7th Annual Davis Math Conference

Schedule and Abstracts

January 12th 2017

1 Schedule

Breakfast	9:00 AM	
Opening Comments	9:25 AM	Jordan Snyder
Geometry & Topology	9:30 AM 10:00 AM	John Sullivan Eric Samperton
Analysis & Math Physics	10:30 AM 11:00 AM	Blake Temple Adam Rupe
Statistics & Optimization	11:30 AM 12:00 PM	Luis Rademacher Shuyang Ling
Lunch	12:30 PM	
Mathematical Biology	1:15 PM 1:45 PM	Sam Walcott Calina Copos
Algebra & Discrete Math	2:15 PM 2:45 PM	Anne Schilling Lily Silverstein
Department Tea	3:15 PM	

2 Abstracts

2.1 Geometry and Topology

John Sullivan

Title: TBA

Abstract: TBA

Eric Samperton

Title: Computational complexity in low-dimensional topology

Abstract:

I'll give an overview of 3-dimensional topology from the perspective of computational complexity theory. Roughly speaking, dimension 3 is the sweet spot for asking complexity theoretic questions: dimensions 2 and lower are too boring, and dimensions 4 and higher are hopelessly complex. One motivation for these questions is to push known structure theorems about 3-manifolds further, by making them as tractable as possible. Another motivation is to better understand the intersection of 3-manifold topology and quantum computation.

2.2 Analysis and Mathematical Physics

Blake Temple

Title: Shock Waves and General Relativity

Abstract:

General Relativity is the modern theory of gravity, introduced by Albert Einstein in 1915. In this theory, gravity is spacetime curvature, and the Einstein equations describe the evolution of the gravitational metric, and this determines the evolution of spacetime curvature. In Einsteins theory, mass converts into energy through the universal law $E = mc^2$, and the great elegance of his theory is that energy and the flow of energy alone create the dynamics of spacetime curvature through the Einstein equations. The Einstein equations impose conservation laws, and in the case of perfect fluids, the conservation of mass and momentum translate into the compressible Euler equations, the equations of shock wave theory. Thus the theory of shock waves enters General Relativity at the very start, simply because Einsteins equations impose conservation of energythe source of spacetime curvature. In this talk we will review authors research into the subject of shock waves and general relativity, a beautiful mathematical theory with many open problems.

Adam Rupe

Title: Computational Mechanics of Coherent Structures in Spatiotemporal Systems

Abstract:

The use of computer simulation and numerical solutions have become common for handling increasingly complex mathematical models of physical phenomena. This has been most successful in nonlinear systems where analytic solutions are scarce, as exemplified by the discovery of deterministic chaos. As attention moves to higher dimensional systems, gaining insight from numerical solutions is no longer trivial. Consistent identification of structures from data is currently an open problem in climate science, for instance. In particular, systems in which simple interactions propagate in a complicated manner to produce complex emergent behavior present serious difficulties for traditional mathematical analysis. Such difficulties are similar to those faced in the theory of computation. Thus a new approach to

complex systems, computational mechanics, has been developed that employs the mathematical structures of computation theory to build intrinsic representations of temporal behavior, rather than relying solely on the equations of motion.

A brief review of computational mechanics is given, as well as its generalization to spatiotemporal systems. Spatiotemporal computational mechanics is then used to develop a rigorous theory of coherent structures in fully discrete classical field theories with local dynamics. The method is demonstrated on the simplest such systems that support emergent structures, namely elementary cellular automata. Results are compared with a similar, but distinct, dynamical systems approach using temporally invariant sets of spatially homogeneous configurations.

2.3 Statistics and Optimization

Luis Rademacher

Title: Provably Efficient High Dimensional Feature Extraction

Abstract: The goal of inference is to extract information from data. A basic building block in high dimensional inference is feature extraction, that is, to compute functionals of given data that represent it in a way that highlights some underlying structure. For example, Principal Component Analysis is an algorithm that finds a basis to represent data that highlights the property of data being close to a low-dimensional subspace. A fundamental challenge in high dimensional inference is the design of algorithms that are provably efficient and accurate as the dimension grows. In this context, I will describe a well-established feature extraction technique, independent component analysis (ICA). I will also present work by my coauthors and myself on new applications of ICA and ICA for heavy-tailed distributions.

