Institute for Pure and Applied Mathematics, UCLA
Annual Progress Report for 2020-2021
Award #1440415
August 16, 2021

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EXECUTIVE SUMMARY

This report covers our activities from June 13, 2020 through June 11, 2021 (which we refer to as the reporting period). This report includes the 2020 summer research programs (RIPS and GRIPS). The 2021 summer programs are underway at the time of reporting and will be included in the Final report.

IPAM held two long programs in the reporting period:

- Mathematical Challenges and Opportunities for Autonomous Vehicles (September 14 - December 18, 2020)
- Tensor Methods and Emerging Applications to the Physical and Data Sciences (March 8 - June 11, 2021)

IPAM held the following workshops in the reporting period:

- Mathematical Models in Understanding COVID-19 (August 10 - 12, 2020)
- Transport and Mixing in Complex and Turbulent Flows (January 11 - 15, 2021)
- Actions of Tensor Categories on C*-algebras (January 25 - 29, 2021)
- Entropy Inequalities, Quantum Information and Quantum Physics (February 8 - 12, 2021)
- Deep Learning and Combinatorial Optimization (February 22 - 26, 2021)

Furthermore, the following public lecture was organized during this period:

- The Frustrating Beauty of Traffic Waves - And How Automated Vehicles Can Prevent Them (November 23, 2020) by Benjamin Seibold.

IPAM typically offers two reunion conferences for each IPAM long program; the first is held a year and a half after the conclusion of the long program, and the second is held one year after the first. Due to the unprecedented crisis posed by the COVID-19 pandemic, the reunion conferences scheduled for winter 2020 were postponed. We were able to convene the second and final reunion conference for the following cohort in Lake Arrowhead:

- Complex High-Dimensional Energy Landscapes Reunion Conference II (June 6 - 11, 2021)

Due to safety concerns, RIPS and GRIPS 2020 were hosted virtually, centered at Los Angeles. RIPS Singapore, GRIPS Sendai, and GRIPS Berlin were cancelled. This report includes two 2020 student research programs:

- Research in Industrial Projects (RIPS) in LA
- Graduate-level RIPS (GRIPS) in LA

A. PARTICIPANT LIST

A list of all participants in IPAM programs will be provided to NSF in electronic form (Excel). The list will include participants for programs whose start dates fall between June 13, 2020 through June 11, 2021.

B. FINANCE SUPPORT LIST

A list of participants that received support from IPAM will be provided to NSF in electronic form (Excel). The list includes all funded participants of programs that occurred between June 1, 2020 through May 31, 2021.

C. INCOME AND EXPENDITURE REPORT

Grant # DMS 1440415:
This table shows appropriations and expenses for the twelve-month period June 1, 2020 through May 31, 2021 for grant #1440415. This is within the approved No-Cost Extension (NCE) period ending August 31, 2021. There is no new appropriation of funds during the NCE period.

Budget Category	Expenses	Encumbrances	Total Expenses & Encumbrances
A. Operations Fund	$1,818,565	$167,937	$1,986,502
B. Participant Costs	294,066	3,184	297,250
C. Indirect Costs	823,412	0	823,412
Total	$2,936,043	$171,121	$3,107,164

The COVID-19 epidemic caused all IPAM activities to proceed with on-line format for this grant year until June 7, 2021. Online programs have dramatically lowered our Participant Support Costs.

A. The Operational Fund (salaries, benefits, equipment, and supplies) for the twelve-month period has total expenditures and encumbrances of $1,986,502. Included in the encumbered expenses is $168,693 for the subaward with California State University, Northridge for Associate Director Maria D'Orsogna.

B. Participant Support Costs include stipends, travel, housing, and subsistence for the scientists working on IPAM Programs. Participant Support Costs for the twelve-month period has total expenditures and encumbrances of $297,250. The majority of these expenses were for the Research in Industrial Projects Students 2020 and are stipends for students and academic mentors.

C. Indirect Costs: Indirect Costs rates are based on current facilities and administrative cost rates negotiated with the Federal government and the University of California. IPAM's work is conducted at an on-campus location which is subject to 54% facilities and administrative cost rate. Indirect costs are not applied to equipment and participant support costs. Indirect Costs for the twelve-month period had total expenditures of $823,412.

Program Income: Registration fees for NSF-supported conferences are accounted for as program income. IPAM charges modest registration fees primarily to discourage non-serious registrations. Registration fees for workshops are $75 for faculty and government/military participants, $100 for industry participants, $50 for post-doctoral scholars and $25 for graduate students. There was no program income during the reporting period as registration fees were waived for online programs during COVID.

D. POSTDOCTORAL PLACEMENT LIST

IPAM did not appoint postdoctoral fellows in 2020-21, so we have no data to report in this section.

E. MATH INSTITUTE DIRECTORS' MEETING REPORT

Mathematical Sciences Institutes Directors (MIDs) Virtual Meeting

April 24, 9:00-1:00pm PT
Dial-in https://msri.zoom.us/j/93605549887

Meeting ID: 936 0554 9887
Find your local number: https://msri.zoom.us/u/abPHAUZmb4

Participating

- AIM: Brian Conrey (Director), Estelle Basor (Deputy Director)
- IAS: Akshay Venkatesh (Robert and Luisa Fernholz Professor of Math)

- ICERM: Brendan Hassett (Director), Caroline Klivans (Deputy Director), Ulrica Wilson (Assoc. Director for Diversity & Outreach)
- IMSI: Kevin Corlette (Director), Doug Simpson (Assoc. Director), Bo Hammer (Exec. Director), Patrick Wolfe (Board Chair)
- IPAM: Dima Shlyakhtenko (Director), Christian Ratsch (Deputy Director)
- MSRI: David Eisenbud (Director), Hélène Barcelo (Deputy Director), Lisa Jacobs (Exec. Asst. to Director & Board Liaison)
- NSF: Juan C. Meza (Division Director), Henry Warchall (Acting Deputy Division Director), Marian Bocea (Institute Management Team, IMT), Stefaan De Winter (IMT), Pedro Embid-Droz (IMT), Yuliya Gorb (IMT), Joanna Kania-Bartoszynska (IMT), Huixia (Judy) Wang (IMT), Junping Wang (IMT)

David Eisenbud convened the meeting at 9:00am.

Welcome and introductions

David Eisenbud welcomed the Institute Directors and National Science Foundation (NSF) participants. The Directors and NSF participants introduced themselves.

DMS Update with Q&A (Juan Meza)

Introduction: The NSF budget has received strong bipartisan support in Congress, with $8.5B allocated in FY21 and $8.3B in FY20. There are several new programs with upcoming solicitations in Mathematical & Physical Sciences (MPS), including ASCENDs and LEAPs. The Simons MoDL program, a collaboration across 3 NSF divisions, is dedicated to the mathematics of deep learning and has a new solicitation as well. The Institutes are requested to advertise these solicitations, since deadlines are approaching in May and June this year.

MPS ASCENDs: This new program is targeted to broaden the participation of underrepresented groups in postdoctoral positions across the MPS divisions and to mitigate the overall decrease in postdoctoral positions, which were negatively impacted by COVID. About 40-50 positions across all divisions are expected.

MPS LEAPs: This new early career program is intended to launch the careers of pre-tenure faculty across MPS divisions at MSIs (minority-serving institutions), PUIs (predominantly undergraduate institutions), and R2 universities. About 10-30 awards across all divisions are expected.

Division of Math Sciences (DMS) responses to COVID: Under the CARE ACT, 20 RAPID response research awards were made across DMS, totaling $2.755M. There was an increase in the

number of workforce awards in the following areas: Mathematical Sciences Postdoctoral Research Fellowships (MSPRF) to support postdoctoral fellows; Research Training Groups (RTG) to support early career researchers; and Research Experiences for Undergraduates (REU) sites to support undergraduates. A total of $3.15M was awarded in MSPRF, which included an additional 21 postdoctoral fellow positions. Of the fellowships awarded, 39% funded women and 16% funded those from underrepresented groups.

Next steps, DMS responses to COVID: In developing next steps, the DMS is guided by the following considerations:

- The groups most negatively impacted by COVID, including those from underrepresented groups (including women) and those from MSIs and less affluent institutions
- Vulnerable transition points where students and researchers are most likely to struggle, such as before and after the postdoctoral fellowship and during the early career period
- Ensuring that responses and scale of costs are proportional to the considerations above

Aligned visions: The National Science Board (NSB) establishes the policies of the NSF and serves as advisor to Congress and the President. As such, there is an alignment of visions across the Administration, NSB and NSF. The Administration's Pillars are outlined as: Pandemic response; Economic recovery; Racial equity; and, Climate change. The NSB's Vision 2030 includes: Research benefits, STEM talent, Geography of innovation, Global S&E (Science & Engineering) community. NSF's priorities include: Advancing research, Accessibility and inclusivity, Global leadership, and Translation, Innovation & Partnership (TIP).

Industries of the Future (NSF): The NSF has identified 5 such industries, which are considered critical to the Nation's long-term economic and national security. The following 2 industries are directly led by MPS: Quantum Information S&E and Advanced Wireless 5G. The other 3 industries are: Artificial Intelligence, Biotechnology, and Advanced Manufacturing.

Critical Aspects of Sustainability CAS meta-program: The CAS meta-program was developed in response to the Administration's commitment to Climate change. CAS housed in the Division of Chemistry and supports basic research through core programs in MPS, ENG, and GEO.

Mid-grant NSF reviews: Mid-grant NSF reviews of the Institutes are not required unless otherwise stated. Such reviews are optional, and if requested, would only be conducted by NSF staff and would not include external reviewers.

DMS Director search: The DMS Director's term is limited to 4 years. The job opening will be posted on USAJOBS, and those selected will follow the standard interview process. The Directors are encouraged to speak to their qualified colleagues about applying for this position.

Discussion: The most vulnerable group negatively impacted by COVID would seem to be postdoctoral fellows in the late stages of their fellowships, who would be transitioning to faculty positions. The new MPS solicitations are targeted to support this group. To further support researchers with NSF grants expiring within the year, a supplement can be requested by the end of May.

Effect of COVID-19 on Institutes' Activities (All Directors)

Demographics of participants in institute activities

For MSRI's programmatic activities, there was no significant difference in the rate of participation in the seminars of women and men, with the exception of 1 program with 2 women organizers. In this program, women attended approximately 10 more seminars per week than men. Across programmatic activities, there was no difference in the rate of participation of those from underrepresented groups.

Domestic participants in ICERM's activities have remained stable, while international participants simultaneously increased. For international participants, the timing of activities has increased the participation of those in Europe. The development of virtual activities has increased networking opportunities for women and those from underrepresented groups.

For activities at IPAM, there was a slight increase in the number of women participants, including women speakers. There were fewer cancellations at workshops. The timing of the workshops was shifted to early morning Pacific Daylight time, which increased the participation of those in Europe and has proved challenging for participants in Asia.

About 75% of participants invited to IAS attended in-person, and 25% chose to participate remotely. There was no significant difference in the attendance of women and men participants. For workshops at AIM, there was a higher acceptance rate and fewer cancellations for workshops.

Recruitment of members and postdocs to institute programs

There was a significant decrease in applications to MSRI's 2021-22 programs.

Successes and drawbacks of virtual activities

Successes: There was an increase in participants at MSRI's workshops after they became virtual. The virtual format of IPAM's and ICERM's activities also resulted in overall increased participation compared with in-person activities.

Virtual workshops at AIM benefitted from utilizing the platform Sococo as well as google drive, whiteboards, a virtual schedule, and various virtual meeting rooms to successfully replicate AIM's in-person workshops and to satisfy participants.

Drawbacks: In MSRI's virtual programmatic activities, there was a marked decrease in new collaborations, compared to past in-person activities. Participants in MSRI's summer programs for underrepresented groups in mathematics, ADJOINT and SRiM, greatly preferred meeting in-person. While ADJOINT 2020 shifted to a virtual format, SRiM 2020 was postponed, due to the lack of child care available to the participants. Whether or not AIM's virtual workshops in Sococo will result in as many papers as the in-person workshops will likely be seen within the year. Though the virtual format of IPAM's and ICERM's activities accommodated more participants, participants also dropped out of activities more easily. Replicating spontaneous in- person follow-up discussions and check-ins virtually has not yet been satisfactorily accomplished.

Participant feedback /assessment of virtual activities

MSRI's exit surveys, administered to participants at the conclusion of an activity, were modified accordingly. A significant finding was that the virtual workshop format was disproportionately preferred by younger men participants. IMSI's assessments included questions about platforms, time zone issues, and scheduling.

