ETH zürich

Institute for Theoretical Studies

Report
2022/2023

ETH-ITS

Cover photo: Guided city tour with the charitable institution "Surprise" in Spring 2023; photo by ETH-ITS

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ETH-ITS group hike to Lägern in Fall 2022.

Foreword

In the academic year 2022 – 2023, we had five Senior Fellows: Sanjeev Arora (Princeton) in the Fall, Viviane Baladi (CNRS, Paris), Alex Eskin (University of Chicago), Daniel Huybrechts (Bonn) in the Spring, and Kannan Soundararajan (Stanford) in the Summer. In addition, there were four Advanced Fellows and seven Junior Fellows. The activities at the ITS have now returned to pre-Covid levels: weekly teas, Fellows seminars, scientific guests, and two workshops (on Feynman integrals and Optimal transport). The reports of the Fellows give a sense of the remarkable research being done here.

Our ITS colloquium had lectures by both Senior Fellows and outside speakers on topics ranging from deep learning to the mathematics of billiards and black holes. The institute outings included a hike along the Lägern ridge in the Fall, a tour of Zurich (see the cover photo), and walk around the Wägitalersee in the Spring.

Rahul Pandharipande, Director

The ETH Institute for Theoretical Studies is supported by Dr. Max Rössler, the Walter Haefner Foundation and the ETH Foundation.

The ETH Institute for Theoretical Studies

History and aims

The ETH Institute for Theoretical Studies (ETH-ITS) is an interdisciplinary Institute dedicated to research in mathematics, theoretical computer science and theoretical natural sciences. It was founded on 1 June 2013 on the initiative of former ETH president Ralph Eichler, with a generous donation of Dr. Max Rössler and the Walter Haefner Foundation. The aim of the Institute is to enable top theoretical scientists to be active for an extended period of time at ETH, interact with local researchers, and establish lasting scientific collaborations in an interdisciplinary context.

Fellows at the ITS

The Institute hosts up to six Senior Fellows and up to twelve Junior and Advanced Fellows. Junior Fellows are talented young independent postdocs spending up to three years at ETH Zurich to work on research subjects of their choice. They are supported by a mentor, who is an ETH professor. Advanced Fellows are young researchers with some experience after their PhD, who have established themselves as leaders in their disciplines. The Junior and Advanced Fellows are appointed by the director, with the assistance of the scientific Advisory Committee, by a nomination procedure: candidates are selected from a group of young researchers that are nominated by faculty members and senior researchers of universities and research institutions.

Schedule for the selection of Junior and Advanced Fellows

Mid-September	Target date for nominations, eligible candidates are invited to apply
Mid-October	Deadline for application of nominated candidates
November	Interviews with ETH members of the Advisory Committee
December	Offers are made

Senior Fellows are leading international researchers in mathematics, theoretical computer science and theoretical natural sciences, spending up to a year at the institute on a sabbatical leave from their home institutions. They dedicate their time to research and participate in the activities of the institute and of ETH Zurich, for example by giving a course on research topics. They are invited by the Vice-President for Research at ETH Zurich on the recommendation of the Advisory Committee. Candidates are often suggested by members of the Advisory Committee or ETH faculty, but they can also apply directly.

https://eth-its.ethz.ch/fellows.html

Announcement of Corinna Ulcigrai's talk in November 2022.

Philipp Grohs gave a talk in December 2022.

Activities

The ITS Science Colloquium

The ITS Science Colloquium aims at exposing students and researchers in mathematics, theoretical computer science and theoretical natural sciences to new questions and research subjects of common interest to different disciplines.

Senior Fellow Alex Eskin at his Colloquium in March 2023.

The ITS colloquium series had a mix of Senior Fellows and external speakers on topics in mathematics, computer science, and physics. The series is attended by members of the ETH community – and it was nice to see the filled lecture halls again after the Covid years.

Programme 2022 – 2023

03.11.2022	Corinna Ulcigrai, University of Zurich	Explaining diffusion and symbolic patterns through dynamics
15.12.2022	Philipp Grohs, University of Vienna	Opportunities and Limitations for Deep Learning in the Sciences
30.03.2023	Alex Eskin, University of Chicago and ETH-ITS	Polygonal Billiards and Dynamics on Moduli Spaces
25.05.2023	Mihalis Dafermos, Princeton University and University of Cambridge	The mathematics of black holes and spacetime singularities

Videos of selected talks can be viewed on https://eth-its.ethz.ch/activities/videos.html

Speaker Mihalis Dafermos and Rahul Pandharipande in May 2023.

