule perspective. One phenomenon recently observed in single-molecule biophysics experiments is subdiffusion, which largely departs from the classical Brownian diffusion theory. In this talk, by introducing fractional Gaussian noise (i.e., the derivative of fractional Brownian motion) into the generalized Langevin equation, we propose a model to describe the subdiffusion. We will study the analytical properties of the model, compare the model predictions with experiments, look at its connection with stochastic networks, and explore the implications of the model on enzyme reactions.

Karl Kunisch
University of Graz, Austria
Department of Mathematics
karl.kunisch@uni-graz.at

"Semi-smooth Newton Methods for Imaging and Interface Problems"

Imaging and interface problems typically contain nondifferentiability phenomena which appear to rule out second order - and specifically Newton type-methods for numerical realisations. Over the last years, semi-smooth Newton methods, combined with proper smoothing and path-following techniques in a function space setting have been developed to efficiently solve such problems. They are typically superlinearly convergent and mesh-independent.

Randy LeVeque
University of Washington
Department of Applied Mathematics
rjl@amath.washington.edu
"Shock Wave Propagation in Tissue and Bone"

Abstract: TBA

Fanghua Lin
New York University
Courant Institute of Mathematical Sciences
linf@cims.nyu.edu

Abstract: TBA

John Lowengrub
University of California-Irvine
Department of Mathematics
lowengrb@math.uci.edu

"Multiscale Models of Solid Tumor Growth and Angiogenesis: Effect of the Microenvironment"

Stanislav Molchanov
University of North Carolina-Charlotte
Department of Mathematics and Statistics
smolchan@uncc.edu

"Phase Transitions and the Limit Theorems for the Long Polymers Chains"

Random walk in the presence of the localized potentials is a popular model for the explanation of the phase transitions in the biopolymers (say, albumin in the egg whites). The corresponding models were studied by the school of I.Lifshitz in the 60th and 70th at the physical level. The potential can be stationary in time (homopolymers) or randomly fluctuating in time (for instance, heteropylimers in DNA). In both cases we have to study the asymptotics of the solutions of the appropriate parabolic problem with compactly supported potentials. The asymptotics with respect to temperature demonstrate the phase transition from the globular to the diffusive state of the polymer. The talk will present the recent works in this area and the review of the open problems.

Geoge Papanicolaou
Stanford University
Department of Mathematics
papanico@math.stanford.edu

"Imaging in Random Media and Optimal Illumination"

I will discuss the mathematical problem of optimally illuminating an object for imaging by an array or by distributed sensors, in a random medium. In a certain regime of parameters and for a special class of objects in a homogeneous medium, this can be done by using spheroidal wave functions. In general situations one must use algorithms that optimally image the object by detecting its edges. Such algorithms are very different from the ones that maximize the energy of the signals received by the array so as to enhance detectability. I will analyze and compare the two types of algorithms.
(Joint work with L. Borcea, C. Tsogka, G. Derveaux and F. Guevara-Vasquez.)

Gretar Tryggvason
Worcester Polytechnic Institute
Department of Mechanical Engineering
gretar@wpi.edu

"Studying the Dynamics of Heterogeneous Continuum Systems using DNS"

Systems where continuum models provide an accurate description of the system behavior, but where there is a large difference between the system scale and the smallest continuum scales are found in a wide range of industrial applications as well as in Nature. Multiphase flows, including bubbly flows and boiling, sprays, and solid suspensions, are common examples. Bridging the gap and using our understanding of the small scales to predict the behavior at the system scale is one of the grand challenges of science. Direct Numerical Simulations (DNS) of the evolution of sufficiently small systems so that all continuum scales are fully resolved, yet large enough so that interactions of structures of different scales can take place, are increasingly playing a central role in studies of the dynamics of heterogeneous continuum systems. Here, we will discuss in some details recent results for wall-bounded bubbly flows, where DNS have yielded new and unexpected insight into the subtle importance of accurately accounting for bubble deformability. The development of numerical methods for more complex multiphase flows, where it is necessary to include thermal and/or electric fields and phase changes, is also underway and a few examples of the influence of electric fields on the dispersion of drops in a channel flow, the effect of flow on the growth of microstructures during solidification, and boiling are presented.

Gunther Uhlmann
University of Washington
Department of Mathematics
gunther@math.washington.edu

"The Scattering Relation and the Broken Scattering Relation in Inverse Problems"

The scattering relation measures the exit points of a medium and directions of ray paths (geodesics) of waves, given its entrance point and entrance direction as well as the travel time. The broken scattering relation measures the exit point and direction of once broken (reflected) ray paths and the travel time. The inverse problems we consider consist of determining the index of refraction of the medium by knowing the scattering relation or the broken scattering relation.

In this talk we will describe some recent results obtained about both inverse problems. This is joint work with L. Pestov and P. Stefanov (scattering relation) and Y. Kurylev and M. Lassas (broken scattering relation). We will also describe several inverse problems arising in geophysics and medical imaging where the scattering relation and broken scattering relation can be determined from boundary observations.

.

Eric Vanden-Eijnden
New York University
Courant Institute of Mathematical Sciences
eve2@cims.nyu.edu

Tutorial: Stochastic and Multiscale Relations

Wojbor Woyczynski
Case Western Reserve University
Department of Statistics
waw@case.edu

"Classical and Fractional Models in Nonlinear Porous Media"

The talk will present an overview of the classical nonlinear porous medium equation as well as the more recent efforts at developing nonlinear fractional models that would permit non-classical scaling behavior, different from Barenblatt asymptotics. Mathematical underpinnings as well as computational Monte Carlo-style methods via interacting particle systems will be discussed.

Jack Xin
University of California-Irvine
Department of Mathematics
jxin@math.uci.edu

Tutorial: Reaction-Diffusion Fronts in Random Flows

In this expository talk, we shall review the analysis of front solutions of stochastic reaction-diffusion-advection equations using large deviation and maximum principle approaches. We begin with a background of such problems arising in turbulent combustion and basic probabilistic tools, and end with open problems on fronts (interfaces) in random media.

Lucy Zhang
Rensselaer Polytechnic Institute
Department of Mechanical, Aerospace, and Nuclear Engineering
zhanglucy@rpi.edu

Abstract: TBA