A significant drop in responses to ICERM's assessments was noted, and assessments requested information on how much of a program was attended. The average participant attended 10-40% of a program's talks, which likely influenced their overall assessment of a program. Generally, participants were less satisfied with virtual activities compared to in-person activities.

At IPAM, some workshop organizers had initially requested postponing their in-person activities rather than shift to a virtual format. IPAM's Directors guided them through the process with a positive result. There was no significant attrition in IPAM's activities.

Plans for fall activities

In early April, MSRI re-opened to members, operating at 25% capacity (15 or fewer members), following the policy of UC Berkeley. It is likely that this capacity will be increased by fall, perhaps to 100%. Both national and International members have already expressed a desire to attend the fall programs in-person. The fall programs will be hybrid; the Simons Auditorium and some offices have been reconfigured to accommodate this. MSRI's policy on vaccination is being developed. UC Berkeley is requiring those on-campus to have been vaccinated, and MSRI may follow suit. Requiring vaccination could affect on-site participation in the programs.

In summer 2021, IPAM will host a small in-person reunion (in June) and a summer school at Lake Arrowhead. Their REU program will likely be held in-person. UCLA has estimated operating at 50-100% capacity in the fall, requiring vaccinations for those on-campus and implementing social distancing protocols. The on-site participation of international attendees,

especially for shorter activities, is uncertain, since IPAM cannot fund their travel and these participants would be required to quarantine.

With a commitment to maintaining hybrid activities in the fall, ICERM will likely be operating at 100% capacity, in accordance with Brown University's policy to welcome all who can attend in-person. Brown University is requiring students to be vaccinated; their policy pertaining to faculty vaccinations will be announced in June. ICERM's summer REU will be held in-person along with a few small collaborative research groups.

In parallel with the University of Chicago, IMSI is planning to be fully open in the fall. A conference scheduled at the end of summer may be held in-person. Two summer schools will be held virtually.

There was an increase in applications for the fall in-person Research Experiences for Undergraduate Faculty (REUF) workshop, an annual, formal collaboration between ICERM and AIM, targeted to leading research mathematicians and faculty based at primarily undergraduate institutions.

Hybrid workshops and other kinds of hybrid events

At ICERM, shorter activities such as workshops could sustain a hybrid model. There is some concern, expressed by IMSI's and MSRI's Directors, that permanent hybrid activities could produce 2 categories of participants, an undesirable outcome that may disproportionately affect participants from underrepresented groups and counter efforts to broaden participation.

Advocacy Letter

MSRI's Committee on Women in Mathematics drafted an Advocacy Letter to address the pandemic's impact on junior mathematicians and women mathematicians, especially those with young children. The letter was subsequently reviewed and revised by the Institute Directors. One additional revision was suggested: change "mathematics" to "mathematical sciences". Following this revision, the Institute Directors will receive a DocuSign request to affirm final approval. The Institute Directors will then determine, via email, where to send the letter. Following this, the NSF Math Institutes site will present the letter, and MSRI will receive and process comments on best practices.

Definition of a virtual participant (Hélène Barcelo)

The Institutes were surveyed regarding their definitions of a virtual participant, and their replies were recorded anonymously. This information was shared at the meeting. A follow-up discussion with the NSF will be held at a later time.

There was a break from approximately 10:33-10:50am.

State of Workforce Programs (postdocs, graduate students, etc.)

Simons Bridge for Postdoctoral Fellowships program: This program will provide additional funding to the Institutes to support postdoctoral fellows starting in the fall 2021 and again in fall 2022. IMSI and AIM did not participate in this program. MSRI formed an ad-hoc committee to review applications. To be eligible, applicants were required to designate their mentor, to be hosted at their mentor's home institution and to not have received other offers. IPAM awarded 3 fellowships and will host these fellows at IPAM. The fellows have mentors at UCLA, and their research is closely aligned with the IPAM's upcoming programs. The fellowships were awarded for 1 year. ICERM funded additional fellows outside of their programs. These fellows have mentors at Brown University or within commuting distance. At MSRI, IPAM, and ICERM, the year-long awards could be extended for an additional year. IAS awarded 4 fellowships, each lasting 2 years.

Information on the job market for postdoctoral fellows and the applications to graduate school (All Directors): Due to the impact of COVID and resulting budget cuts, there will likely be a significant decrease in faculty hiring at academic institutions, a trend which could span several years. Postdoctoral fellows currently or soon-to-be seeking employment are likely to be most affected and thus may pursue external jobs in industry. In hiring postdoctoral fellows, there is no

systematic coordination between the Institutes, but there are rarely hiring conflicts, due to the Institute's intentional diversification in programming. The Institutes have successfully coordinated on initiatives to benefit the fellows post-hiring, such as AIM's workshop on professional development. Funding was not renewed for this popular and beneficial workshop.

Possibilities for increasing the number of postdoctoral positions for US mathematicians and/or US graduate stipends (Juan Meza): The aim of the DMS Workforce Program is to increase the number of well-prepared U.S. citizens, nationals, and permanent residents who successfully pursue careers in the mathematical sciences and in other professions in which expertise in the mathematical sciences plays an increasingly important role. The DMS Workforce Program comprises the following three program solicitations: Mathematical Sciences Postdoctoral Research Fellowships (MSPRF); Research Experiences for Undergraduates (REU) Sites; and, Research Training Groups in the Mathematical Sciences (RTG). These programs may continue to be relevant in future years.

Equity, Diversity and Inclusivity (EDI) initiatives (All Directors, Juan Meza & Ulrica Wilson)

NSF update: Equity, diversity and inclusivity initiatives are a high priority for the Administration, which is reflected in the new MPS solicitations, ASCENDs and LEAPs. In addition, there is a new graduate student supplement to broaden participation, which is eligible to active PIs. In addition, to support new PIs across MPS, DMS co-sponsors annual workshops (virtual in 2021), which include an overview of the review process and panels and a mock review.

Institutes updates:

MSRI:

- ADJOINT is a 2-week summer program designed to provide US researchers, especially those from the African Diaspora, opportunities for in-person research collaboration. Qualified applicants will have already obtained a Ph.D. degree in the mathematical sciences. Researchers at all career stages are invited to apply, and mentoring is a key feature of the program. The program offers additional support to the researchers throughout the following year.
- SriM is a 2-week summer program designed to provide an opportunity for in-person collaboration to small groups of mathematicians, especially women and gender-expansive individuals with already established research projects whose ongoing research may have been disproportionately affected by various obstacles including family obligations, professional isolation, or access to funding. Applications to this program have doubled each year, indicating

high demand. MSRI invited the other Institutes to consider hosting and expanding this program, given demand.

- The workshop on *Mathematics and Racial Justice* will be held virtually in early June for 2 weeks, with the overarching goal of exploring the role that mathematics plays in today's movement for racial justice.

AIM:

- SQuaREs allows a dedicated group of 4-6 mathematicians to spend a week at AIM with the possibility of returning in following years. A SQuaRE could arise as a follow-up to an AIM workshop, or it could be a freestanding activity.
- The *Latinx Mathematicians Research Community (LMRC)*, co-sponsored by the NSF, is a year-long program for early-career Latinx mathematicians which provides tiered mentoring research opportunities, professional development opportunities, and establishes a large research network of Latinx mathematicians.
- Co-sponsored by ICERM and funded by the NSF, the REUF program encourages and supports involvement in research with undergraduates by faculty at colleges and universities that emphasize undergraduate education.

ICERM:

- The primary mission of the *Underrepresented Students in Topology and Algebra Research Symposium (USTARS)* is to showcase the excellent research conducted by underrepresented students studying topology and algebra. USTARS seeks to broaden participation in the mathematical sciences by cultivating research and mentoring networks.
- ICERM will host two workshops to support women researchers in algebraic combinatorics.
- The virtual workshop on *Mathematical and Computational Approaches to Social Justice*, held March 8-10, promoted new areas of research on quantitative approaches to social justice. This workshop was fully funded by a Simons Foundation Targeted Grant to Institutes.

IPAM:

- The *Science Advisory Board*, which approves all scientific programs sponsored by IPAM, is an inclusive group, with significant membership from underrepresented mathematicians.

- In 2022, IPAM will host the third *Latinx in the Mathematical Sciences Conference (LatMath)*, a 3-day meeting which aims to encourage young Latinx to pursue careers in the mathematical sciences; promote the advancement of Latinx currently in the discipline; showcase the research of Latinx at the forefront of their fields; and, build community around shared academic interest.
- There is an upcoming workshop and summer school on algorithmic fairness.

IMSI:

- Hosted by IMSI in fall 2020, the annual *GROW* conference is targeted to female- identified undergraduate students who may be interested in pursuing a graduate degree in the mathematical sciences. IMSI will provide administrative support for *GROW 2021*, which will be held at the University of Illinois, Chicago.
- Co-sponsored by the AMS and IMSI, the *paraDIGMS: Diversity in Graduate Mathematical Sciences* conference aims to build a community of practice for graduate education in mathematics, with the goal of making the profession stronger and more equitable.
- Beginning in 2021, the *Young Scholars Program* at UIC, an expansion of the University of Chicago's Young Scholars Program, is a summer program for middle school and high school students that will focus on excellence and inclusion, allowing many more students from schools throughout Chicago to participate.

IAS:

- Established in 2002, the *Women and Mathematics Program (WAM)* is an annual program with the mission to recruit and retain more women in mathematics, with features tailored to undergraduate students, graduate students, and researchers from a broad spectrum of US institutions.

Promoting events supported through the Math Institutes Diversity Initiative (MSIDI): In 2020, events supported by MSIDI were postponed to 2021 due to COVID. The Blackwell-Tapia conference will be held November 19-20, 2021. LatMath will be held March 3-5, 2022. The Modern Math workshop with SACNAS will be scheduled for fall 2021.

There was a break from approximately 10:47am-12:00pm.

Website/Communications/Outreach

Development of the Math Institutes website (Brendan Hassett): The webpage for the Mathematics Institutes is maintained by ICERM, and the purpose is to provide accurate and up- to-date information on each Institute's activities. ICERM recently updated the site to more clearly advertise the scientific activities offered at the Institutes and to increase transparency about the application processes for these events. ICERM also periodically rebuilds the site in accordance with modern security and architecture standards, while optimizing ease of use. A new iteration is expected in July, which does not deviate greatly from the current version, and mockups will be submitted to the other Institutes for feedback in the coming months.

Institute highlights (Juan Meza): To advertise the success of the Institutes, DMS is requesting that Directors provide more frequent updates on highlights from Institute activities, including research

highlights or research notes. Such updates can be submitted via short emails. DMS will provide feedback on submissions to reflect the usefulness and relevance of these updates.

There was no New Business.

David Eisenbud concluded the meeting at 12:26pm.

F. PARTICIPANT SUMMARY

In this report, we are reporting on participants of programs that took place between June 13, 2020 through June 11, 2021. We have included the participants of the reunion conference. This report does not include the participants of our RIPS/G-RIPS 2021 summer programs which will be captured in the next reporting cycle.

Also note that typically we do not collect RSVPs for "Public Lectures".

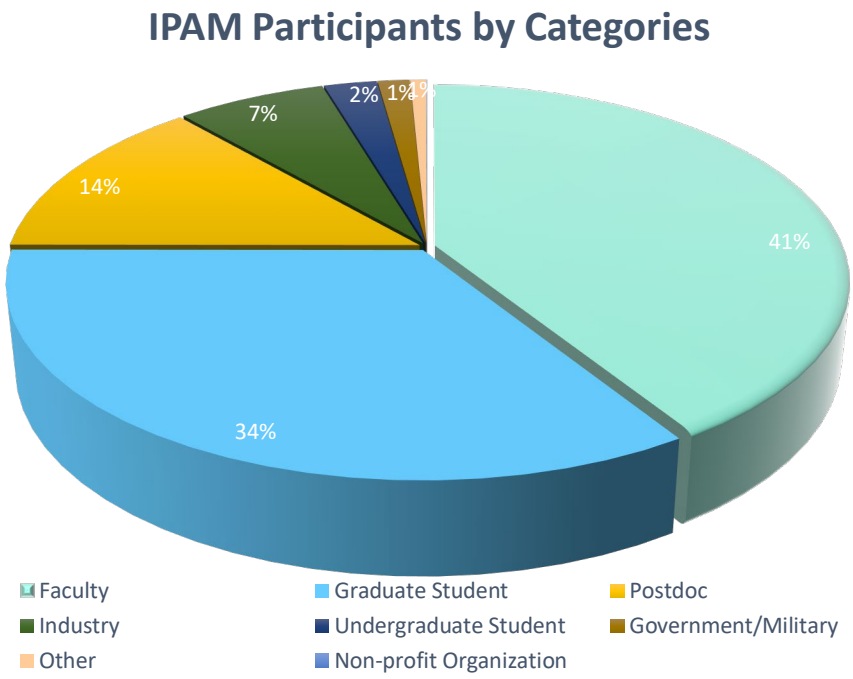
Table F: All Participants' Gender and Ethnicity by Program Type (June 13, 2020 - June 11, 2021)

Program Type	Total Participants	Gender		Underrepresented Ethnic Groups			
		Female	No. Reporting Gender	Amer. Indian	Black	Hispanic	No. Reporting Ethnicity
Long Programs	644	160	628	2	19	34	578
Public Lectures	121	27	115	0	1	7	102
Reunion Conferences	17	3	17	0	0	0	17
Special Events and Conferences	0	0	0	0	0	0	0
Student Research Programs	196	63	190	0	6	18	190
Workshops	2991	741	2853	14	109	197	2536
Total	**3969**	**994**	**3803**	**16**	**135**	**256**	**3423**
Percent of No. Reporting:		25%	95.82%	0.40%	3.40%	6.45%	
	All underrepresented ethnic groups:				*407*	*10.25%*	

There were 2,547 unique participants for this same period. (Some of the participants attended more than one program, usually multiple workshops within a long program.) Out of those reporting gender, 25% were women. Out of those reporting ethnicity, 11% of unique participants were members of an underrepresented ethnic group.