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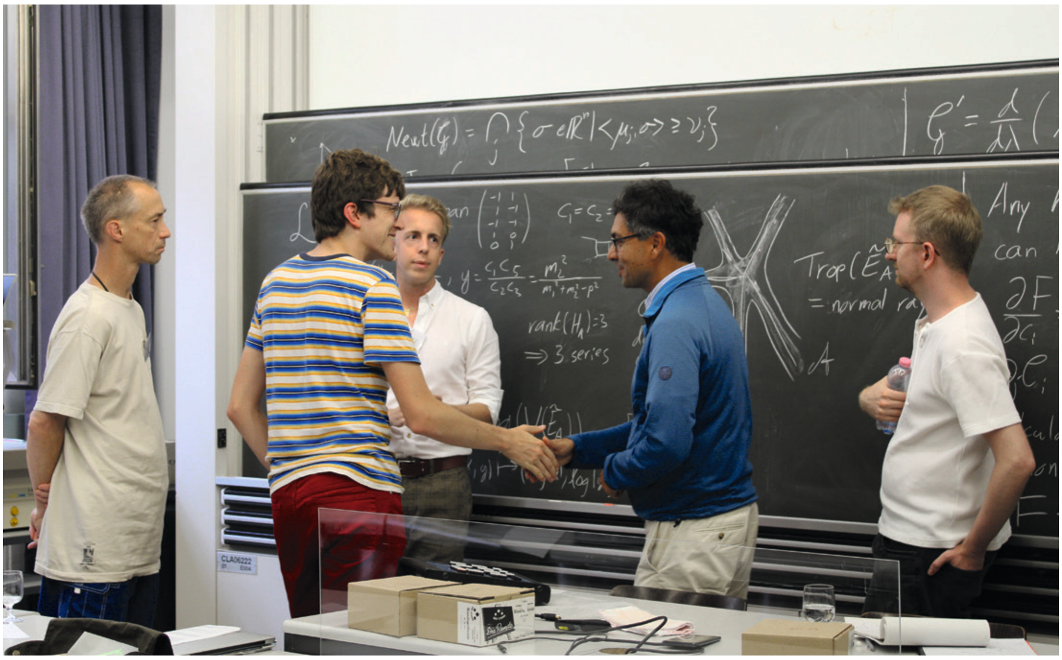
ITS Fellows' Seminar

The aim of the Fellows' Seminar, hosted by existing ITS Junior and Advanced Fellows, is to present the research of the Fellows of the ETH-ITS. It is open to all interested and the rule is that talks should be accessible to other Fellows, which are typically from a different field.

Programme 2022 – 2023

27.09.2022	Gramoz Goranci	Vertex sparsification in dynamic algorithms and beyond
18.10.2022	André Guerra	Morrey's problem and quasiconformal mappings
14.03.2023	Deeksha Adil	Fast Algorithms for Regression Problems



Rahul Pandharipande meeting Erik Panzer (2nd left) and other participants at the workshop site in Fall 2022.

Tropical and Convex Geometry and Feynman integrals

In recent years, convex and tropical geometry have been recognized as playing key roles in several areas of mathematical physics. In particular, the theory of Feynman integrals in particle physics is related to Euler-Mellin integrals, geometric sector decomposition, stringy canonical integrals, GKZ systems, singularities, their regularization and Newton polytopes of graph polynomials. All of these aspects have connections to convex and tropical geometry.

The workshop from 05 – 09 September 2022 brought together an enthusiastic group of researchers, focusing on the study of Feynman integrals through the lens of tropical and convex geometry. It served as a forum for mathematicians and physicists to identify precise relationships, share knowledge, and explore potential cross-applications of tools and results across domains.

This gathering was made even more successful thanks to the immense support from the ITS staff. Their dedication to the organization and smooth running of the workshop was invaluable.

