UNIVERSITY OF MICHIGAN
Department of Mathematics

Seminar & Events Bulletin: Applied Interdisciplinary Mathematics

01-01-2013 to 06-30-2013

Friday, January 11, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Bogdan Vioreanu (University of Michigan) *Spectra of multiplication operators as a numerical tool* -- 1084 East Hall

Friday, January 18, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Jean M.-S. Lubuma (University of Pretoria, South Africa) *On nonstandard finite-difference schemes in biosciences* -- 1084 East Hall

Friday, January 25, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Charlie Doering (University of Michigan) *Features of fast living: on the weak selection for longevity in degenerate birth-death processes* -- 1084 East Hall

Friday, February 01, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Shravan Veerapaneni (University of Michigan) *A fast algorithm for spherical grid rotations and its application to singular quadrature* -- 1084 East Hall

Friday, February 08, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Pej Rohani (Ecology and Evolutionary Biology, University of Michigan) *Unmasking the interaction between influenza and bacterial pneumonia* -- 1084 East Hall

Friday, February 15, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Deniz Akcabay (Naval Architecture and Marine Engineering, University of Michigan) *Cantilever beams in axial flows: flutter Instabilities, post-critical dynamics, scaling laws, and energy harvesting applications* -- 1084 East Hall

Friday, February 22, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Jun Zhang (Psychology, University of Michigan) *Topological characterization of interval and semi-orders* -- 1084 East Hall

Friday, March 01, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- John Boyd (Atmospheric, Oceanic, and Space Sciences, University of Michigan) *Hermite function interpolation on a finite interval and the interrelationships of polynomial and radial basis functions* -- 1084 East Hall

Friday, March 15, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Andrew Wynn (Imperial College) *Optimal Mode Decomposition: a new technique to analyse fluid flow data* -- 1084 East Hall

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3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Aaron King (Ecology and Evolutionary Biology, University of Michigan) *Using mathematics to explain and forecast infectious disease dynamics* -- 1084 East Hall

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3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Brian Arbic (Earth and Environmental Sciences, University of Michigan) *Impact of stratification and climatic perturbations to stratification on barotropic tides* -- 1084 East Hall

Friday, April 05, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Denis Zorin (Courant Institute of Mathematical Sciences, New York University) *O(N) direct solver for integral equations on 2D domains* -- 1084 East Hall

Friday, April 12, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Yuan Young (New Jersey Institute of Technology) *Nonlinear dynamics of a lipid membrane under a DC field* -- 1084 East Hall

Friday, April 19, 2013	
3:00pm-4:00pm	**Applied Interdisciplinary Mathematics** -- Martin Strauss (University of Michigan) *Some open problems in sustainable energy* -- 1084 East Hall

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Abstracts

Applied Interdisciplinary Mathematics
Friday, January 11, 2013, 3:00pm-4:00pm
1084 East Hall
Bogdan Vioreanu (University of Michigan)
Spectra of multiplication operators as a numerical tool

We introduce a numerical procedure for the construction of interpolation and quadrature formulae on bounded regions in the plane. The construction is based on the behavior of spectra of certain multiplication operators and leads to nodes which are inside a prescribed region in R^2 . The resulting interpolation schemes are numerically stable and the quadrature formulae have positive weights and almost (but not quite) optimal numbers of nodes. The performance of the algorithm is illustrated by several numerical examples and applications.

Applied Interdisciplinary Mathematics
Friday, January 18, 2013, 3:00pm-4:00pm
1084 East Hall
Jean M.-S. Lubuma (University of Pretoria, South Africa)
On nonstandard finite-difference schemes in biosciences

Biological processes that arise in science are very complex. A lot of effort has been and is being made to build differential models that aim at elucidating these phenomena. However, these models cannot be completely solved by analytic techniques. Consequently, reliable numerical simulations are of fundamental importance in gaining some useful insights on the solutions of the differential equations. Of paramount importance for the involved dynamical systems is the design of numerical simulations that replicate their underlying dynamics such as the positivity of solutions, the dissipativity of the systems, the conservation laws, the stability of equilibria.

In this talk we design, analyze and implement nonstandard finite difference (NSFD) schemes for some differential models in biosciences. The NSFD schemes are reliable in three directions. They are topologically dynamically consistent for one-dimensional models. They can replicate the global asymptotic stability of the disease-free equilibrium of the MSEIR model in epidemiology whenever the basic reproduction number is less than 1. They preserve the positivity and boundedness property of solutions of advection-reaction and reaction-diffusion equations.

