KIERON BURKE PERSONIFIES IPAM’S INTERDISCIPLINARITY

When Kieron Burke was working on his PhD at the University of California, Santa Barbara, in the late 1980s, he remembers density functional theory (DFT) being “a slightly obscure thing.”

In the 1960s, Burke’s doctoral adviser, Walter Kohn, had developed the fundamental elements of DFT — a method for setting up and solving quantum mechanics equations for the electrons in any substance. But long after Burke completed his doctoral studies, DFT became a mainstay in many branches of science, particularly chemistry and materials science — thanks in no small measure to research by many people, including Burke. Today, Burke notes, as many as 50,000 scientific papers each year reference the use of DFT in their calculations. “In my lifetime it’s gone from a theorist’s game in trying to catch up with the experiments, to something that’s driving a huge amount of science,” he marvels.

Given the quantum mechanics, solving the equations for electrons in everyday matter becomes exponentially more costly as their number increases — to the point that even the most powerful supercomputer at the Department of Energy (DoE) can’t abide standard methods beyond 20-30 atoms. Through a simple approximation, DFT allows for quick solutions to quantum chemical calculations for molecules.

GEOMETRY, STATISTICAL MECHANICS, AND INTEGRABILITY
(MARCH 11 – JUNE 14, 2024)

In the last 20-30 years probability theory and statistical mechanics have been revitalized with the introduction of tools from geometry, notably conformal geometry and discrete analyticity, but also algebraic geometry and integrable systems.

Other recent work on the dimer model has led to connections with knot theory, Lorentzian geometry, and symplectic geometry. From another direction, the combinatorics of the totally nonnegative Grassmannian has connections with the dimer model. Likewise, the isotropic Grassmannian and orthogonal Grassmannian have connections with spanning trees and the Ising model.

Finally, there are well-known connections between some statistical mechanics models and representation theory, such as Young diagrams, Gelfand-Tsetlin patterns, Knutson-Tao puzzles and Littlewood-Richardson coefficients and their generalizations. The Bethe Ansatz and the Yang-Baxter equation were developed for the 6-vertex model but are now fundamental tools in combinatorial representation theory.

This program will bring together researchers in this somewhat disparate realm of ideas, united by the underlying themes of geometry and statistical mechanics.”

FEATURES

Equity for Transportation Systems
Experience as IPAM Postdoc
Mathematics of Intelligences

HIGHLIGHTS

Director’s Note
News Stories
Donor Recognition

INFORMATION

Upcoming Programs
Call for Proposals
Mark Your Calendars
SAMITHA SMARANAYAKE SPEARHEADS IPAM’S EFFORT TO ENSURE EQUITY IN TRANSPORTATION SYSTEMS

As cities strive to become more liveable through transportation and other infra-structure development, planning decisions increasingly rely on algorithms and artificial intelligence. But Cornell University’s Samitha Samaranayake, whose interests include modeling and understanding operations around large-scale transportation networks, points out that if these algorithms are developed without attention to where needs are greatest, their potential to perpetuate societal inequities.

“In transit planning, there can be a ridership-versus-coverage tradeoff — if you want to move as many people as possible, you run the buses on the high-density corridors, which is typically where property values are higher; but if you want to serve people living in the low-income communities, you might need to compromise on how many people you move,” explains Samaranayake, an assistant professor in Cornell’s School of Civil and Environmental Engineering and a graduate student faculty member in the School of Operations Research and Information Engineering, the Center for Applied Math, and the Systems Engineering Program at Cornell.

“Historically, transportation is an area that has been highly discriminatory in terms of having adverse effects on low-income communities,” Samaranayake adds, “and if we aren’t purposeful with these algorithms, that is what will continue to occur.”

Samaranayake studied computer science at MIT as an undergraduate, during which he spent a significant portion of his time conducting his thesis research at Synopsys, a Silicon Valley tech company. He then worked as a software engineer at Oracle before returning to school for his PhD in transportation networks at the University of California, Berkeley, followed by a postdoctoral fellowship at MIT.

