WPI Mathematical Sciences Grants and Awards 2022/2023

Andrea Arnold Receives NSF Award to Develop Computational Filtering Methods

August 16, 2018

Andrea Arnold, assistant professor of mathematical sciences, has receives a three-year, $220,458 award from the National Science Foundation for a project titled "Computational Filtering Methods for Time-Varying Parameter Estimation in Nonlinear Systems. " The aim of the study is to design and analyze novel computational methods for estimating time-varying parameters through use of nonlinear filtering. The research has applications in the life sciences, such as modeling the spread of infectious diseases, determining the optimal treatment strategy for HIV drug therapy, and modeling tissue response to laser-based microsurgery.

Arnold's research in applied mathematics focuses on inverse problems and uncertainty quantification, which involves estimating unknown system parameters using indirect observations and analyzing the changes in predicted outcomes due to changes in the inputs. Many applications in modern science involve system parameters that are estimated using little prior information. This poses a challenge in applied and computational mathematics, particularly for problems where knowledge of parameters is crucial in obtaining trustworthy model output.

The study will develop mathematically sound and computationally efficient systematic approaches for estimating time-varying parameters with unknown dynamics. This work also will involve developing models for parameter evolution that take into account any prior knowledge relating to the structure or behavior of the parameter over time without defining explicit functions to describe the dynamics. Arnold will include WPI undergraduates and graduate students on the project team starting in the summer of 2019. Learn more about this grant.

Total Award period: 07/012018-06/30/2023 Award amount: $220,458

Vladimir Druskin receives $200,000 award from Air Force Research Laboratories for “Active Array Imaging in Complex Media in the Presence of Losses and Dispersion Effects”

In Vladimir's own words: *This project is focusing on extension to the air force imaging applications of the novel data-driven model reduction approach introduced earlier by the PI and his collaborators. The scope includes algorithmic development and mathematical justification of this approach for radar imaging in strongly inhomogeneous media with multiple scattering (echoes) effects, losses and dispersion.* Learn more about Vladimir Druskin

Total award period: July 2020 - June 2023 Award amount: $200,000

Research Experiences for Undergraduates in Industrial Mathematics and Statistics

National Science Foundation

Tilley, B., (PI) Sturm S., (Co-PI)

The Worcester Polytechnic Institute (WPI) REU in Industrial Mathematics and Statistics provides a distinctive educational experience for students in the mathematical sciences by introducing them to the ways in which mathematicians and statisticians use math in the "real world". Students work in teams on research problems of industrial and mathematical significance that come directly from industry and that are of immediate interest to the companies involved in the program. Students work closely with company representatives to define the problem and to develop solutions. They work closely with faculty advisors to maintain a clear focus on the mathematics and statistics at the core of the project. This summer research provides challenges not faced in traditional undergraduate programs and helps to develop skills usually not addressed in academic programs. It also provides a glimpse of some of the many career possibilities that are open to students with a strong mathematical background. For further information on this grant, please visit https://www.nsf.gov/awardsearch/showAward?AWD_ID=1757685

Total Award Period: February, 2018 to January 31, 2023 (estimated) Total Award Amount: $299,606

Burt Tilley and Vadim Yakovlev receive $775,336 award from AFOSR titled ``Permittivity Gradients, Polarization, and Gas Dynamics in Composite Electromagnetic Heat Exchangers'

In Professor Tilley's and Professor Yakovlev's own words, the project consists of a five-year research program to quantify the fundamental heat-transfer processes in the conversion efficiency from incoming electromagnetic radiation into elevated internal energy of a compressible coolant. The idea is to use electromagnetic-radiation absorbing materials, either porous or designed with channels through which a coolant can flow, that can withstand temperature up to 2000 K, heat these materials through the application of electromagnetic waves, and then run coolant through the material to harness the desired energy. Since electrical conductivity of these materials depends on temperature, multiple steady temperatures are possible at the same input power. The research program centers on using asymptotic multiscale methods including homogenization to formulate an effective medium theory to describe the energy conservation and electric field propagation through this medium, for incompressible and compressible coolants. The spatial variation of loss factor will be examined in order to compensate for conduction losses found at higher temperatures, and as a simple model for metal-ceramic composites. These results depend on the examination of the energy transfer between the composite and the coolant, and we shall consider these modes for incompressible and compressible coolants. Three-dimensional electric field amplitude equations, developed in our current award using high-frequency homogenization, will be extended to incorporate heat transfer, viscous fluid flow spatial dimensions, and comparisons with solutions using finite-difference time-domain and with finite-element methods will be performed. The goal is to develop a systematic method to better understand wave propagation, heat transfer and power delivery to the coolant for a general three-dimensional spatially-periodic microstructure.