It is worth noting that due to safety concerns and the travel restrictions brought on by the COVID pandemic, all IPAM activities, including the long programs in fall 2020 and spring 2021 and their associated workshops, were held in a virtual format. This led to a higher number of international participants than we usually experience. The programs in general were quite successful and we received a lot of positive feedback in follow-up surveys.

The majority of IPAM participants were faculty and graduate students. See the pie chart below for the percentage of participants in each category.



G. POSTDOCTORAL PROGRAM SUMMARY

536 postdocs participated in many of IPAM's programs during the reporting period (June 13, 2020 - June 11, 2021). 6 postdocs participated in IPAM's student research program, RIPS, as academic mentors. See table G.

Table G: Postdocs' Gender and Ethnicity by Program Type (June 13, 2020 - June 11, 2021)							
Program Type	Total Participants	Gender		Underrepresented Ethnic Groups			
		Female	No. Reporting Gender	Amer. Indian	Black	Hispanic	No. Reporting Ethnicity
Long Programs	99	32	96	0	0	9	83
Public Lectures	12	5	10		0	0	9
Reunion Conferences	2	1	2	0	0	0	2
Special Events and Conferences	0	0	0	0	0	0	0
Student Research Programs	6	0	6	0	0	3	6
Workshops	417	109	394	0	12	38	352
Total	**536**	**147**	**508**	**0**	**12**	**50**	**452**
Percent of No. Reporting:		27%	94.78%	0.00%	2.24%	9.33%	84%
		All underrepresented ethnic groups:			*62*	*11.57%*	

H. GRADUATE STUDENT PROGRAM SUMMARY

Graduate students participated in IPAM's workshops and long programs during the reporting period, as well as in Graduate-level RIPS. A few participated in RIPS-LA as academic mentors. Graduate students often find a compelling thesis topic at an IPAM program, and also frequently make contacts that lead to their first jobs. See table H or further breakdown.

Table H: Graduate Students' Gender and Ethnicity by Program Type (June 13, 2020 - June 11, 2021)							
Program Type	Total Participants	Gender		Underrepresented Ethnic Groups			
		Female	No. Reporting Gender	Amer. Indian	Black	Hispanic	No. Reporting Ethnicity
Long Programs	208	59	196	1	9	15	193

Public Lectures	26	9	26	0	1	3	23
Reunion Conferences	3	1	3	0	0	0	3
Special Events and Conferences	0	0	0	0	0	0	0
Student Research Programs	22	7	22	0	0	3	22
Workshops	1092	292	1047	4	44	86	946
Total	**1351**	**368**	**1294**	**5**	**54**	**107**	**1187**
Percent of No. Reporting:		27%	96%	0.37%	4.00%	7.92%	87.86%
	All underrepresented ethnic groups:				*166*	*12.29%*	

I. UNDERGRADUATE STUDENT PROGRAM SUMMARY

Typically, undergraduate students participate in RIPS-LA and RIPS-Singapore, and RIPS Projects Day. Due to safety concerns, RIPS and GRIPS 2020 were hosted virtually, centered at Los Angeles. RIPS Singapore (and GRIPS Sendai, and GRIPS Berlin) were cancelled.

Table I: Undergraduate Students' Gender and Ethnicity by Prog. Type (June 13, 2020 - June 11, 2021)

Program Type	Total Participants	Gender		Underrepresented Ethnic Groups			
		Female	No. Reporting Gender	Amer. Indian	Black	Hispanic	No. Reporting Ethnicity
Student Research Programs	96	45	93	0	0	12	93
Total	**96**	**45**	**93**	**0**	**0**	**12**	**93**
Percent of No. Reporting:		47%	96.88%	0.00%	0.00%	12.50%	97%
	All underrepresented ethnic groups:				*12*	*12.50%*	

J. PROGRAM DESCRIPTION

COVID-19 Advisory: In abidance with LA County and California State mandate, IPAM held all programs over March 16, 2020 through June 5, 2021 virtually. Workshop registrants received Zoom links along with instructions a few days prior to the workshops. The video recordings of the sessions were made available on IPAM website. Participation was free of charge.

STUDENT RESEARCH PROGRAM: Research in Industrial Projects for Students (RIPS) and Graduate Research in Industrial Projects for Students (G-RIPS) Los Angeles 2020. JUNE 22 - AUGUST 21, 2020.

The Research in Industrial Projects for Students (RIPS) Program provides an opportunity for talented undergraduates studying math, computer science, and related disciplines to work in teams on a real-world research projects proposed by sponsors from industry or the public sector. Each student team, with support from their academic mentor and industry mentor, researches the problem and presents their results, both orally and in writing, at the end of the program. The REU program is nine weeks. IPAM provides each undergraduate student with a stipend of $3,500. IPAM organizes two RIPS cohorts every year: one at the UCLA campus in Los Angeles, and another in Singapore.

Graduate-Level Research in Industrial Projects for Students (G-RIPS) offers graduate level students in mathematics and related disciplines the opportunity to work on industry-sponsored by our partners in Germany and Japan. Students from the U.S. and the host country get to work on cross-cultural teams on research problems designed by industrial sponsors. The projects are of serious interest to the sponsor and offer a stimulating challenge to students; most involve both analytic and computational work. At the end of the program, the teams present the results of their work and prepare a final report. IPAM encourages the U.S. students to publish and/or present their research at conferences in the year following the program. English is the only language required for participation.

In a typical year, round-trip travel and accommodations costs are covered by IPAM. Students also receive a meal allowance and a stipend, and conference support to present their research. These terms apply to U.S. participants recruited by IPAM.

Due to the unprecedented global outbreak of COVID-19, our partners in Singapore, Germany, and Japan made the difficult decision to cancel hosting RIPS and G-RIPS programs in foreign locations in 2020. As an alternative, we created a modified version of the program in Los Angeles that combined both RIPS and G-RIPS held virtually.

35 students participated in the combined RIPS 2020. Of them, 3 were part of G-RIPS.

2020 Sponsors	Project description
Aerospace Corp	A Reinforcement Learning Approach to Dynamic Network Routing
Air Force Research Laboratory	An Unstructured Mesh Approach to Nonlinear Noise Reduction
Alibaba	Large-Scale Inventory Optimization
Aquatic	Memory-Bound Elastic Net Over Dense Matrices with Applications in Quantitative Trading
AMD	Emulating Ray Tracing using Machine Learning
Google LA	Measuring and Improving Result Quality Within the Privacy Framework of Google's Ads Data Hub
HRL	Analyzing, Predicting, and Mitigating Defect Formation in Metal Additive Manufacturing
LLNL	Parallel Time Integration for Constrained Optimization
AMD (G-RIPS)	Using Machine Learning as an Alternative Wave Function Ansatz to Improve Variational Monte Carlo

Project 1: Aerospace Corp.

Routing of information in dynamic networks is a challenging problem due to large design space and complex objectives. The ever-growing demand for efficient and reliable transfer of information among the nodes of the network imposes additional constraints. Common approaches to this problem, often generic and based on static network assumptions, are not able to capture constantly changing networks and high-load dynamic conditions that appear in modern-day space communication systems.

Students used a reinforcement learning-based tool for dynamic network routing taking advantage of state-of-the-art machine learning techniques. The proposed implementation was to be compared against classical implementations in terms of average delivery time for packets and load requirements.

Desired Skills: Students would ideally have a background and experience in Python Programming, Communication Networks, Machine Learning and Optimization Concepts.

Project 2: Air Force Research Laboratory

Cross maps are typically constructed between different observables of a coupled nonlinear system by exploiting time-delay embedding. They typically lead to optimal reconstructions as

the amount of data collected increases. The goal here is to reconstruct multiple high speed current signals taken from different locations within a coupled plasma system; however, if the signal to noise ratio is poor, the reconstructions can fail to converge towards perfect reconstruction either because of true noise or additional unresolved dynamics present in the signal. Students worked on a state-based sampling method recently developed and considered an unstructured grid. The convergence behavior of this unstructured approach as the number of samples and cells is increased was explored first for a simple chaotic ODE, the Lorenz system. The method was then be applied to a pair of experimental signals from a Hall Effect thruster experiment that has already been shown to produce high quality cross map reconstructions. The applicability of the approach to real experimental measurements was then evaluated.

Desired skills: Students would ideally have a background and experience in Python/Matlab; Secondary desired skills: Differential Equations, Numerical Methods (ODE Integrators/Convergence Metrics/etc.), Statistics (Pearson Correlation, Nonparametric Density Estimation), Dynamical Systems Theory, Control Theory.

Project 3: Alibaba

How to best match products to consumers? This is a large-scale mathematical optimization problem for finding the best allocation between demands and supplies. For instance, for product recommendation, we need to present diversified and well-selected assortments on web pages in order to maximize consumer engagement (e.g., clicks, purchases, dwell time). Meanwhile, there are inventory and other business constraints that limit the total numbers and the frequencies of product deliveries. The underlying task is, therefore, to globally maximize consumer engagement while satisfying all the inventory constraints.

Students had access to the sponsor's general-purpose mathematical solver and were expected to develop problem decomposition and stochastic sampling techniques and try them on a large test dataset.

Desired skills: Students would ideally have a background and experience in Python, Stochastic analysis.

Project 4: Aquatic

Trading strategies based on quantitative analysis rely on mathematical computations and number crunching to identify trading opportunities. The team researched the current state of the art Coordinate Descent (CD) and/or Alternating Direction Method of Moments (ADMM) or another

competitive method and modified the algorithm to optimize its performance on two sample optimization problems arising in automated securities trading.

Desired skills: Students would ideally have a background and experience in applied numerical optimization and computer science. The team will benefit from experience in Python to prototype and C/C++ to optimize performance.

Project 5: AMD

Ray tracing is a technique for rendering images whereby the path of light from different sources is traced across the pixels in an image and the interaction of the light paths with objects in the scene is simulated. Ray tracing has been used for many years in rendering images, especially in films. While the results of ray tracing can lead to very realistic looking images, ray tracing is a computationally intensive task. As such, rendering images in real time using ray tracing has not been feasible. However, emerging GPU architectures are beginning to support ray tracing algorithms in hardware, enabling real-time ray tracing. This project sought to study the emulation of ray tracing in images using machine learning.

This project explored common frameworks and algorithms in generative modeling, with the objective of building models that automatically generate images that appear to have been rendered using ray tracing. The results of this study will be applicable to any rendered image of a three-dimensional scene.

Desired skills: Students would ideally have a background and experience in Machine Learning, Programming in Python in Linux environments.

Secondary desired skills: Programming with C++; Tensorflow, CAFFE2, PyTorch; Numerical mathematics, Numerical Linear Algebra; Applied mathematics; Optimization.

Project 6: Google LA

The goal of this project was to develop metrics to evaluate customer success when accessing a list of queries on a database, in the presence of late-arriving data. The students also explored techniques the customer can use to increase their success according to those metrics, and develop alternative differential privacy techniques. Techniques such as adding noise to a customer's query result may satisfy customer needs while adequately protecting privacy.

Desired skills: Students would ideally have a background in statistics, programming, modeling and simulation.