In his PhD studies he focused on problems related to traffic flow, and on the on-going development of ride-sharing: a misnomer, he notes, since people aren’t typically sharing rides with others, but rather using the apps for the equivalent of potential safer and more efficient taxi use — fails to improve the ratio of passenger miles traveled to vehicle miles traveled. “If we want to use transportation technology to improve societal impacts in cities, it has to include a well-integrated component of moving masses of people together, rather than individuals at one time,” he says.

With that in mind, Samaranayake is organizing a workshop on Mathematical Foundations for Equity in Transportation Systems, to be held at IPAM next January. The workshop will bring together a diverse group of participants — including computer scientists, social scientists, transportation experts, and mathematicians — to exchange ideas on the desired objectives of these systems, improve the understanding of how equity should be considered in the plans, and determine how math can help to meet those objectives.

Samaranayake’s primary research interest is in mathematical modeling and algorithm design for large-scale transportation network problems — particularly, those at the intersection of mass transit and emerging transportation technologies. Through algorithm engineering — gaining theoretical insights from successful data-driven and heuristic approaches, and vice versa — he has focused on developing hybrid transit systems: services designed to fully integrate traditional fixed-line mass transit and agile, demand-responsive transportation modes. Samaranayake works closely with public transit agencies and private shuttle operators to gain practical insights, calibrate models, and ensure the real-world relevance of his algorithms.

Samaranayake’s first IPAM experience came in 2015, when he attended a long program, New Directions in Mathematical Approaches for Traffic Flow Management, as a postdoctoral fellow. “It was a great experience, mixing with so many important people in transportation who are people like myself,” he says. “Unlike typical conferences, you’re with the same people all day, with plenty of time outside of the talks to get to know about their work. It helped me not only to interact with people in my area, but also to understand the bigger picture, both upstream and downstream of the area I work in.” Samaranayake returned to participate in an IPAM workshop on emerging technologies in 2019, and then was part of the long program, Mathematical Challenges and Opportunities for Autonomous Vehicles, in 2020.

Today, Samaranayake’s primary research interest is in mathematical modeling and algorithm design for large-scale transportation network problems — particularly, those at the intersection of mass transit and emerging transportation technologies. Through algorithm engineering — gaining theoretical insights from successful data-driven and heuristic approaches, and vice versa — he has focused on developing hybrid transit systems: services designed to fully integrate traditional fixed-line mass transit and agile, demand-responsive transportation modes. Samaranayake works closely with public transit agencies and private shuttle operators to gain practical insights, calibrate models, and ensure the real-world relevance of his algorithms.

Ensuring Equity in Transportation Systems

Thanks to her year at IPAM, Elisa Negrini entered her postdoctoral position in the UCLA Mathematics Department uniquely prepared — having already gotten to know the people in the department, as well as having forged collaborations both with fellow department members and in fields to which Negrini previously had little exposure. Negrini began her PhD program at Worcester Polytechnic Institute in Massachusetts focusing on pure math, but as she progressed toward her doctorate the pivoted toward applied math — in particular, applications of machine learning to physical systems. The opportunities afforded by IPAM allowed her to collaborate across disciplines, prompted her to apply to the institute as a Simons Postdoctoral Fellow. “I wanted a postdoc that would allow me to work with real data and explore applications.”

“Typically, at conferences, it’s just the people in your field, and the discussions are restricted to the language you all speak,” Negrini says. “At IPAM, I got to meet people from all of these disciplines, and instead of going out and trying to network, they were coming into my office. Because my expertise has applications in so many areas. I got to collaborate with chemists and physicists on projects involving topics I hadn’t known anything about, meet people outside my field whom I wouldn’t have met otherwise, and produce original research.”

Negrini — an expert in computing in microscopy, was an ideal way to develop my knowledge on deep learning and AI.

For her upcoming UCLA postdoc, Negrini is focusing on physics-informed machine learning for plasma physics, she will also be teaching. In summer 2023, she served as a mentor for IPAM’s Research in Industrial Projects for Students (RIPS) program, in which students study at centers to impactful problems, is the ideal setting for doing this.”