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Applied Interdisciplinary Mathematics
Friday, January 25, 2013, 3:00pm-4:00pm
1084 East Hall
Charlie Doering (University of Michigan)
Features of fast living: on the weak selection for longevity in degenerate birth-death processes

Deterministic descriptions of dynamics of competing species with identical carrying capacities but distinct birth, death, and reproduction rates predict steady state coexistence with population ratios depending on initial conditions. Demographic fluctuations described by a Markovian birth-death model break this degeneracy. A novel large carrying capacity asymptotic theory confirmed by conventional analysis and simulations reveals a weak preference for longevity in the deterministic limit with finite-time extinction of one of the competitors on a time scale proportional to the total carrying capacity. This is joint work with Yen Ting Lin and Hyejin Kim, published in Journal of Statistical Physics 148, 646-662 (2012).

Applied Interdisciplinary Mathematics
Friday, February 01, 2013, 3:00pm-4:00pm
1084 East Hall
Shravan Veerapaneni (University of Michigan)
A fast algorithm for spherical grid rotations and its application to singular quadrature

We present a fast and accurate algorithm for evaluating singular integral operators on smooth surfaces that are globally parametrized by spherical coordinates. Problems of this type arise, for example, in simulating Stokes flows with particulate suspensions and in multi-particle scattering calculations. For smooth surfaces, spherical harmonic expansions are commonly used for geometry representation and the evaluation of the singular integrals is carried out with a spectrally accurate quadrature rule on a set of rotated spherical grids. We propose a new algorithm, nearly optimal in computational complexity, that interpolates function values on the rotated spherical grids via hybrid nonuniform Fast Fourier Transforms.

Applied Interdisciplinary Mathematics
Friday, February 08, 2013, 3:00pm-4:00pm
1084 East Hall
Pej Rohani (Ecology and Evolutionary Biology, University of Michigan)
Unmasking the interaction between influenza and bacterial pneumonia

Polymicrobial infections, whereby transmission and pathogenicity of one agent are affected by interactions with others, are increasingly recognized. An important putative manifestation of this phenomenon involves pneumococcus bacteria and their role during influenza pandemics and seasonal epidemics. While experiments in animal models have unequivocally demonstrated presence of influenza-pneumococcus interaction, epidemiological support for an association in humans remains unclear. In this talk, I will describe how using high-resolution case reports, a mechanistic transmission model, and a likelihood-based inference framework, we have characterized the nature, timing and magnitude of the interaction. We find support for a strong but short-lived interaction, with influenza infection increasing susceptibility to pneumococcal pneumonia ~100-fold. Given the nature and the timescale of the interaction, the ability to detect any association from epidemiological data may depend on the variability in the magnitude of influenza outbreaks. Further, I will explain the implications of these results by studying a within-host model of pathogenesis, characterized as coupled delay differential equations.

Applied Interdisciplinary Mathematics
Friday, February 15, 2013, 3:00pm-4:00pm
1084 East Hall
Deniz Akcabay (Naval Architecture and Marine Engineering, University of Michigan)
Cantilever beams in axial flows: flutter Instabilities, post-critical dynamics, scaling laws, and energy harvesting applications

Structures may lose their stability if exposed to external flows; a very famous example of this is the collapsed Tacoma Narrows Bridge in 1940. Accordingly, proper designs should ensure the stability of exposed structures to avoid failure or permanent deformations. However, there are many cases where flow exerted deformations on solids might be desired. Examples include energy harvesting applications where the fluid induced deformations might be converted to electricity through electroactive polymers (EAP), as well as the use of flexible lift-generating surfaces, such as propeller blades, hydrofoils, that might perform better in off-design operating conditions than their rigid counterparts.
The first part of this talk presents the current results of our studies on the dynamics of two-dimensional cantilevered beams in incompressible, viscous fluid flows. The solution method involves solving the Navier-Stokes equations for the fluid using a fractional-step method and the Kirchhoff-Love equations for the beam and coupling the fluid and solid dynamics with Peskin's Immersed Boundary method. The results include identifying the critical non- dimensional parameters, identifying the flutter stability boundary, and classifying the different vorticity shedding patterns and beam oscillation modes as a function of these critical parameters. The second part of this talk focuses on piezoelectric cantilever beams and their use to harvesting energy under flutter conditions. The electromechanical coupling brings on two additional critical parameters in terms of a non-dimensional energy conversion and electric damping coefficient. The talk will conclude on assessing the feasibility of applying two-different scaling laws onto this system: the Reynolds number (Re) and Mach number (Ma) scale. It will be shown that designing reduced-scale experiments with Re scaling brings various difficulties (impossibilities) mostly due to material selection issues, while the Ma scaling is very favorable for moderate to high Re operating conditions. This is a joint work with Prof. Yin Lu Young.