Project 7: HRL

Additive manufacturing has the potential to drastically alter the design and fabrication of functional materials. The goal of this project was to develop high throughput software for analyzing datasets from two experimental techniques to detect defects in such materials. The defect correlation analysis that we envision would make use of computer vision (on static images/volumes), feature engineering (e.g. volume averaging, incorporating lumped parameter heat transfer models, interpolation schemes), and machine learning classification algorithms available in existing software frameworks (e.g. Keras, PyTorch, Scikit-learn) to develop software aiding in the analysis of existing and future datasets.

Desired skills: Students would ideally have a background and experience in programming (e.g. Python), basic statistics, basic physics (e.g. diffusion, heat transfer).

Project 8: LLNL

Many optimization problems are time dependent, for example, optimizing the shape of a car or an airfoil to minimize drag. These applications traditionally involve sequential time marching both forward and backward in time. Unfortunately, the traditional simulation approach of sequential time marching is becoming a bottleneck as computer architectures must increasingly rely on higher concurrency to provide greater peak performance.

This project investigated the performance of a new parallel time integration solver for time dependent constrained optimization problems. It is a project in scientific computing and numerical analysis. Some basic understanding of partial differential equations, non-linear dynamics, discretization, and numerical algorithms is desirable.

Desired skills: Students would ideally have experience in programming in C or C++.

Project 9: AMD (G-RIPS)

QMCPACK is a quantum Monte Carlo code that leverages stochastic integration to solve the weak formulation of the Schrödinger equation. Solutions to Schrödinger's equation describe not only molecular, atomic, and subatomic systems, but also macroscopic systems, and is used to predict electronic structure of chemical, physical, and materials problems of interest. The QMCPACK application is expected to scale to the entire machine. To ensure application readiness at this unprecedented scale, this project aimed to identify the key compute kernels in QMCPACK and explore methods for accelerating them. Objectives of this project included:

Identify key performance elements of QMCPACK, optimize key kernels for performance at exascale, accelerate key kernels using machine learning, and potentially, publication of the methods and results.

Note: G-RIPS is partially supported by an IRES grant from NSF's Office of International Science and Engineering.

Comments from our participant survey:

"I think that this program was amazing considering it was online! I know that if it was in person it would have been even more exceptional, but I think it was organized the best it could have been online. It exceeded my expectations! I would have loved some more guest speakers but again it is understandable that the timing was not easy to come by with participants in different time zones as well."

"Both my industry and academic mentor were extremely helpful and available/willing to make time despite being in different time zones."

"Experience working in math industry was very valuable to me and exactly what I was looking for"

"This was the perfect program for me to gain insight into the math industry world, and Iam so excited to continue on my path towards this!"

"Coming from an internship with a Big 4 Accounting firm last summer, I greatly wanted an experience that would show me math in industrial settings and give me research background (something I did not get much of as an undergrad due to my time on a varsity athletic team). In 9 short weeks, I feel I have gained so much knowledge on research from how to ask a research question, draft a work statement, and actually conduct the research. It gets me really excited to know I can look beyond consulting, which did not get me nearly as excited as this summer's work did."

"RIPS has given me a lot more confidence in this field."

"IPAM did a great job of adapting the program to an online environment!"

"The online transition couldn't have been handled better."

"I think the program went really well especially considering it was online! Huge thanks to

everyone on the RIPS staff."

"I really liked my team. I honestly felt very lucky to be placed on it. There were moments I worried about how much I was contributing, but my team really helped me and inspired me to learn more. I felt that I grew a lot as a mathematician this summer."

"I would just like to thank everyone who organized this program and for all the help and support that was provided to us all! It was amazing and very impressive, especially in its online format. I do wish we had more social time to engage with others outside of the groups, but I think the social hours were great as they were. It is unfortunate that Zoom makes it harder to fully engage with everyone in the larger calls, but obviously there was no way around that. I hope that we will be able to meet in the future because doing REUs in person and engaging face to face is definitely a much different experience than behind a computer on Zoom. I think that the program was as amazing as it could be without having the in-person resources and engagements, and the organizers did their absolute best in finding ways to engage and still make this program as successful as it was! Thank you so much for this opportunity!!!"

"It was an extremely valuable experience for future career options. And very valuable connections with people were made."

"the heavy feedback on presentations definitely both clarified my thinking and made me a better presenter. i will use these skills going forward."

SPECIAL EVENT: Mathematical Models in Understanding COVID-19. AUGUST 10 - 12, 2020.

Organizing Committee:
Andrea Bertozzi (University of California, Los Angeles (UCLA), Mathematics)
Joel Miller (La Trobe University, Mathematics and Biology)
Mason A. Porter (University of California, Los Angeles (UCLA), Mathematics)
David Schriger (University of California, Los Angeles (UCLA), Emergency Medicine)

The emergence of the COVID-19 pandemic is forcing policymakers to make crucial decisions about unprecedented scenarios. Mathematical models allow us to leverage available data to forecast the impacts of different policies using computational experiences. As a result, mathematical modeling has had a major effect on COVID-19-related policy decisions around the world. A wide range of models have been used to inform decisions from nationwide lockdowns and testing policies to targeting strategies of contact tracing.

The implementation and effectiveness of policies have been influenced by the quality of the mathematical modeling, the communication of the modeling, and the communication of the policies. Although there are some success stories, models have also sometimes been misused or misunderstood in designing policy. Models and policy will be most effective when (1) the modeling is appropriate to the situation at hand, and (2) the public understands and buys into the policy aims. It is also crucial to develop policy as important questions arise. For example, how can low- and middle-income countries (LMIC) cope with the impact of COVID-19 and the impact of policies to mitigate its spread? Additionally, how can we understand the heterogeneous situations – in concert with heterogeneous policies and behaviors of people – in the United States, Europe, New Zealand, and elsewhere?

IPAM hosted a virtual three-day workshop on the interactions between mathematical modeling, public policy, and science communication for the COVID-19 response. Each day started with an overview lecture followed by a panel of experts in these areas.

Comments from our participant survey:

"Comments from our participant survey"

"Excellent indeed."

"Incredible talks."

"I was skeptical at first, but happily surprised by how interesting and diverse it was."

"Very enriching as they give a deeper perspective and can suggest modeling parameters."

"I really enjoyed days 2 and 3 of the workshop. It was helpful to get insights from people who interact with policymakers."

"Mr. McFarland was great at providing detailed instructions regarding the workshop and how to access the webinar; he also made sure to readily answer to all my questions. Excellent workshop"

"The workshop was great, in particular, the organization was flawless. Thank you."

"Very much enjoyed the event; got some very good pointers to material I will follow up. Many thanks."

"This was an excellent workshop. I really liked the mix of mathematics, biology, epidemiology, public policy and especially people from health departments. The variety of models was also good to see."

"There was a real plus to being able to clearly see and hear all speakers from different locations. Not having to travel to attend was also a plus. In the future, simulcast with in person and webinar would be good. There is a bit of a loss in not being able to mingle with speakers and other participants. This could be handled by having some breakout rooms for interaction over coffee at breaks. I did not even have a sense of who participated."

"The organization was spectacular."

"Aside from just the time change everything was perfect and easy, the countdown clock between sessions was helpful."

"I think this was a great effort on the part of the organizers and I would like to commend you. I look forward to future programmes including mathematical modeling using software applications in MATLAB, R etc."

"The workshop was very useful and attractive. It gives great opportunities to see problems in different perspective. Thank you IPAM and Organizes!"

"You did great. I was impressed. And educated!"

WORKSHOP: RIPS Projects Day, AUGUST 20, 2020.

The nine RIPS and G-RIPS Los Angeles teams virtually presented their industry-sponsored research on the projects listed above. Representatives of the industry sponsors, academic mentors, IPAM supporters, and members of UCLA's math and science community were in attendance.

LONG PROGRAM: Mathematical Challenges and Opportunities for Autonomous Vehicles. SEPTEMBER 14 - DECEMBER 18, 2020.

Organizing Committee:
Ruzena Bajcsy (University of California, Berkeley, CITRIS)

Paola Goatin (INRIA)
Jana Kosecka (George Mason University)
Hani Mahmassani (Northwestern University)
Benedetto Piccoli (Rutgers University)
Benjamin Seibold (Temple University, Mathematics)
Jonathan Sprinkle (University of Arizona, Electrical and Computer Engineering)
Daniel Work (Vanderbilt University)

Autonomous vehicle (AV) research and development has achieved a similar status in terms of money invested, societal excitement, and media coverage as space travel and exploration. At the same time, AV research is not rocket science; it is more complicated: while in itself, an AV is no more complex than a spacecraft, it must reliably interact and communicate with many other agents, particularly humans both inside and outside of the vehicle, much of it in a decentralized fashion. Hence, AVs, and their impact on us humans and our transportation systems, incur some of the most complicated science and engineering challenges that we shall face in the near future. At the same time, there is some disconnect across the various research communities: professional product development is highly opaque, and public expectations and media communications are frequently inaccurate or exaggerated.

This long program aimed to address these problems by connecting research communities, bridging gaps between theory and practice, exposing software experts to hardware and vice versa, and bringing mathematicians, other scientists, and engineers together to shape the research and development agenda on AVs, both in terms of individual and holistic components.

Key mathematical themes in this program were:

- Robustness of machine learning
- Connecting micro and the macro scales
- Reinventing traffic flow theory in a non-local world
- Multi-agents systems, sparse controls, distributed leaders
- Fleet optimization and routing in a fully connected world
- Mathematics of societal impact of AVs

Comments from our participant survey:

“The virtual meetings and workshops are really great and exceed my expectation. IPAM's online experience is so far the best among other virtual conferences I attended including NeurIPS and CVPR.”

"The combination of Sococo and Zoom is great. Sococo is great for more casual discussions and working group meetings."

WORKSHOP: Mathematical Challenges and Opportunities for Autonomous Vehicles Tutorials. SEPTEMBER 15-25, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

Organizing Committee:
Ruzena Bajcsy (University of California, Berkeley, CITRIS)
Paola Goatin (INRIA)
Jana Kosecka (George Mason University)
Hani Mahmassani (Northwestern University)
Benedetto Piccoli (Rutgers University-Camden)
Benjamin Seibold (Temple University, Mathematics)
Jonathan Sprinkle (University of Arizona, Electrical and Computer Engineering)
Daniel Work (Vanderbilt University)

The program opened with nine half days of tutorials that provided an introduction to major themes of the entire program and the four workshops. The goal was to build a foundation for the participants of this program who have diverse scientific backgrounds.

WORKSHOP: Individual Vehicle Autonomy: Perception and Control. OCTOBER 5 - 9, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

Organizing Committee:
Wolfram Burgard (Toyota Research Institute)
Jana Kosecka (George Mason University)
Adam Oberman (McGill University, Mathematics and Statistics)
Stefano Soatto (University of California, Los Angeles)

Modern automated vehicle platforms combine large volumes of data into decisions using techniques that are increasingly powered via artificial intelligence that learn and change over time. Artificial intelligence techniques have provided several breakthroughs to bring forth automated vehicles that, in demonstrations, can be shown to operate similar to human drivers.

Challenges include: 1) interpretability of decision making; 2) safety for data-driven systems (e.g., assuring safety of systems composed of learning-enabled components; generalizing to rare and unsafe events); 3) robustness of machine learning algorithms, particularly robustness of deep learning for perception and control to adversarial attacks on extreme and real but previously unseen environments; 4) development of reinforcement learning algorithms that are resistant to reward hacking, or are required to search dangerous or unsafe parts of the state space, etc. Moreover, there is no established notion of what precisely constitutes safe, efficient, or even natural driving when immersed on a highway with other human drivers; and depending on the level of autonomy, the AI will need to interact with the human in the vehicle.

This workshop brought together researchers working on the theoretical sides of deep learning techniques for perception and control of automated vehicles with researchers interested in assuring these autonomous systems operate with safety guarantees. Moreover, experts in sensing and imaging technology were brought to the table to cover the full pipeline from the collection of the data, over the AI theory and development, all the way to the software and actuation challenges. Additional themes addressed in this workshop included interactions between vehicle sensing and the infrastructure, and cybersecurity aspects related to sensing and machine learning (how to purposefully mislead sensors and AI).

This workshop included a virtual poster session.

Comments from our participant survey:

“Keep doing the good work. Also, the present online format helps people like me from another country attend the workshops virtually; it is a blessing!”

“My expectation entering the workshop was that there would be more explicit link/ description of AV "perception" (feature representation, feature importance, and feature independence) with deployed models. I still learned a lot and thought the talks were interesting.”