Ensuring Equity in Transportation Systems (continued from page 2)

today, the big question is how we can improve the ratio of passenger miles traveled to vehicle miles traveled. “If we want to use transportation technology to improve societal impacts in cities, it has to include a well-integrated component of moving masses of people together, rather than individuals at one time,” he says. (continued on next page)
**DONOR RECOGNITION**

**CORPORATE GIVING**

IPAM offers opportunities for corporations to participate in our scientific programs, propose topics for programs, and support activities that promote diversity in math and science. IPAM received gifts from the following companies and government agencies in the past year:

- Advanced Micro Devices Inc.
- The Aerospace Corporation
- Air Force Research Laboratory
- Relay Therapeutics

In addition to support from our main NSF grant, IPAM also received grant funding from the Simons Foundation, and the NSF Infrastructure Program through the NSF Mathematical Sciences Institutes Diversity Initiative.

For more information on corporate giving, please visit our donor page at www.ipam.ucla.edu/donate/corporate-giving.

**IPAM’S EQUITY, DIVERSITY, AND INCLUSION ENDOWMENT**

Many thanks to everyone who donated. We have surpassed our goal of the $600,000 endowment to support EDI activities. The fund will be used to increase diversity and inclusion in our programs.

**IPAM’S FUNDRAISING PRIORITIES**

- **Facilities Improvement.** Upkeep and enhancement of IPAM’s space is essential in ensuring a healthy and safe workplace. Your gift will help create and maintain a welcoming place for our participants and the math community.
- **Child Care Fund.** Help IPAM support participants whose attendance in programs is dependent on securing reliable care for their children.
- **Equity, Diversity, and Inclusion.** Help IPAM improve EDI in all of its activities.

**IPAM’S FRONTIER SOCIETY**

Please consider joining IPAM’s Frontier Society. Your contribution will help us continue to run high quality programs attracting both internationally renowned experts as well as promising young scholars. Depending on the level of your membership, benefits include an IPAM gift (T-shirt or other), preferred seating at all IPAM public lectures, free parking, invitations to exclusive IPAM events, and free registration to all IPAM workshops and conferences. See the IPAM webpage for details of the membership levels.

All Frontier Society members will be listed in the annual newsletter. With a gift of $2,000, you may name a seat in IPAM’s lecture hall. Donors giving $5,000 or more will be recognized on IPAM’s donor wall.

**DONATE HERE**

For more information and to donate, check here:

www.ipam.ucla.edu/donate

**NEWS STORIES**

**2022** had brought focused national attention to the question of how machines could assist or even replace human ingenuity. Our work on industry-sponsored research problems. In 2014 IPAM started G-RIPS Berlin in partnership with the Research Campus MODAL, which is a public-private partnership between the Zuse Institute Berlin (ZIB), the FU Berlin, and industrial partners. The inaugural G-RIPS partners were SAP Germany, Deutsche Bahn, and OpenGrip Europe. Since 2014, many more of the over 30 industrial partners of MODAL have participated in G-RIPS, and offered students an opportunity to experience cutting-edge research in a team setting. Inspired by the success of G-RIPS Berlin, IPAM added a second G-RIPS program in 2018 in Sendai, Japan. It is in partnership with the Tokohu Forum for Creativity (TFC) and the Advanced Institute for Materials Research (AIMR) at Tohoku University. The participating industrial sponsors of the last 5 years include Toyota, NEC, Fujitsu, Mitsubishi, and HHI. Former G-RIPS Student Jeffrey Yeh commented: “I will definitely recommend G-RIPS to other graduate students. It is often difficult for me to see the real applications of mathematics while studying it, and this program really helped me to see the connection between math and industry problems.”

The research projects in each program cover a wide range of topics that include optimization, biomedical applications, image processing, quantum computing, and more. In both G-RIPS programs, the emphasis on strong research projects is enhanced by a cultural experience for the students. The research teams always consist of 2 US students together with 2 Japanese students (Sendai) or 2 European students (Berlin). In addition to the research program that includes seminars, visits to the participating industrial sponsors, and formal written and oral presentations, each program is complemented by cultural activities and language classes. Former G-RIPS student Hannah Hofmann wrote: “I would definitely recommend G-RIPS to other graduate students, especially if they have any interest in traveling abroad.”