Award period: September 2018 - August 2023 Award amount: $775,336

Bayesian Models for Cash Rents of U.S. Counties

National Agricultural Statistics Service (NASS, USDA)

Nandram, B.

In Professor Nandram's own words: This work at NASS is to develop Bayesian small area models to get reliable estimates of cash rental rates. I also advise researchers at NASS on the use of these small area models, which use Markov chain Monte Carlo methods extensively and routinely. NASS informs many crop insurance and agricultural support programs administered by other agencies such as the Farm Service Agency (FSA) and the Risk Management Agency (RMA). Many farmers rent their lands to other farmers, and it is useful to know annually what a fair price is by practice (irrigated, non-irrigated, and pasture land) for each of 49 states consisting of nearly 3000 counties with nearly two million operations. Data are collected in the annual Cash Rent Survey and other sources of information (e.g., the Census of Agriculture) are also used, particularly last year's data. Models must be operationalized to provide fast analysis and precise positive estimates of cash rental rates with standard errors. This is a very important on-going activity at NASS because NASS is responsible to the US government to perform this research activity.

Award Period: 2021-2022 **Award Amount:** $262,000

Cargo Transport by Myosin Va and Kinesin-1 Molecular Motors: In Vitro Model Systems that Build Complexity in 3-Dimensions

NIH

Walcott, S., (co-PI), Warshaw, D. (Pi)

In Sam's own words: The Warshaw lab performs molecular-scale biophysical measurements, and my group develops multi-scale mathematical models. The overall objective of this project is to build a mechanistic understanding of how molecular motor-based intracellular transport is both achieved and regulated. My role is to build predictive mathematical models of the experimental system developed by the Warshaw lab, including myosin Va and kinesin molecular motors, actin and microtubule protein filaments, liposome cargos, adapter proteins and microtubule- and actin-binding proteins.

For more information, please see: https://reporter.nih.gov/project-details/10204620

Award Period: May 2021 - April 2022

CRII: AF: Optimization and sampling algorithms with provable generalization and runtime guarantees, with applications to deep learning

Division of Computing and Communication Foundations (CCF) at the National Science Foundation

Mangoubi, O.

In Professor Mangoubi's own words: "*The aim of this project is to design novel optimization and sampling algorithms for training deep learning and other machine learning models, and to prove guarantees on the running time, generalization error and related robustness properties of these algorithms. Training algorithms with good generalization properties can lead to machine learning models which are more robust to changes in the dataset, allow for robust predictions, and help mitigate algorithmic bias when the training dataset may not be fully representative of the diversity of the population dataset. Guaranteeing a low generalization error is especially challenging in deep learning, since the number of trainable parameters is oftentimes much larger than the size of the dataset, and the loss function used to train the model is nonconvex. To prove stronger generalization and related robustness guarantees, we will use ideas from manifold learning and differential geometry to model the low-dimensional structure of datasets which arise in many machine learning applications.*"

For more information, please see:
https://www.nsf.gov/awardsearch/showAward?AWD_ID=2104528

Award Period: 2021-2023 **Award Amount:** $174,187

Modeling the dynamics of spindle behavior in cells with supernumerary centrosomes

NIH (R01 GM140465-01)

Olson, S (PI), Manning, A. (co-PI)

In Professor Olson's own words: Mitosis is the process of cell division, involving an intricate balance of forces to ensure a successful result—two genetically identical daughter cells. In normal cells, the mitotic spindle contains two spindle poles (bipolar), each having microtubules nucleated from a centrosome. Cells in disease states may have extra centrosomes, leading to either formation of a multipolar spindle and multiple daughter cells with poor viability, or formation of a pseudo-bipolar spindle with daughter cells that are viable. A hallmark of cancer cells is the ability to successfully divide with extra centrosomes. Through a combination of live-cell imaging and model simulations, we will provide new fundamental knowledge and insight into how the normal mitotic machinery has been co-opted to allow for bipolar division in cells with extra centrosomes. The developed modeling frameworks for fluid-structure interactions will lead to new computational methods that will leverage high performance computing architectures to simulate centrosome movement and stochastic MT dynamics.