“it's hard to be a speaker when you can't get feedback from the audience. I miss being there in person. However, given the situation, I don't have any idea how it could be better.”

“thanks for a great workshop. thanks to the staff for excellent organization.”

WORKSHOP: Safe Operation of Connected and Autonomous Vehicle Fleets. OCTOBER 26 - 30, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

Organizing Committee:
Ruzena Bajcsy (University of California, Berkeley, CITRIS)
Lillian Ratliff (University of Washington)
Richard Sowers (University of Illinois at Urbana-Champaign)
Jonathan Sprinkle (University of Arizona, Electrical and Computer Engineering)
Daniel Work (Vanderbilt University)

The goal of ensuring safe mobility has been at the forefront of government agencies and industry since the introduction of the mechanized transportation. Connected vehicle technologies were initially introduced to allow vehicle to vehicle and vehicle to infrastructure systems to enable the next generation of safe vehicles. Similarly, autonomous vehicles have often been looked at as a way to reduce accidents and fatalities, often associated with human error. However, fulfilling the promise of vision zero (zero deaths, accidents, etc.) is still a long way off (or maybe not possible at all?). This workshop was aimed at understanding if it is possible to build provably safe vehicles that operate in the presence of humans, both as passengers of the AVs and as pedestrians, bicyclists, etc. Techniques from the formal methods communities have already been successfully applied to a number of cyber-physical systems including industrial automation and the aerospace industry, however autonomous driving presents a new generation of problems. Specifically, formal methods have been quite successful in the past at analyzing systems (e.g., controls systems) which do not learn over time and do not directly interface with complex human interactions. In contrast to today's promising advances in machine learning based sensing and driving best exemplified by many of the recent impressive technology demonstrations, ensuring safety for learning-based systems is an open question. This workshop was aimed at bringing together the formal methods community and the transportation community to understand how to build safe systems in the extremely complex driving environments where humans and robots will interact.

This workshop included a virtual poster session.

Comments from our participant survey:

"I really enjoyed the experience and everything went smoothly"

"Surprisingly good experience"

"Very friendly atmosphere, nice chats in the breakout rooms, very well managed workshop webpage. Too bad not to be in person, but there will be future opportunities. Thank you all!"

"The talks very highly informative and competent"

WORKSHOP: Large Scale Autonomy: Connectivity and Mobility Networks. NOVEMBER 16 - 20, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

Organizing Committee:
Paola Goatin (INRIA)
Hani Mahmassani (Northwestern University)
Monica Menendez (New York University Abu Dhabi)
Samitha Samaranayake (Cornell University)
M. Grazia Speranza (Università di Brescia)

A critical question is how to predict and manage the emergent properties of a transportation system that relies on increasing degrees of automation and artificial intelligence. Connectivity between vehicles on the roadway can enhance safety, but it also introduces non-local information flows that can change the dynamics of the flow of traffic. On the operational side, mobility-as-a-service forms are pushing the limits of real-time, demand responsive vehicle scheduling algorithms that are central to sharing a large fleet of automated vehicles. On the transportation management side, competing fleets of AVs have potential to destabilize emergent traffic patterns if they are too aggressive and do not cooperate. This workshop aimed to bring together the essential communities from mathematics and engineering to address these forthcoming issues central to our future transportation systems. It brought together operations research experts developing the next generation of dynamic fleet dispatching and optimization algorithms vital to mobility on demand services, transportation engineers responsible for planning the future of our public and private transportation systems, and modelers responsible for predicting new congestion dynamics at local and city scales. The workshop also explored how these systems will operate in city, suburb, and rural contexts to support mobility needs for people and goods.

This workshop included a virtual poster session.

Comments from our participant survey:

"It was the best or one of the best online workshops/conferences I have attended. I just find inperson workshops much better."

"The lectures were effective, in my opinion, more effective than in-person (thanks to IPAM staff!). But, being remote, opportunities to interact with other participants was not as effective as in-person."

"The IPAM staff were absolutely amazing, in everything they did!"

"Absolutely incredible support and organization from IPAM staff"

"Nice work by the staff and organizers to keep the spirit up despite the difficult situation."

"Thank you IPAM staff for a terrific job under challenging circumstances. Can't wait for the next opportunity to meet and work in person."

WORKSHOP: Social Dynamics beyond Vehicle Autonomy. NOVEMBER 30 - DECEMBER 4, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

Organizing Committee:
Spring Berman (Arizona State University)
Sebastien Motsch (Arizona State University)
Benedetto Piccoli (Rutgers University)
Joan Walker (University of California, Berkeley)

In some application fields, automation will eventually remove humans from the loop, and autonomous systems will operate far away from any human agents. Not so with autonomous vehicles. Recent trends in urbanization are showing that future cities will flourish with human activity (pedestrians, bicycles), and autonomous vehicles will need to actively work with and around the humans. The development of autonomous vehicles can therefore not be undertaken without a better understanding of human nature, including but not limited to: pedestrian motion and decision-making, heterogeneous traffic (bicycles, mopeds, buses, cars), cyber-security, and crime modeling. At the same time, with full autonomy (level 5, which removes the human from the driving process), a fundamental paradigm shift will occur in how we, as humans and as a

society, will see, perceive, and interpret the process of driving. Who is operating the vehicle? Who is responsible if an accident occurs? Will there be a central control entity, or must one aim for decentralized controls? What degree of connectivity and information exchange is desirable? How can such human-in-the-loop cyber physical systems be efficiently designed, particularly when many other vehicles are not fully autonomous yet? What is the role of public and private entities in our future transportation systems? What are the ethics of programming a level 5 AV? This workshop brought together researchers from a variety of disciplines, including experts on social/behavioral, ethics, legal, and policy aspects, as well as researchers working on other heterogeneous systems (swarming and animal motion/migration, distributed leaders and sparse control, cell biology) that can serve as inspirations.

This workshop included a virtual poster session.

Comments from our participant survey:

"Really amazing staff and the work conducted at IPAM. It was really exciting to see all the workshops and the fruitful results they could lead to."

"While the digital format was effective for the talks, it was more difficult to interact with the speakers and other participants after/between talks."

"Thanks to the schedule (being based in Europe, it was convenient)"

WORKSHOP: Autonomous Vehicles Culminating Retreat at Lake Arrowhead.
DECEMBER 13 - 18, 2020.

Part of the Long Program "Individual Vehicle Autonomy: Perception and Control".

The culminating workshop (along with the Reunion Conferences) could not be held at Lake Arrowhead as per tradition due to the COVID-19 pandemic. Instead, a 4-day workshop was held over zoom which was quite successful.

REUNION CONFERENCE: Quantitative Linear Algebra Reunion Conference II.
DECEMBER 13 - 18, 2020.

The Reunion conference was postponed due to the COVID-19 pandemic. We plan to arrange the event at a later time.

REUNION CONFERENCE: Geometry and Learning Reunion Conference I. DECEMBER 13 - 18, 2020.

The Reunion conference was postponed due to the COVID-19 pandemic. We plan to arrange the event at a later time.

REUNION CONFERENCE: Big Data Meets Large-Scale Computing Reunion Conference I. DECEMBER 13 - 18, 2020.

The Reunion conference was postponed due to the COVID-19 pandemic. We plan to arrange the event at a later time.

WORKSHOP: Transport and Mixing in Complex and Turbulent Flows. JANUARY 11 - 14, 2021.

Organizing Committee:
Colm-cille Caulfield (University of Cambridge)
Charles Doering (University of Michigan, Complex Systems, Mathematics and Physics)
Anna Mazzucato (Pennsylvania State University)

Transport and mixing are among the most important properties of fluid flows. Indeed, movement of mechanical and thermal energy and material underlies the most basic dynamical phenomena in astrophysics, geophysics and the environment, as well as in biology and myriad industrial and engineering applications. Understanding the fundamental mechanisms and ways to control, bound, limit or enhance transport and mixing are central to many active research fields. The primary objective of this workshop was to bring together mathematicians working on theoretical aspects of fluid mechanics, transport, mixing, and computational aspects of fluid dynamics and data science, with applied scientists working on quantitative modeling and experimental aspects of mixing and transport phenomena. Recent theoretical developments combined with the explosion of data available from observations, experiments and simulations made this an especially appropriate time to bring these disparate communities together to cross-pollinate insights and encourage knowledge transfer and creation.

This workshop included a virtual poster session.

Comments from our participant survey:

“This online workshop was surprisingly effective. I usually dislike online workshops, this one was very good.”

“It was the best online meeting that I have attended since the pandemic began, in terms of organization and ability to interact with others. In-person is still preferable in my opinion.”

“The limitations [of virtual format] are more than compensated by saving the time and cost of travel”

“More efficient (couldn't have been there in person), though meeting people in person cannot be fully replaced”

“Although I thought this was extremely well run as workshops go, the chance conversations one can have over coffee when in person are what I miss.”

“The IPAM staff have done a great job to make the whole process as smooth as possible, and I appreciate their hard work.”

“It was very well run all through.”

“Better than in person because the coordinator has tools for orderly management”

“The zoom breakout rooms after talks were a good idea.”

“Software and technical support from the IPAM staff was really good. The online format increased the outreach aspect and allowed me e.g. to participate. This was great. Handling of poster, display, and lightning round was good, too. Slides + recorded talks are great to catch up on a missed talk.”

“Given the circumstances, if seems to me that the chosen format is rather effective. The talks and the question times are as effective as in person. Casual interaction is hard to replace. I am convinced that we can easily transfer to online all the "planned" aspects of our research, but it is very hard to do the same for the many "unplanned" aspects...”

“Good balance between math and physics. Keep that up.”

“Given the circumstances, the chosen format has probably been the best option!”

"Posting of youtube videos swiftly was extremely helpful, particularly when we missed the live streams."

"It was really good"

"Clearly, opportunities for discussion were restricted in the online settings, but I think the workshop was very good given the circumstances."

"The IPAM team is fantastic. I wish we could be in person."

"Great work and great support by the IPAM staff! I am looking forward to visiting in person when possible!"

WORKSHOP: Actions of Tensor Categories on C*-algebras. JANUARY 21 - 28, 2021.

Organizing Committee:
David Penneys (Ohio State University, Mathematics)
Emily Peters (Loyola University, Chicago)
Aaron Tikuisis (University of Ottawa)
Stuart White (University of Oxford)

Classical group actions on spaces can be viewed as symmetries of the corresponding operator algebra of continuous or measurable functions on the space. This vastly generalizes to quantum symmetries on non-commutative spaces. The underlying space is replaced by a non-commutative operator algebra, and the group action by the more general notion of symmetry via tensor categories.

Many major recent breakthroughs in the classification of C*-algebras of finite topological dimension have been underpinned by the large scale transfer of von Neumann techniques on multiple levels. Today C*-algebras stand at exactly the analogous stage to where von Neumann algebra theory was around the early '80s when Jones' pioneered subfactor theory.

The overarching objective of this workshop was to bring together researchers at the interface of the rapidly developing areas of the structure and classification of C*-algebras and subfactor theory/tensor categories. Advanced minicourses (Jan 21-22) enabled a rich dialogue between the two communities, and participants left with many new problems to explore, as well as deeper insights about how C*-algebraic and von Neumann algebraic techniques interact.

Comments from our participant survey:

“In terms of delivering lectures, this was as effective if not more effective. However, social interactions were obviously hampered by the constraints imposed by Zoom. It's not possible or at least not easy drop in and out of conversations.”

“The online workshop was effective and was the smoothest online conference I have been to. However, it still does not compare with an in person conference -- especially for a workshop such as this where the goal is to get two different communities are researchers together to exchange ideas. There are various complications such as differences in time zones between participants and obligations that participants have at their homes and local institutions that make zoom conferences less useful, and I don't think there is any real way around this.”

“This was one of the best online workshops I have attended so far.”

“It was excellent. No comments on improvement.”

“The IPAM staff did a wonderful job in making this on line workshop a success. This is one of the best on line experiences I had during the pandemic. Obviously, a real gathering of people at IPAM would be better and would have all the advantages of informal meetings and discussions, which cannot really be imitated on line.”

“The staff did a great job of communicating information related to the running of the workshop their modes of delivery were informative and frequent without feeling overwhelming.”

“The online format allowed me to participate without having to spend time and money for international travel. I guess this is also good for our carbon footprint.”

“I likely would not have been able to attend the workshop in person, so this online format was very beneficial for me.”

“The broad spectrum of topics covered was amazing.”

“The mini courses were especially helpful.”

“The workshop was very well-organised.”

“The discussion sessions between talks (both the formal ones and the informal ones) were very

helpful."