G-RIPS is a great program for students to get applied research experience and the opportunity to live in a foreign country. Working with an international team on an industrial problem is a great experience to help prepare for a career in research after graduate school.”

IPAM is grateful to Hiroshi Suito in Sendai and Tim Conrad in Berlin for all the work they are putting into this fruitful collaboration that has enabled many students to spend an unforgettable summer abroad. We are looking forward to continuing and expanding both programs in the future.

** machine learning developers, often groups that have largely worked separately, are potential boosters to the question of how machines could assist or even replace human ingenuity.**

**MACHINE ASSISTED PROOFS**

In February of 2023, IPAM hosted a workshop on Machine-Assisted Proofs. This program had been in the works for more than a year, but ended up being held at a timely moment, when unexpected rapid development in large language models (LLMs) in late 2022 had brought focused national attention to the question of how machines could assist or even replace human ingenuity.

As the title of the workshop suggests, the dominant mood at the workshop was one of excitement and synergy. We saw Geordie Williamson (“What Can We See Geordie Williamson (“What Can We See Geordie Williamson (“What Can Deep Learning?”) talk about his collaboration with DeepMind, in which machine learning was used to identify a potential proof strategy. If the proof verifier builds by the formalization community. In formal mathematics, by contrast with so many other domains where LLMs are being applied, there are robust barriers against “hallucinations”.

Participants left the workshop with a feeling of wide-open potential and a clear sense of avenues for future work at the interface between machine learning and pure mathematics.

**GRADUATE LEVEL SUMMER RESEARCH PROGRAM G-RIPS**

The Graduate-Level Research in Industrial Projects for Students (G-RIPS) program offers graduate students in mathematics and related disciplines the opportunity to work on industry-sponsored research problems. In 2014 IPAM started G-RIPS Berlin in partnership with the Research Campus MODAL, which is a public-private partnership between the Zuse Institute Berlin (ZIB), the FU Berlin, and industrial partners. The inaugural G-RIPS partners were SAP Germany, Deutsche Bahn, and OpenGrip Europe. Since 2014, many more of the over 30 industrial partners of MODAL have participated in G-RIPS, and offered students an opportunity to experience cutting-edge research in a team setting. Inspired by the success of G-RIPS Berlin, IPAM added a second G-RIPS program in 2018 in Sendai, Japan. It is in partnership with the Tokohu Forum for Creativity (TFC) and the Advanced Institute for Materials Research (AIMR) at Tohoku University. The participating industrial sponsors of the last 5 years include Toyota, NEC, Fujitsu, Mitsubishi, and HHI. Former G-RIPS Student Jeffrey Yeh commented: “I will definitely recommend G-RIPS to other graduate students. It is often difficult for me to see the real applications of mathematics while studying it, and this program really helped me to see the connection between math and industry problems.”

The research projects in each program cover a wide range of topics that include optimization, biomedical applications, image processing, quantum computing, and more. In both G-RIPS programs, the emphasis on strong research projects is enhanced by a cultural experience for the students. The research teams always consist of 2 US students together with 2 Japanese students (Sendai) or 2 European students (Berlin). In addition to the research program that includes seminars, visits to the participating industrial sponsors, and formal written and oral presentations, each program is complemented by cultural activities and language classes. Former G-RIPS student Hannah Hofmann wrote: “I would definitely recommend G-RIPS to other graduate students, especially if they have any interest in traveling abroad.”

G-RIPS is a great program for students to get applied research experience and the opportunity to live in a foreign country. Working with an international team on an industrial problem is a great experience to help prepare for a career in research after graduate school.”

IPAM is grateful to Hiroshi Suito in Sendai and Tim Conrad in Berlin for all the work they are putting into this fruitful collaboration that has enabled many students to spend an unforgettable summer abroad. We are looking forward to continuing and expanding both programs in the future.