Shuyang Ling

Title: Rapid, Robust, and Reliable Blind Deconvolution via Nonconvex Optimization

Abstract: We study the question of reconstructing two signals f and g from their convolution $y = f * g$. This problem, known as *blind deconvolution*, pervades many areas of science and technology, including astronomy, medical imaging, optics, and wireless communications. A key challenge of this intricate non-convex optimization problem is that it might exhibit many local minima. We present an efficient numerical algorithm that is guaranteed to recover the exact solution, when the number of measurements is (up to log-factors) slightly larger than the information-theoretical minimum, and under reasonable conditions on f and g. The proposed regularized gradient descent algorithm converges at a geometric rate and is provably robust in the presence of noise. To the best of our knowledge, our algorithm is the first blind deconvolution algorithm that is numerically efficient, robust against noise, and comes with rigorous recovery guarantees under certain subspace conditions. Moreover, numerical experiments do not only provide empirical verification of our theory, but they also demonstrate that our method yields excellent performance even in situations beyond our theoretical framework.

2.4 Mathematical Biology

Sam Walcott

Title: Using math to understand biological systems from the molecular to the macroscopic scales

Abstract: Recent experimental tools have given a clear picture of biology at the single molecule scale, but it remains unclear how these molecular measurements relate to the function of, say, a cell or an organ. A central problem is that molecules working together interact with each other. Thus, a molecule working as part of an ensemble behaves differently from a single molecule in isolation. In close collaboration with experimentalists, I use mathematical tools to predict this emergent large-scale behavior based on molecular-scale measurements. In this talk, I will discuss two biological problems: (1) regulation of muscle contraction; and (2) the transport of material within cells. In each case, I will describe how mathematical modeling has connected single molecule measurements to biological function at larger scales, with a particular emphasis on the important biological insights provided by the modeling.

Calina Copos

Title: Understanding cell locomotion: a mechanical approach

Abstract:

Cell movement is required in many physiological and pathological processes such as the immune system response and cancer metastasis. One of a broad spectrum of migratory mechanisms is amoeboid migration, characterized by repetitive cycles of rapid morphological expansion and contraction and highly coordinated traction forces applied on the environment by crawling cells. Despite recent intense studies, the exact mechanism of rapid shape changes and how they drive movement remains an open question. Here, we develop a simple model to mechanistically explain how key sub-cellular processes work in concert to robustly produce the experimentally reported features of amoeboid cell locomotion. Such models, provide mechanistic explanations for biological functions that have been only considered from a biochemical standpoint.

2.5 Algebra and Discrete Mathematics

Anne Schilling

Title: Experimental Mathematics

Abstract: In the spring quarter, Dan Romik and I will co-teach a special topics class on experimental mathematics, which involves studying certain mathematical problems using the computer. I will give you a flavor of research problems that can be attacked this way and how to use the open source software system SageMath in the process.

Lily Silverstein

Title: Random Monomial Ideals

Abstract: Randomness has been used in the algebra of polynomial rings for a long time. A classic example is the work of Littlewood and Offord, and later Kac, who studied the expected number of real roots of a random algebraic equation. More recently, Ein and Lazarsfeld considered the distribution of Betti numbers generated randomly using concepts from Boij-Sderberg theory. Combining these ideas with methods from Random Graph Theory and related fields, we provide a formal probabilistic setup for constructing and understanding distributions of monomial ideals, and the induced distributions on their invariants and measures of complexity such as degree, dimension, and regularity. This is joint work with Jesus De Loera (UC Davis), Sonja Petrovi (Illinois Institute of Technology), Despina Stasi (IIT), and Dane Wilburne (IIT).