"The communications from the organizers to the speakers in advance, when it was to be determined how to run the workshop virtually, made it clear that they truly cared about our needs. I myself didn't have special needs but it still affected my sense of feeling valued in the community."

"The entire IPAM team was exceptional, especially Roland and Kayleigh. Thank you all for creating a very well-run virtual workshop."

"I have been to more than one virtual workshop at IPAM and when it ends, I always feel impressed with the professionalism of the staff and the seamless way in which the events are orchestrated."

"I benefited from participating. Thanks for the opportunity!"

"The breaks and the breakout rooms were quite nice and the staff was quite nicely organising, thanks! Aside, there were some repeated talks from elder workshops. Just as a possible hint/suggestion: Maybe one can pick a few exotic researchers and/or mix the talks from invited speakers with some contributed talks. All in all however a very nice workshop, thanks!!"

WORKSHOP: Entropy Inequalities, Quantum Information and Quantum Physics.
FEBRUARY 8 - 11, 2021.

Organizing Committee:
Eric Carlen (Rutgers University, Department of Mathematics)
Nilanjana Datta (University of Cambridge)
Marius Junge (University of Illinois at Urbana-Champaign)

The concept of entropy has emerged as a fundamental construct linking diverse areas of mathematics, physics and information theory. The pace at which new connections are being made has quickened in recent decades. Entropy methods have found various applications in the theory of diffusion process. For any diffusion process the question: "How long does it take to reach equilibrium?" is of both theoretical and practical interest. To answer such a question in any generality requires incisive functional inequalities involving some sort of relative entropy. Conversely, diffusion processes have played an important role in proving entropy inequalities. The classic example is Claude Shannon's Entropy Power Inequality, which was first rigorously proved by Stam using a diffusion (heat equation) argument. The quantum strong subadditivity

inequality of Lieb and Ruskai, originally motivated by efforts to study thermodynamic limits, has become a cornerstone of the quantum information theory edifice. This workshop was organized around several related goals.

The first goal was to focus on recent research on convergence to equilibrium and entropy estimates for quantum mechanical systems. Much of this research combines probabilistic methods often combined with optimal mass transport methods, log-Sobolev inequalities and other functional inequalities. A key open problem is to show that every diffusive quantum mechanical system in finite dimension admits fast decay to equilibrium. It is evident from recent research that new ideas and concepts are required to tackle this challenging problem. It appears particularly important to strengthen the geometrical aspects of the problem and to use more physical classical tools such as steepest descent and transport inequalities in a "space without points".

A second goal of this workshop was to better connect the quantum information community with researchers in high energy physics. In the last decade, the work of scientists including Hawking, Hayden and Preskill on the gravity/guage duality has used entropy as a tool to describe the interaction of the boundary and the bulk in a theory combining gravity and quantum field theory. Finite-dimensional models from quantum information theory, in the form of tensor networks with particular geometries, have been put forward to describe both the gravity/guage duality and black hole physics. Of course, all these threads come together by embedding algebras of observables for bulk and boundary as operators on one common physical Hilbert space, leading to consideration of the type III von Neumann algebras arising in quantum field theory. Quite interestingly, it is again geometrical insight, which appears to explain additional entropy inequalities. Vice versa, monotonicity of relative entropy has a physical meaning in quantum field theory, as explained by Witten.

The ultimate goal of this workshop was to enable both of these research groups to find new grounds for collaboration, and new pathways forward in the development of pure and applied mathematics.

This workshop included a virtual poster session.

Comments from our participant survey:

"There are pros and cons. On the one hand, being able to access the event from anywhere in the world is a huge plus. On the other hand, everybody disperses in an online medium, making the workshop a little lonelier."

"outstanding"

"The timing was excellent. It allows people on the East coast and Europe to join as well. Unfortunately, it seems rather inconvenient for Asia, but it does not seem possible to satisfy everyone's preferences."

"The speed at which IPAM posts the conference videos is very impressive. Keep up the good work. In the online format, we need more creative ways for spontaneous interaction and socializing."

"The workshop was very successful at bringing together experts in different topics. Coming from a slightly different research area, I found a few talks hard to follow, but at least half of them were mostly understandable, and I got something out of almost every talk. The biggest issue seems to be that in the online workshop it is difficult for all participants to have spontaneous conversations in small groups, to do networking, and to ask more basic questions about the topics. Thus, special effort should be given to including the more junior participants and giving them a chance to interact more, perhaps by providing a discussion time in smaller groups, but without a specific research goal."

WORKSHOP: Deep Learning and Combinatorial Optimization. FEBRUARY 22 - 25, 2021.

Organizing Committee:
Peter Battaglia (DeepMind Technologies)
Xavier Bresson (Nanyang Technological University, Singapore)
Stefanie Jegelka (Massachusetts Institute of Technology)
Yann LeCun (New York University, Canadian Institute for Advanced Research)
Andrea Lodi (École Polytechnique de Montréal)
Stanley Osher (University of California, Los Angeles (UCLA), Mathematics)
Oriol Vinyals (DeepMind Technologies)
Max Welling (University of Amsterdam)

In recent years, deep learning has significantly improved the fields of computer vision, natural language processing and speech recognition. Beyond these traditional fields, deep learning has been expended to quantum chemistry, physics, neuroscience, and more recently to combinatorial optimization (CO). Well-known CO problems are Travelling Salesman Problem, assignment problems, routing, planning, Bayesian search, and scheduling. CO is basically used every day in finance and revenue management, transportation, manufacturing, supply chain, public policy, hardware design, computing and information technology.

Most combinatorial problems are difficult to solve, often leading to heuristic solutions which require years of research work and significant specialized knowledge. For example, the famous TSP problem has been studied for more than 80 years, and the best solver leverages 30 years of theoretical developments, data structures and heuristics from computer science. In the last few years, deep learning has developed some preliminary but promising approaches to deal with classical CO problems such as TSP, MaxCut, Minimum Vertex Cover, Knapsack, Quadratic Assignment Problem and Vehicle Routing Problems. DL is particularly attractive to address CO problems given its high flexibility, approximate nature, and self-learning paradigm. In other words, DL has the potential to learn universal high-quality algorithms and therefore could lead to a breakthrough in traditional CO, where algorithms are hand-crafted. On the other hand, synergies between DL and CO algorithms could lead to the possibility of taking the best of the two domains and deriving new algorithms, especially for applied problems.

The workshop brought together experts in mathematics (optimization, graph theory, sparsity, combinatorics, statistics), CO (assignment problems, routing, planning, Bayesian search, scheduling), machine learning (deep learning, supervised, self-supervised and reinforcement learning) and specific applicative domains (e.g. finance, transportation, hardware design, computing and information technology) to establish the current state of these emerging techniques and discuss the next directions. Besides, such generalization of deep learning techniques to CO problems will also push forward the mathematical analysis of the properties of these learning systems like generalization and transfer, stochastic optimization and dynamic predictivity that make the success of these techniques.

Comments from our participant survey:

“1. It is possible to attend great virtual workshops over the world without physical traveling/ visa application and ... 2. Providing an appropriate chat and networking platform scientific relationships can be more effective and extensive that physical events”

“Online workshop is very easy to attend and it is great to have recorded talks.”

“I wouldn't have participated in an in-person workshop, so for me it was clearly more effective.”

“Less networking, but less time spent traveling.”

“It is different, but very welcome and useful. I would probably not attended otherwise”

“In one aspect, being the ease of participation is better i.e. elimination of the traveling needs for

many people having difficulties or lack of enough resources."

"In terms of learning, it may be even more effective as it's more natural to watch back presentations and more people can join. In terms of talking to people I prefer in person (but this is best given the circumstances)."

"I would not attend, if not virtual."

"It worked well, good moderators on the chat, break out rooms worked well, videos online quickly."

"The platform, namely Zoom is great overall. Maybe some talks in the breakout rooms were irrelevant but not a problem due to the original spirit of the break time. I was totally pleased with the timing considerations. everything was ok and well-planned."

"I am very thankful for this opportunity. It is not possible for me to attend physically. A great learning experience for me! Wish health Fateme Safaeifard"

"Very good organization! /clap /clap /clap"

"This was my second mixed-discipline machine learning workshop and I'm definitely a fan."

"The organization was top-notch. Thank you."

SPECIAL EVENT: Latinx in The Mathematical Sciences Conference 2021. MARCH 4 – 6, 2021.

The LatMath conference was postponed due to the COVID-19 pandemic to March 3-5, 2022.

LONG PROGRAM: Tensor Methods and Emerging Applications to the Physical and Data Sciences. MARCH 8 - JUNE 11, 2021.

Organizing Committee:
Thomas Barthel (Duke University)
Victor Batista (Yale University, Chemistry)
Fernando Brandao (California Institute of Technology)
Gero Friesecke (Technische Universtitat München)

Lek-Heng Lim (University of Chicago, Statistics)
Jianfeng Lu (Duke University, Mathematics)
Elina Robeva (University of British Columbia)
Ming Yuan (Columbia University, Statistics)

Linear algebra is an essential tool in mathematics, science, and engineering, as almost all natural processes are linear in small increments. The most natural generalization of linear algebra is multilinear algebra where matrices are replaced by tensors. It describes natural phenomena where the variation is linear if we keep all but one factor constant. Furthermore, tensors and multilinear algebra emerge from discretization of multivariate functions – one can simply view the grid values as coefficients of a multivariate tensor.

In recent years researchers have actively been working on tensor related problems in multiple fields, ranging from many-body quantum problems to analysis of large data sets in high dimension. Tensor representation, analysis and algorithms have found tremendous applications in almost every discipline of science and engineering including applied mathematics, statistics, physics, chemistry, machine learning, engineering, and others. On the physical sciences side, tensor network formats have been widely used to represent ground and thermal states for many-body quantum systems. Tensor-based numerical methods, such as the density matrix renormalization group (DMRG) method, have become the method of choice for one-dimensional physical systems and are beginning to overtake previous methods of choice such as the coupled-cluster method in quantum chemistry. On the data science side, tensor decompositions have been used successfully for learning latent variable models, training neural networks, reinforcement learning, and others. In mathematics, tensor decompositions have been connected to algebraic geometry, and have been shown to have a direct relationship with some of the long-standing problems in computational complexity: P vs NP and matrix multiplication.

While exciting results have emerged from various research communities, there has not been much exchange and collaboration between theoreticians and developers of practical algorithms. The aim of this long program was to bring together experts and junior participants from different fields and experiences, to exchange ideas, tackle challenges, collaborate, and advances the general field of tensor methods. We envisioned this program to be a milestone platform for the future development of the research area and to have a long standing impact.

Comments from our participant survey:

“The 1 on 1 mentorship meetings were the best thing!”

“I really appreciated the opportunity to attend virtually.”

"Staff were all great!"

"Tea times were great! Wish more people participated and that there were more!"

"All the organizing members were very helpful and recordings helped a lot, I got to talk to several great people in my area I probably would not met otherwise. It is only moving the whole program to the morning hours is not really sustainable for active participation, and collaborating on something new and vague online is hard and takes multiples more time just to set up a discussion. So I think that the workshop parts of the program worked well, but the informal part was not as efficient as it could be in person."

WORKSHOP: Tensor Methods and Emerging Applications to the Physical and Data Sciences Tutorials. MARCH 9 - 12, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

Organizing Committee:
Thomas Barthel (Duke University)
Victor Batista (Yale University)
Fernando Brandao (California Institute of Technology)
Gero Friesecke (Technische Universität München)
Lek-Heng Lim (University of Chicago, Statistics)
Jianfeng Lu (Duke University, Mathematics)
Ming Yuan (Columbia University, Statistics)

The program opened with four days of tutorials that will provide an introduction to major themes of the entire program and the four workshops. The goal was to build a foundation for the participants of this program who have diverse scientific backgrounds.

Comments from our participant survey:

"Staff are great!"

"I was able to participate fully, but some people I wanted to talk to were in far-away time zones that required us to schedule odd meeting times. This is a small price to pay for the convenience of being able to attend at all! (I normally cannot take three months off of work &

family to go to something like this.)"

"I really like sococo - it worked to have a few pop-in meetings during the breaks. Zulip is much better than Slack."

"Sococo is a fun platform!"

"Excellent talks"

"Very nice speaker selection and range of topics!"

"I have an opportunity to get knowledge from the expert and it's related to my research topic. Hence I get an idea to further research."

"Very well thought out, wide-ranging lectures, with those by Seigal and Moitra particular highlights"

"I would like to say thank you to the IPAM organizer for the most interesting and inspiring workshop!"