**human mathematicians are hard at work on proving, Heather Macbeth (“Algorithm and Abstraction in Formal Mathematics”) talked about the ways our value system as mathematicians will have to change as more mathematics is formalized, and Tony Wu, from Google (“Autoformalization with Large Language Models”) talked about a grand project that synthesized many of the themes of the workshop, namely using LLMs to generate short formal proofs of desired mathematical statements, which — being formal — can then be automatically checked by the proof verifiers built by the formalization community. In formal mathematics, by contrast with so many other domains where LLMs are being applied, there are robust barriers against “hallucinations”.

Participants left the workshop with a feeling of wide-open potential and a clear sense of avenues for future work at the interface between machine learning and pure mathematics.**

**MACHINE ASSISTED PROOFS**

In February of 2023, IPAM hosted a workshop on Machine-Assisted Proofs. This program had been in the works for more than a year, but ended up being held at a timely moment, when unexpected rapid development in large language models (LLMs) in late 2022 had brought focused national attention to the question of how machines could assist or even replace human ingenuity.

As the title of the workshop suggests, the dominant mood at the workshop was one of excitement and synergy. We saw Geordie Williamson (“What Can We See Geordie Williamson (“What Can We See Geordie Williamson (“What Can Deep Learning?”) talk about his collaboration with DeepMind, in which machine learning was used to identify a potential proof strategy. If the proof verifier builds by the formalization community. In formal mathematics, by contrast with so many other domains where LLMs are being applied, there are robust barriers against “hallucinations”.

Participants left the workshop with a feeling of wide-open potential and a clear sense of avenues for future work at the interface between machine learning and pure mathematics.
Kieron Burke Personifies IPAM’s Interdisciplinarity

(continued from page 1)

Kieron Burke feels right at home when he attends programs of the Institute for Pure & Applied Mathematics (IPAM), where fostering collaborations and collaborations across disciplines is a core part of the mission. His first IPAM experience came in 2012, when Burke was invited to give a tutorial on DFT at a long program on machine learning in electronic structure calculations. “It was a meeting that was well ahead of its time, and it led to a vast amount of work that has become ever more important,” Burke says.

In the decade-plus since, Burke has returned for many programs, including conferences at Lake Arrowhead, where he has developed and renewed collaborations. “Because the electronic structure world is so huge, there are a number of different communities running these calculations and many are using some of my formulas,” he says, “Because I’m only an hour’s drive away, I try to be there whenever there is something of interest.”

The rapid increase in computational power is driving progress in a variety of scientific fields, but also worries that as more people enter the field focus on the sophisticated computational tools, traditional, mathematical training and analytic expertise are becoming scarce. “The people running these algorithms will often come up against equations that require this type of mathematical background to solve, and in that sense, IPAM’s ability to bring together mathematicians and domain scientists is very fruitful,” he explains.

Burke recently joined IPAM’s Science Advisory Board, which he hopes to use as a platform to get more physicists involved in the institute’s programming. “In between the pure math and running the computer is old-fashioned physical intuition — telling you what makes sense and what doesn’t,” he says. “Physicists, as experts in how nature works and what effects need to be captured, can help to bridge that gap.”

For Burke, the value of IPAM is in its ability to bring together experts from different backgrounds, with mathematics serving as a universal language that allows participants to communicate across the cultural barriers that have traditionally kept them siloed. “IPAM draws different kinds of mathematicians who are interested in applying their expertise to scientific problems, along with chemists, physicists, materials scientists, and others who may be computational people but can use some math help,” Burke says. “Lots of good can come from these interactions, and IPAM is probably the best place in the world for fostering that.”
The quest to understand intelligence is one of the great scientific endeavors—on par with quests to understand the origins of life or the foundations of the physical world. Several scientific communities have made significant progress in fields like animal cognition, cognitive science, collective intelligence, and artificial intelligence, as well as the social and behavioral sciences. Yet these communities remain largely disconnected. Now is the time to bring them together with mathematicians to develop the mathematical foundations necessary for transformational advances in understanding natural and artificial intelligences.

This long program seeks to develop those foundations. It will build community and collaboration between participants from the domain sciences and participants from relevant mathematical fields, including dynamical systems, statistical physics, theoretical machine learning, probability and (Bayesian) statistics, information theory, high-dimensional geometry, functional analysis, the theory of programming languages, game theory, and category theory.