Applied Interdisciplinary Mathematics
Friday, February 22, 2013, 3:00pm-4:00pm
1084 East Hall
Jun Zhang (Psychology, University of Michigan)
Topological characterization of interval and semi-orders

The concept of semi-order was introduced by Luce (1956) to capture the intransitive indifference relation prevalent in social and behavioral sciences. Its numerical representation manifests a threshold structure (Scott-Suppes representation) characteristic of comparative judgments in psychophysics. Later, it became known that semi-order (and its fixed-threshold representation) was a special case of the more general interval order (and its interval graph representation) as succinctly characterized by Fishburn. In this talk, we first show how interval order induces a "nesting" relation, a partial order itself. A set with a semi-order on it is then precisely an interval-ordered set that does not contain any nesting among its elements. When nesting occurs, an interval-ordered set has two lexicographic orders, which agree on the subset of elements that do not nest one-another. Next, we investigate topologies on interval-order sets, and construct a topology (based on the notion of upper- and lower-holdings) that allows us to relate topological axiomatic separations to order relations. Specifically, under our proposed topology, two distinct elements are (i) nested iff they are T0 but not T1 separated; (ii) indifferent but non-nested iff they are T1 but not T2 separated; (iii) comparable iff they are T2 separated. Therefore, we achieve topological characterization of pairwise relations of all points in an interval-order set in terms of their topological separability.

(Work done with student collaborator Yitong Sun)

Applied Interdisciplinary Mathematics
Friday, March 01, 2013, 3:00pm-4:00pm
1084 East Hall
John Boyd (Atmospheric, Oceanic, and Space Sciences, University of Michigan)
Hermite function interpolation on a finite interval and the interrelationships of polynomial and radial basis functions

Radial basis functions (RBFs) are class of spectral basis functions that often succeed where polynomial interpolation fails. For example, RBFs can be successfully applied to irregular domains punctuated by islands and peninsulas on a "truncated uniform grid". This is constructed by embedding irregular domain in a rectangle, constructing uniform grid with a rectangle, then deleting all points which lie outside the chosen irregular domain. Multivariate polynomial interpolation is a complete disaster on such a grid because it usually diverges due to the Runge phenomenon. But what is the magic? What is the secret of RBFs?

In previous work, I showed that the RBF cardinal functions for five different species on an unbounded, uniform grid were, to a high degree of accuracy, the product of the sinc function, $\sin(\pi x)/(\pi x)$, with $(\pi x)(\rho \sinh([\pi/\rho]x)$. In this sense, Gaussian, sech, inverse quadratic, multiquadric and inverse multiquadric RBFs are really all the same. Equally significant, this analysis shows that RBF cardinal functions are *spatially localized*, decaying exponentially away from their peak, in contrast to the sinc cardinal functions, which decay only as $1/|x|$.

Extending these studies shows that RBF cardinal functions on a finite uniform grid are, to a high degree of approximation, the product of polynomial cardinal functions with a Gaussian. This suggests approximating functions on a finite interval by the product of a Gaussian with a polynomial. This is equivalent to a basis of Hermite functions, usually employed only for an unbounded domain. The Runge phenomenon, which is the divergence of interpolation on a finite, uniform grid, is greatly reduced. Although motivated by similarities to radial basis functions, the Hermite function interpolants are superior in accuracy, condition number and efficiency in much of the numerical parameter space. In particular, no matrix inversion is required.

Applied Interdisciplinary Mathematics
Friday, March 15, 2013, 3:00pm-4:00pm
1084 East Hall
Andrew Wynn (Imperial College)
Optimal Mode Decomposition: a new technique to analyse fluid flow data

Many techniques exist to extract coherent information from a large sample of flow-field data such as an ensemble of PIV snapshots. Examples include Proper Orthogonal Decomposition, introduced to the fluids community in the 1960s, and Dynamic Mode Decomposition (DMD), developed by Schmid in 2010. Such techniques identify intrinsic mode shapes from the data set which can be used, for example, as a basis to construct a Galerkin approximation for the underlying system.

In this talk a new modal decomposition technique, Optimal Mode Decomposition, is presented and it is shown that it can be viewed as an improvement to and generalization of DMD. For a given dimension, the technique provides the optimal (in a sense to be defined in the talk) linear approximation to data's evolution by a system of that dimension. Such low-order flow representations are important, for example, if a control system is to be designed to influence the flow.

Applied Interdisciplinary Mathematics
Friday, March 22, 2013, 3:00pm-4:00pm
1084 East Hall
Aaron King (Ecology and Evolutionary Biology, University of Michigan)
Using mathematics to explain and forecast infectious disease dynamics

Stochastic dynamical systems are extremely useful as concise expressions of biological hypotheses. When long time series data are available, they can be used to evaluate these hypotheses, but doing so rigorously is a hard mathematical problem. I'll describe recent work showing how this problem can be effectively solved and highlight some results that change our understanding of the basic ecology of cholera. I'll also present some work demonstrating how stochastic dynamical systems models can be used to provide effective forecasts of severe cholera outbreaks.