Award Period: 9/5/2020 - 6/30/2023 **Award Amount:** $916,956

Valid time-series analyses of satellite data to obtain statistical inference about spatiotemporal trends at global scales

NASA/University of Wisconsin-Madison

Wang, F.

Start Date: 2/21/2020 (2 years). Amount: $174,762.00

As remote sensing has matured, there is a growing number of datasets that have both broad spatial extent and repeated observations over decades. These datasets provide unprecedented ability to detect broad-scale changes in the world through time and to forecast changes into the future. However, rigorously testing for patterns in these datasets, and confidently making forecasts, require a solid statistical foundation that is currently lacking. The challenge presented by remotely sensed data is the same as its remarkable value: remotely sensed datasets consist of potentially millions of time series that are non-randomly distributed in space. We propose to develop new statistical tools to analyze big, remotely sensed datasets that will add rigor to the conclusions about patterns of past changes and confidence to forecasts of future trends. Our focus is providing statistical tests for regional scale hypotheses using pixel-scale data, thereby harnessing the statistical power contained within all of the information in remotely sensed time series.

DeepM&Mnet: A General Framework for Building Multiphysics & Multiscale Models using Neural Network Approximation of Functions, Functionals, and Nonlinear Operators

Brown University (Prime: Defense Advanced Research Projects Agency)

Zhang, Z

Start Date: June 15, 2020 (3 years). Amount: $149,854

The proposal focuses on mathematical analysis for the neural network approximation (NNA) as well as the design of efficient deep learning algorithms for multiphysics and multiscale systems. The key idea is to train NNA for separated systems offline and then combine all the trained networks to solve multiphysics systems online. The research will result in fast and reliable solvers for multiphysics and multiscale systems. The main goal of the WPI investigator is to analyze and to improve the performance of the NNA as universal approximations in learning functions, functionals, and nonlinear operators and fusion of all pre-trained networks to solve multiphysics systems.The project is collaborative with Brown University and John Hopkins University

Simulating Large-Scale Morphogenesis in Planar Tissues

National Science Foundation, DMS 2012330

Wu, M.

Start Date: 6/15/2020 (3 years). Amount: $200,000

Cutting-edge developments in biotechnology and medicine involve reconstructing large-scale tissues and organs. This work can be limited by lack of knowledge in tissue morphogenesis, the process by which living tissues develop their size-and-shape characteristics. Though live-imaging techniques have enabled the observation of morphogenetic processes, progress in fundamental understanding has been slow. This project aims to improve tools for modeling a wide range of living tissues that are relatively planar and have been extensively studied experimentally. The project will develop methods for numerical simulation of morphogenesis processes and attempt to reproduce the observed large-scale morphogenesis structures in planar tissues. The project provides graduate student training through involvement in the research. This project concerns numerical simulation of large-scale continuum models for tissue morphogenesis that involve free boundaries, bulk-interface coupling, and highly nonlinear interactions. The work centers on a new mathematical model in which the field variables are nonlinearly coupled via reaction-convection equations and non-standard spatial partial differential equations. The project will develop semi-implicit and fully implicit time-stepping methods to avoid a potential time-step restriction for explicit time-stepping methods. Due to the high nonlinearity of the system, the boundary configuration must be updated together with the velocity field as well as other field variables. For this purpose, a novel interface-tracking method based on reference-map techniques will be investigated. Linear analysis close to trivial solutions will be conducted to assist the design of fast-converging iterative methods for solving the nonlinear system derived from the implicit time-stepping discretization of the original model. Simulations to understand in vitro micro-tissue and in vivo epithelial-tissue morphogenesis from live-imaging data will be carried out.

For more information on this grant, please visit https://www.nsf.gov/awardsearch/showAward?AWD_ID=2012330&HistoricalAwards=false

CAREER: Numerical Methods and Biomechanical Models for Sperm Motility

National Science Foundation

Olson, S.