WORKSHOP: Tensor Methods and their Applications in the Physical and Data Sciences.
MARCH 29 - APRIL 2, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

Organizing Committee:
Garnet Chan (California Institute of Technology)
Lieven De Lathauwer (Katholieke Universiteit Leuven)
Ankur Moitra (Massachusetts Institute of Technology)
Elina Robeva (University of British Columbia)
Reinhold Schneider (Technische Universität Berlin, Institut für Mathematik, FG Modellierung, Simulation & Optimieru)
Tao Xiang (Chinese Academy of Sciences)

This workshop aimed to bring together experts from different communities working on tensor methods and their applications. Tensors and tensor networks are an important object of study in computational many-body physics and chemistry as well as quantum information theory. With

the emergence of big data, methods and theory for tensor decomposition have become important in probability, statistics, and machine learning as well. Tensor methods have also received a fair amount of attention from the mathematical community due to their intriguing algebraic and geometric properties, as well as their relationship to computational complexity. This workshop featured introductory talks from leading experts in all of these fields. The aim of the workshop was to initiate the exchange of ideas between the fields, lead to the beginnings of new interdisciplinary collaborations, and give a good start to the long-term program.

This workshop included a virtual poster session.

Comments from our participant survey:

"Thank you so much for organizing the workshop! My only suggestion is that the breaks are a bit short to accommodate participants' schedule in non-CA time zones."

WORKSHOP: Tensor Network States and Applications. APRIL 19 - 23, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

Organizing Committee:
Thomas Barthel (Duke University)
Victor Batista (Yale University)
Gero Friesecke (Technische Universität München)
Karen Hallberg (Instituto Balseiro and Centro Atomico Bariloche)
Didier Poilblanc (CNRS, Toulouse, LPT, Institut Fermi)

Due to their high complexity, our understanding of strongly correlated quantum many-body systems is still limited. This concerns, for example, both static and dynamical equilibrium properties of fermionic systems and quantum magnets in condensed matter physics, as well as complex molecules with strong entanglement in quantum chemistry. Other big challenges are the analysis of non-equilibrium dynamics of closed systems, systems interacting with an environment, and transport problems. Tensor network states such as MPS, TTN, PEPS, and MERA are designed to capture the structure of entanglement in quantum systems in compressed representations. They are also particularly well-suited for the study of topological ordered phases of matter which cannot be described within the framework of spontaneous symmetry breaking. A better mathematical understanding of approximate tensor network representations is emerging for cycle-free networks like MPS and TTN. Current interesting questions concern, for example,

the algorithmic stability and complexity, error accumulation, and the optimal choice of single-particle orbitals. Much less is known about the mathematical properties of formats like PEPS which allow cycles and are very natural physically for (D>1)-dimensional systems. The cycles can lead to mathematically intricate situations where, for example, the set of tensor network states is not closed. A major long-term challenge is to identify formats and algorithms that combine key physical properties of PEPS with the algorithmic robustness of MPS and TTN. In this workshop, we focused on the interplay between specific applications and theoretical developments. In particular, we discussed specific challenging applications, new algorithms, and mathematical properties of tensor network state methods for the study of ground states, systems at nonzero temperatures, dynamical response, and non-equilibrium phenomena.

Comments from our participant survey:

"It's a different format. More efficient, more talks, more targeted but less in-person interaction"

"Very good to be able to participate from overseas but miss not being able to have face to face discussions."

"In person discussions are very important. However, given the current circumstances, this has been a wonderful opportunity to get to know other participants and maintain some discussions."

"IPAM did a good job, but online is not as good as in person."

"Impressed by digital organization of workshop"

WORKSHOP: Mathematical Foundations and Algorithms for Tensor Computations. MAY 3 - 7, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

Organizing Committee:
Lek-Heng Lim (University of Chicago, Statistics)
Jiawang Nie (University of California, San Diego (UCSD))
Norbert Schuch (University of Vienna, Physics and Mathematics)
Anna Seigal (University of Oxford, Mathematics)
André Uschmajew (Max-Planck-Institut für Mathematik in den Naturwissenschaften)
Aravindan Vijayaraghavan (Northwestern University)

Tensor computations have garnered broad interests from pure, applied, and computational mathematics. Compared to matrix computations, tensor computations exhibit additional theoretical and practical challenges in regard to decompositions, approximations, and other problems. These challenges may be of an algebraic, analytic, numerical, or algorithmic nature. A common difficulty is the lack of tensor counterparts to classical matrix normal forms like the singular value decomposition or Jordan form. As a result, one often needs to combine tools from multiple areas such as numerical linear algebra, nonlinear optimization, computational algebra, probabilistic computation, high-dimensional approximation, etc., in order to develop efficient, provably correct algorithms for tensor computations.

This workshop aimed to bring together researchers with different expertise to exchange ideas on designing computational methods for various tensor problems. One of the main features was a focus on rigorous algorithms for which one may guarantee convergence to a global solution under reasonable conditions. Topics included provable algorithmic guarantees in terms of computational efficiency and robustness, algorithmic techniques like spectral methods, iterative methods for nonconvex optimization, and powerful convex relaxation hierarchies like sum-of-squares, etc., where correctness guarantees may be established under suitable assumptions motivated by applications. A secondary goal was to better delineate and understand the boundary separating the possible from the impossible in tensor computations — computational tractability vs intractability, existence/uniqueness vs nonexistence/nonuniqueness of solutions, tameness vs wildness, etc.

The workshop covered a wide range of tensor problems drawn from applications in signal and image processing, machine learning, quantum information, and scientific computing. A major impetus was the application of tensor networks in quantum many-body physics, covering both their use in simulating physical systems and limitations imposed by quantum complexity theory.

This workshop included a virtual poster session.

Comments from our participant survey:

“Some things are more effective, some are less effective. It is really great that anyone from any part of the world can join. I also choose to attend only the talks that are relevant for me. IPAM has organized the discussion with speakers very well. The only thing that is missing are informal discussions with other participants as behind one's laptop it's easier to skip it as there is always much to do.”

“The recordings of talks are really great!”

"Thank you so much for IPAM about this conference. It is an excellent opportunity for the new mathematicians. Personally, I hope to see a workshop on Algebra-Ring Theory."

WORKSHOP: Efficient Tensor Representations for Learning and Computational Complexity. MAY 17 - 21, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

Organizing Committee:
Anima Anandkumar (California Institute of Technology)
Fernando Brandao (California Institute of Technology)
Rong Ge (Duke University)
David Gross (Universität zu Köln)
Michael Walter (Universiteit van Amsterdam)
Ming Yuan (Columbia University, Statistics)

Tensors are well-suited to capture higher order correlations or complex relations in data. Unfortunately, the number of parameters describing a tensor scales exponentially with its order. Naive tensor estimation methods would thus require an impractical amount of samples. To counter this problem, a number of efficient tensor representations have been introduced. These include low-rank decompositions which capture latent structures, or tensor networks that are tailored to quantum many-body systems with local interactions. The first emphasis of this workshop was on the theory of recovering efficient tensor representations from empirical data, as studied e.g. in the context of low-rank tensor completion or matrix-product state learning. We focused both on algorithmic and on statistical aspects.

In addition to describing data, tensors can also represent computational problems, such as the problem of multiplying large matrices or the evaluation of permanents. In this context, low-rank decompositions correspond to efficient algorithms, while the non-existence of such decompositions amounts to lower bounds. The second emphasis of the workshop was thus on applications of efficient tensor representations to theoretical computer science, particularly computational complexity theory. A closely related area that was also covered is the resource theory of tensors in quantum information theory.

This workshop included a virtual poster session.

WORKSHOP: Tensor Methods and Emerging Applications to the Physical and Data Sciences Culminating Retreat at Lake Arrowhead. JUNE 6 - 9, 2021.

Part of the Long Program "Tensor Methods and Emerging Applications to the Physical and Data Sciences".

The culminating workshop could not be held at Lake Arrowhead as per tradition due to the COVID-19 pandemic. Instead, a 4-day workshop was held over zoom which was quite successful.

REUNION CONFERENCE: Machine Learning for Physics Reunion Conference I. JUNE 6 - 11, 2021.

The Reunion conference was postponed due to the COVID-19 pandemic. We plan to arrange the event at a later time.

REUNION CONFERENCE: Complex High-Dimensional Energy Landscapes Reunion Conference II. JUNE 6 - 11, 2021.

The reunion conference was organized by the original long program organizing committee and was hosted at Lake Arrowhead. This was the second reunion conference for participants of the spring 2017 long program "Complex High-Dimensional Energy Landscapes". It was a timely get-together to continue some of the collaborations that were started during the long program and at the first reunion. Presentations were given by all participants, with plenty of time between talks for discussions and collaborations. It was the first in-person activity IPAM undertook in over a year. All COVID safety protocols were observed.

OUTREACH ACTIVITIES, 2020-2021

MathFest XXX: October 9 - October 10, 2020 (virtual)

The 2020 Undergraduate MATHFest was held on Friday, October 9 through Saturday, October 10, 2020. The program was held virtually on the Zoom platform. The organizers are the members of the NAM Program Committee: Naiomi Cameron (Vice President and Program Committee Chair), Brittany Mosby (Region C Member), Leona Harris (Interim President and Executive

Director), Shea Burns (Secretary), and Omayra Ortega (Newsletter Editor). RIPS Program Director, Susana Serna represented IPAM at the event.

Additionally, IPAM advertised its RIPS (undergraduate) and GRIPS (graduate) programs through minority institutions and organizations.

The Field of Dreams Conference, November 6-7, 2020 (virtual)

The Field of Dreams Conference introduces potential graduate students to graduate programs in the mathematical sciences at Alliance schools as well as professional opportunities in these fields. Scholars spent time with faculty mentors from the Alliance schools, got advice on graduate school applications, and attended seminars on graduate school preparation and expectations as well as career seminars. Each Fall, Alliance Scholars, together with their Alliance Mentors, are invited to the Field of Dreams Conference. In 2020, IPAM Deputy Director, Christian Ratsch, hosted a virtual career fair at the conference to introduce opportunities offered at IPAM that could open up new horizons to graduate students of math and sciences.

Public Lecture by Benjamin Seibold: "The Frustrating Beauty of Traffic Waves – And How Automated Vehicles Can Prevent Them", November 23, 2020 (virtual)

On November 23, 2020, IPAM organized a virtual public lecture by Benjamin Seibold.

Speaker Bio:

Benjamin Seibold is an Associate Professor of Mathematics at Temple University, and the Director of the Center for Computational Mathematics and Modeling. His research combines mathematical analysis, computation and simulation, and experiments to answer questions about many real-world phenomena, including traffic flow, autonomous vehicles, fluid flows, radiation transport, and invasive species.

Abstract:

A distinguishing feature of vehicular traffic flow is that it may exhibit significant wave patterns. This talk demonstrates that those frustrating (when stuck in traffic) traffic features possess an intriguing structural beauty (when seen from the outside). Moreover, these waves can arise without apparent reason, as phantom traffic jams, from the collective behavior of all drivers on the road; and they result from similar dynamics as detonation waves, cloud patterns, or galaxies. Then it is shown, via computer simulations and experiments, how only a small number of

automated vehicles on the roads suffices to prevent traffic waves, thus making traffic for everybody safer, cleaner, and more energy-efficient.

RIPS Students Participate in JMM and NCUWM, January 6 – 9 and 22 – 24, 2021 (virtual)

IPAM's Research in Industrial Projects for Students (RIPS) participants were amongst those who attended the 2021 Joint Mathematics Meetings (JMM) that took place virtually during January 6-9, 2021. Though virtual, it remained devoted to mathematics research, teaching, advancement, and achievement, as well as time for conversation with friends and colleagues. At the virtual MAA Undergraduate Poster Session at JMM, the HRL team was honored with the "Outstanding Poster" award. Four more teams were chosen for "Honorable Mention": Aerospace, AFRL, AMD, and LLNL. In addition, three members of the RIPS 2020 cohort participated in the 23rd Annual Nebraska Conference for Undergraduate Women in Mathematics (NCUWM) which was held online January 22-24, 2021. The conference seeks to provide undergraduates with role models, insider knowledge, opportunities to present undergraduate research, and a growing community of peers interested in issues related to creating a supportive environment for women in mathematics.

IPAM had a virtual presence at JMM's Mathematical Institutes Open House. The Open House took place at 3pm Pacific Time on Wednesday, January 6, 2021. The event was open to the general public; each institute hosted a Zoom meeting, showcasing its activities.