Applied Interdisciplinary Mathematics
Friday, March 29, 2013, 3:00pm-4:00pm
1084 East Hall
Brian Arbic (Earth and Environmental Sciences, University of Michigan)
Impact of stratification and climatic perturbations to stratification on barotropic tides

As is well known, tides in a stratified system include a baroclinic, or internal, mode characterized by relatively short horizontal scales and large interfacial displacements at depth. We show here that the introduction of stratification into global numerical tide models changes the large-horizontal scale, or barotropic, tide as well, typically by about 1-5%. Motivated by the impact of stratification on the barotropic tide, we then show that perturbations to the oceanic stratification yield further changes in both the barotropic and baroclinic components of surface tidal elevations. An analytical model of tides in a two-layer system also shows that stratification and perturbations to stratification impact the barotropic as well as baroclinic tides. Taken together, the numerical and analytical results therefore suggest that climatic perturbations to oceanic stratification may contribute to the secular changes in tides seen in tide gauge observations taken over the last century or so. As an aside we note that the analytical tide model shown here is in some ways more general than analytical models of tidal conversion since in our model the entire tidal solution is developed from a given astronomical tidal forcing, whereas in the latter the barotropic tide is taken as a given.

This will be a "tag-team" presentation by Prof. Arbic and AIM PhD student Alfredo Wetzel.

Applied Interdisciplinary Mathematics
Friday, April 05, 2013, 3:00pm-4:00pm
1084 East Hall
Denis Zorin (Courant Institute of Mathematical Sciences, New York University)
O(N) direct solver for integral equations on 2D domains

Most commonly used solvers for boundary integral equations are iterative, using FMM-accelerated matrix-vector multiplication. While these methods are efficient in many contexts, examples of problems that can be challenging to iterative methods include Fredholm equations of the first kind, elasticity problems on geometrically complex domains with thin features, and scattering problems near resonances -- problems with relatively poor conditioning. Direct solvers are a promising alternatives in these contexts, as well as in cases when the same equation needs to be solved with different right-hand sides.

We present an efficient direct solver for integral equations, reaching practical O(N) performance for a broad range of problems. The solver is based on a hierarchical compression method previously developed for boundary integral equations on curves. While a direct extension of the method to planar domains has asymptotic cost is O(N^{3/2}), we demonstrate that the method can be reformulated in a way that an additional level of compression is applied to operators involved in the algorithms. All stages of the resulting direct solver have optimal O(N) complexity, as demonstrated by numerical examples and theoretical analysis . The computational examples further demonstrate good practical performance in terms of both speed and memory usage, as compared to existing state-of-the-art direct solvers: for example, even problems involving 10^{7} unknowns can be solved to precision 10^{-10} using a simple Matlab implementation of the algorithm executed on a single core.

This is joint work with E. Corona and P.-G. Martinsson.

Applied Interdisciplinary Mathematics
Friday, April 12, 2013, 3:00pm-4:00pm
1084 East Hall
Yuan Young (New Jersey Institute of Technology)
Nonlinear dynamics of a lipid membrane under a DC field

Cells are enveloped by a lipid membrane, which is impermeable to ions and acts as a capacitor when an electric field is applied. In this work we present a long-wave model for the nonlinear dynamics of a planar (unsupported) lipid membrane under a DC field. The lipid membrane is modeled as an interface with a constant area. The governing equations for the non-linear long-wave dynamics are derived under different conditions. Analysis on the equilibrium profile shows the existence of multiple equilibrium profiles. Numerical simulations of the nonlinear dynamics illustrate various novel behaviors, and elucidate the importance of charge distribution on the membrane. We will also examine the possible effects of tangential electric field on the membrane dynamics.

This work is a collaboration with Michael Miksis (Northwestern University) and Shravan Veerapaneni (University of Michigan, Ann Arbor).

Applied Interdisciplinary Mathematics
Friday, April 19, 2013, 3:00pm-4:00pm
1084 East Hall
Martin Strauss (University of Michigan)
Some open problems in sustainable energy

The topic of sustainable energy is timely and important, but extremely broad. There are opportunities for researchers of differing backgrounds to make substantial contributions with great potential impact.

In this talk, we survey a few topics of interest to mathematicians and computer scientists. In a "smart" electricity grid, the grid operator can sense and control not only the sources of electrical power, but also the users of electrical power. This results in a huge dynamical system with many agents. How should the operator manage the grid to maintain voltage near nominal levels and keep current and voltage in phase? What if solar and wind energy, which are much less predictable than other sources, contribute substantial power to the grid? How can a grid operator set prices to result in desired behavior? How can we safeguard the privacy and security of residential customers, when customer data is seen by others and when others can flip switches in the customer's home? If time permits, we will also consider issues outside the smart grid.