2015-2022

Mammalian sperm must navigate the female reproductive tract, swimming a distance greater than 1000 times their own length to reach and fertilize the egg. In order to aid in the treatment of reduced sperm motility, it is important to understand interactions of the sperm flagellum with different regions of the reproductive tract. In particular, fluid flow helps bring the egg to the uterus (in the opposite direction of sperm progression). Recent experiments have shown that a large percentage of sperm exhibit positive rheotaxis, the ability to reorient and swim against a background flow. Additionally, sperm will bind and unbind to the oviductal wall and the role of a background flow on sperm detachment is not known. The main scientific goals of this project include further analyzing existing experimental data (through image processing techniques) and developing new computational models to understand the clinical importance of migration through the female reproductive tract and sperm binding and detachment from walls in a background flow. Several new computational modeling frameworks will be developed to allow simulations of sperm in the presence of a background flow and a wall. The PI will provide interdisciplinary training for several students (undergraduate and graduate) as well as one postdoc in the areas of computational biofluids, image processing of experimental movies, and model development. In addition, the PI will work to develop image processing and modeling modules to be used in area High Schools and at summer programs for High School students at WPI. Learn more about the grant.

Zheyang Wu Receives NSF Award for Work Related to ALS

Zheyang Wu, associate professor of mathematical sciences, has received a three-year, $150,000 award from the National Science Foundation for a project titles, “Optimal and Adaptive p-Value Combination Methods with Application to ALS Exome Sequencing Study.” The project is focused on developing tests that will give scientists a better understanding of which DNA segments are related to ALS susceptibility. Using ALS exome-sequence data, researchers will develop better data analysis methodology to paint a clearer picture of how genes influence ALS.

ALS, or amyotrophic lateral sclerosis, is a progressive neurodegenerative disease that affects nerve cells in the brain and spinal cord, affecting one’s speech and ability to swallow and to control the muscles. Ultimately, it causes paralysis and death. Each year, more than 5,000 people in the United States are diagnosed with ALS, which is also known as Lou Gehrig's disease.

Genetics plays a critical role in ALS. Despite numerous advances in recent years, doctors still cannot trace the genetic cause of a significant amount of ALS cases. This research project is taking on the “missing heritability” problem, using innovative genetic data analysis algorithms and more powerful p-value combination tests to analyze large exome sequencing data for detecting novel ALS genes. The methodology being developed in this project has broad applications and could be used to better understand other diseases, as well. A WPI graduate student will work on this research with Wu. For more information on this grant please visit https://www.nsf.gov/awardsearch/showAward?AWD_ID=1812082

Total award period: July 1, 2018 - June 30, 2022

Christopher Larsen receives $250,000 award from the Division of Mathematical Sciences (DMS) at the National Science Foundation "New Mathematical Methods for Dynamic Fracture Evolution"

In Professor Larsen's own words: *"For a large range of applications, from civil infrastructure to national defense, understanding the failure of materials is critical. Yet, our ability to predict this failure is limited by both modeling, which is somewhat ad hoc, and the mathematics available to formulate and analyze models, as well as to justify numerical methods. These issues are most severe in dynamic problems, such as impacts, when loading changes quickly. The main goal of this project is the development of new mathematical methods for dynamic fracture evolution. In particular, the principal investigator (PI) will extend methods for regular crack paths to more realistic paths, with kinking and branching. A second goal is to address fundamental mathematical issues that are necessary for further progress in completely general settings. Finally, the PI will study phase-field approximations of fracture, which have become very popular tools in the engineering community but remain poorly understood.*

The ability to accurately predict failure depends on the quality of the underlying mathematical models of defects as well as on understanding fundamental properties of solutions. When crack paths are regular, mathematical methods are available to study these evolutions. However, when they are not, the only methods so far involve considering the paths to be limits of more regular paths. The main technical issue here is that strong convergence of the corresponding elastodynamics is necessary for energy balance, as well as for other properties of solutions, but this convergence remains open in many situations. Another fundamental issue is uniqueness of elastodynamic solutions for a given crack path. The investigator will show uniqueness in certain settings, and explore general consequences, such as bounds on crack speed.

The final goal of the project is to analyze phase-field models for fracture. While very popular in the engineering community, a number of properties, including whether they approximate the correct surface energy, or satisfy a maximal dissipation condition, remain open questions."

For more information please see
https://www.nsf.gov/awardsearch/showAward?AWD_ID=1909991&HistoricalAwards=false
Total award period: 2019-2022 Award Amount: $250,000