K. PROGRAM CONSULTANT LIST

IPAM consulted a variety of scholars and practitioners in the scientific planning of its programs. The list below includes program organizers for the programs that took place during this reporting period or upcoming programs for which organizing committees have begun meeting. The list excludes IPAM's scientific staff (directors) and members of IPAM's Science Advisory Board and Board of Trustees, who are listed in "Section O, Committee Membership". On occasion, IPAM scientific staff and Board Members are organizers of workshops and long programs, and are therefore included in the list below.

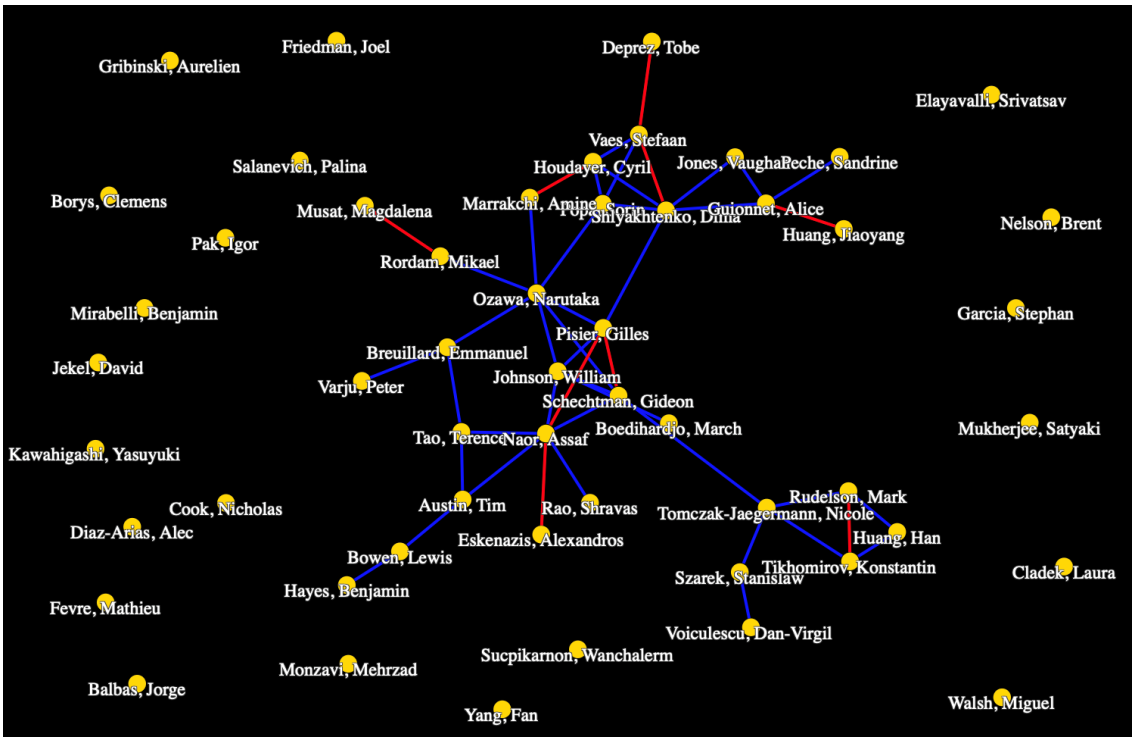
Last Name	First Name	Institution Name
Bajcsy	Ruzena	University of California, Berkeley (UC Berkeley)
Barthel	Thomas	Duke University
Batista	Victor	Yale University
Battaglia	Peter	DeepMind Technologies

Berman	Spring	Arizona State University
Bertozzi	Andrea	University of California, Los Angeles (UCLA)
Brandao	Fernando	California Institute of Technology
Bresson	Xavier	Nanyang Technological University, Singapore
Burgard	Wolfram	Toyota Research Institute
Carlen	Eric	Rutgers University
Caulfield	Colm-cille	University of Cambridge
Chan	Garnet	California Institute of Technology
Datta	Nilanjana	University of Cambridge
Doering	Charles	University of Michigan
Friesecke	Gero	Technische Universität München
Goatin	Paola	INRIA
Hallberg	Karen	Instituto Balseiro and Centro Atomico Bariloche
Jegelka	Stefanie	Massachusetts Institute of Technology
Junge	Marius	University of Illinois at Urbana-Champaign
Kosecka	Jana	George Mason University
LeCun	Yann	New York University
Lim	Lek-Heng	University of Chicago
Lodi	Andrea	École Polytechnique de Montréal
Lu	Jianfeng	Duke University
Mahmassani	Hani	Northwestern University
Mazzucato	Anna	Pennsylvania State University
Menendez	Monica	New York University Abu Dhabi
Miller	Joel	La Trobe University
Motsch	Sebastien	Arizona State University
Nie	Jiawang	University of California, San Diego (UCSD)
Oberman	Adam	McGill University
Osher	Stanley	University of California, Los Angeles (UCLA)
Penneys	David	Ohio State University
Peters	Emily	Loyola University, Chicago
Piccoli	Benedetto	Rutgers University
Poilblanc	Didier	CNRS, Toulouse
Porter	Mason A.	University of California, Los Angeles (UCLA)
Ratliff	Lillian	University of Washington
Robeva	Elina	University of British Columbia
Samaranayake	Samitha	Cornell University
Schneider	Reinhold	Technische Universität Berlin
Schriger	David	University of California, Los Angeles (UCLA)
Schuch	Norbert	University of Vienna

Seibold	Benjamin	Temple University
Seigal	Anna	University of Oxford
Soatto	Stefano	University of California, Los Angeles (UCLA)
Sowers	Richard	University of Illinois at Urbana-Champaign
Speranza	M. Grazia	Università di Brescia
Sprinkle	Jonathan	University of Arizona
Tikuisis	Aaron	University of Ottawa
Uschmajew	André	Max-Planck-Institut für Mathematik
Vijayaraghavan	Aravindan	Northwestern University
Vinyals	Oriol	DeepMind Technologies
Walker	Joan	University of California, Berkeley (UC Berkeley)
Welling	Max	University of Amsterdam
White	Stuart	University of Oxford
Work	Daniel	Vanderbilt University
Xiang	Tao	Chinese Academy of Sciences
Yuan	Ming	Columbia University

L. PUBLICATIONS LIST

This report includes publications that resulted from the spring 2018 long program, as well as the publications of our Director, Deputy Director, Associate Director, and Director of Special Projects from the past year. We asked the participants of Quantitative Linear Algebra (spring 2018) to list their publications that were a result of or significantly influenced by the IPAM program as both groups completed their second reunion conferences during this reporting period. These publications were entered into the project reports "Products" form in Research.gov. We chose not to include pre-prints. We confirmed that the publications in this report were not reported in our previous annual reports. Below is a visual presentation of the automated bibliographical analysis of all participant publications and the collaborative partnership they facilitated.



Note: New collaborations are identified in red, and old collaborations indicated in blue.

M. INDUSTRIAL AND GOVERNMENTAL INVOLVEMENT

We have significant involvement of industry and government labs in our summer program, Research in Industrial Projects for Students (RIPS)-Los Angeles. Companies and other organizations sponsor research projects and one or more representatives of the organization interact with the student team. Many of them are listed as participants of RIPS and RIPS Projects Day.

IPAM received grants and gifts during this period from government and military agencies to support specific programs, including:

- Air Force Office of Scientific Research (10/1/20-9/29/21; $50,000)
- IRES grant through NSF-OISE supports GRIPS-Berlin (9/1/2018-8/31/2021; $233,235)
- NSF Mathematical Sciences Institutes Diversity Initiative – Latinx in the Mathematical Sciences (9/15/19-8/31/22; $117,130)
- Research in Industrial Projects for Students (RIPS) collects sponsorship fees from its corporate and other sponsors, which cover some of the program expenses

- Livermore National Lab: RIPS2020; $20,000
- Air Force Research Laboratory: RIPS2020; $20,000

We seek the advice of government and industry by recruiting corporate and government leaders to serve on our Science Advisory Board and Board of Trustees. See section O for a complete list of members and their affiliations.

Out of all of IPAM's participants during this reporting period, 29 held positions in government or military organizations, such as Los Alamos, Argonne, Lawrence Berkeley, Army Research Laboratory, Lawrence Livermore, NASA - Ames Research Center, US Food and Drug Administration, and Oak Ridge National Labs. Three of our program speakers came from government or military labs.

Participants also included industry representatives, such as Apple, Google, AMD, IBM, Microsoft Research, Amazon, Alibaba, Walt Disney Animation Studios, Lockheed Martin Aeronautics Company, the Boeing Company, and more. Fifteen workshop speakers were from the industry and private sector.

N. EXTERNAL SUPPORT

In addition to the funding listed in Table N below, IPAM receives substantial in-kind financial support from UCLA. The Director's entire salary and administrative stipend are paid directly by UCLA. The Director of Special Projects is released from two courses at the cost of replacing him by a junior person. IPAM is not charged for the use of its building or for custodial care. The value of these items is considerable. Additionally, senior long-term participants from other universities are usually funded on a teaching replacement-buyout basis, by which they are released from teaching for the cost of hiring a junior person as a replacement. The table shows other funding received by IPAM from June 1, 2020 through May 31, 2021.

Table N: Other Funding Support	
Federal Funding	
Air Force Office of Scientific Research	$50,000
NSF-IRES Track 1 - GRIPS Berlin	$77,421
Sub-total	$127,421
Support from Foundations and Endowments	
IPAM 20th Anniversary Fund	$207,350

IPAM's Director Endowment	$23,190
Simon's Foundation	$192,985
Simon's Foundation – Post Doctoral Scholars	$357,408
Sub-total	$780,933
UCLA Funding	
Dean Physical Sciences	$130,732
Vice Chancellor for Research	$143,047
Sub-total	$273,779
Industrial Affiliates and Other Support	
Aerospace Corporation	$28,000
Alibaba Group	$20,000
Air Force Research Laboratory	$20,000
HRL	$48,000
Google	$28,000
Lawrence Livermore National Laboratory	$20,000
GumGum	$28,000
Microsoft	$10,000
Sub-total	$202,000
Others	
Other Donors	$3,475
TOTAL	$1,387,608

O. COMMITTEE MEMBERSHIP

IPAM's committees include the Board of Trustees and Science Advisory Board. The members during the reporting period are listed below. The IPAM directors are *ex officio* members.

Board of Trustees, 2020-21 Membership

Name	Institution	Department or title
David Balaban	Amgen	Scientist
Katy Börner	Indiana Uni., Bloomington	Distinguished Professor of Engineering and Information Science
Russel Caflisch	New York University	Director, Courant Institute
Tony Chan	KAUST	President
Brenda Dietrich	Cornell University	Professor

Karina Edmonds	Google	Google Cloud University Relations Lead
Katherine Ensor	Rice Univeristy	Noah G. Harding Professor of Statistics
James Gidney	The Aerospace Corporation	Director, Navigation and Geopositioning Systems Department
Mark Green	UCLA	Mathematics
Alfred Hales	CCR West	
Sallie Keller	Virginia Tech University	Professor of Statistics, Director
Alan Lee	AMD Research	Corporate VP of Engineering Research
Monique Miller	Wilshire Funds Management	Managing Director
Nancy Potok	US Government	Chief Statistician
Ronald Stern	UC Irvine	Professor Emeritus
Tatiana Toro	University of Washington	Mathematics
Leland Wilkinson	H2O.ai	Chief Scientist
Jeannette Wing	Columbia University	Director, Data Science Institute

Science Advisory Board, 2020-21 Membership

Name	Institution	Discipline or department
Michael Brenner	Harvard	School of Engineering and Applied Sciences
Emery Brown	MIT	Medical Engineering and of Computational Neuroscience
Emmanuel Candes	Stanford University	Mathematics and of Statistics
Cecilia Clemente	Rice	Chemistry
Cynthia Dwork	Harvard University, SEAS	Gordon McKay Prof. of Computer Science
Jordan Ellenberg	Univ of Wisconsin	Mathematics
Peter Wilcox Jones	Yale University	Mathematics
Richard Kenyon	Yale University	Mathematics
Yann LeCun	New York Uni./Facebook	Computer Science
David Levermore	University of Maryland	Applied Math
Xihong Lin	Harvard	T H Chan School of Public Health
Robert Klaus-Müller	TU Berlin	Machine Learning Group
Assaf Naor	Princeton	Mathematics
Pablo Parrilo	MIT	Electrical Engineering and Computer Science
Terence Tao	UCLA	Mathematics
Ryan Tibshirani	Carnegie Mellon University	Statistics and the Machine Learning
Luca Trevisan	UC Berkeley	Electrical Engineering and Computer Science
Amie Wilkinson	Univ. of Chicago	Mathematics
Daniela Witten	University of Washington	Biostatistics