The workshop not only sparked discussions but also forged productive research partnerships. A standout collaboration involved Borinsky and PhD candidates Henrik Munch and Felix Tellander. Their joint venture expanded on Borinsky's 2020 work, which used tropical geometry in Feynman integral evaluations. The culmination of this effort was a widely acclaimed publication in February 2023.

Additionally, the workshop played a key role in encouraging the growth of this emergent field. Further evidence of this growth is the scheduling of a subsequent workshop, in Fall 2023 at the Institute of Advanced Studies in Princeton, United States. Organized by Nima Arkani-Hamed, Hofie Hannesdottir, and Sebastian Mizera, the upcoming event will be centered on 'Tropical Geometry and Infrared Divergences' of Feynman integrals.

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Group photo of the participants of the workshop on Optimal Transportation in June 2023.

Emerging topics in applications of optimal transport

During 05 – 09 June 2023, Yunan Yang, an Advanced Fellow at ITS, organized an important workshop on Optimal Transportation in collaboration with Alessio Figalli from ETH Zürich and Lénaïc Chizat from EPFL. Optimal transport theory has emerged as a powerful mathematical framework with wide-ranging applications in various fields, such as PDEs, image processing, inverse problems, sampling, optimization, and machine learning. Over the past decade, this theory has played a crucial role in advancing these areas of applied mathematics.

The workshop's primary objective was to facilitate an exchange of ideas and knowledge between researchers working on both the theoretical and practical aspects of optimal transport. The workshop aimed to foster cross-fertilization between theory and applications by bringing together experts in their respective areas. It recognized that real-world applications often give rise to intriguing open questions in optimal transport theory. At the same time, recent theoretical advancements can offer solutions to practical challenges encountered in various fields.

Furthermore, the workshop established a cohesive research community within the rapidly expanding field of optimal transport. The workshop encouraged and enhanced collaborations, identified open problems, and sparked discussions on cutting-edge research directions by gathering researchers at different stages of their careers. The organizers believed that creating a stimulating environment where participants could interact and exchange ideas would contribute to the development of the field as a whole.

Overall, the workshop was highly successful, and it served as a platform for researchers to share their latest findings, discuss emerging trends, and form new collaborations. It focused on bridging the gap between theory and applications, inspiring novel approaches to tackle real-world problems using optimal transport theory, and fostering advancements in the fundamental understanding of this mathematical framework.

Awards

Former Senior Fellow **Daniel Huybrechts** was awarded with the Compositio Prize at HU Berlin on 10 February 2023.

Dominik Schröder, ITS Junior Fellow from 2019 – 2022, received an SNF Ambizione grant in 2022 to pursue his research program in the Mathematics department at ETH Zürich.

Senior Fellow Sanjeev Arora and Rahul Pandharipande on the Lägern ridge in October 2022.

Viviane Baladi enjoying a cup of tea at the ITS Tea Time in Spring 2023.

Fellows' report

Senior Fellows

Professor **Sanjeev Arora** visited for two months starting late August 2022, while on leave from Princeton University. He works on better mathematical understanding of modern AI, especially large AI models based upon deep learning. During his time at ETH, he worked on the notion of skill localization in large language models, whereby one can isolate out small portions of a language model that is responsible for performing specific tasks. He also worked out (with his group back in Princeton) an analysis of linear data models, a new idea for understanding the influence of individual training points on a deep model's performance. This relied upon harmonic analysis.

During his stay he also gave three public lectures (the Paul Bernays lectures at the Math department).

Lecture 1: Tour d'Horizon of Artificial Intelligence and Machine Learning today

Lecture 2: Deep Learning: Attempts toward mathematical understanding

Lecture 3: What do we not understand mathematically about deep learning?

Viviane Baladi's second stay at ITS took place in the Spring of 2023. The work carried out in 2022 during her first visit had led to a paper with Jérôme Carrand and Mark Demers proving the existence, uniqueness, and Bernoullicity of the measure of maximal entropy of two-dimensional Sinai billiard flows under a (generic) sparse recurrence to singularities condition. Baladi gave a Colloquium at the EPF Lausanne on billiards in April 2023, including these recent results with Carrand and Demers. Baladi also participated in a workshop on Probability and dynamics in May 2023, in Roscoff (France).

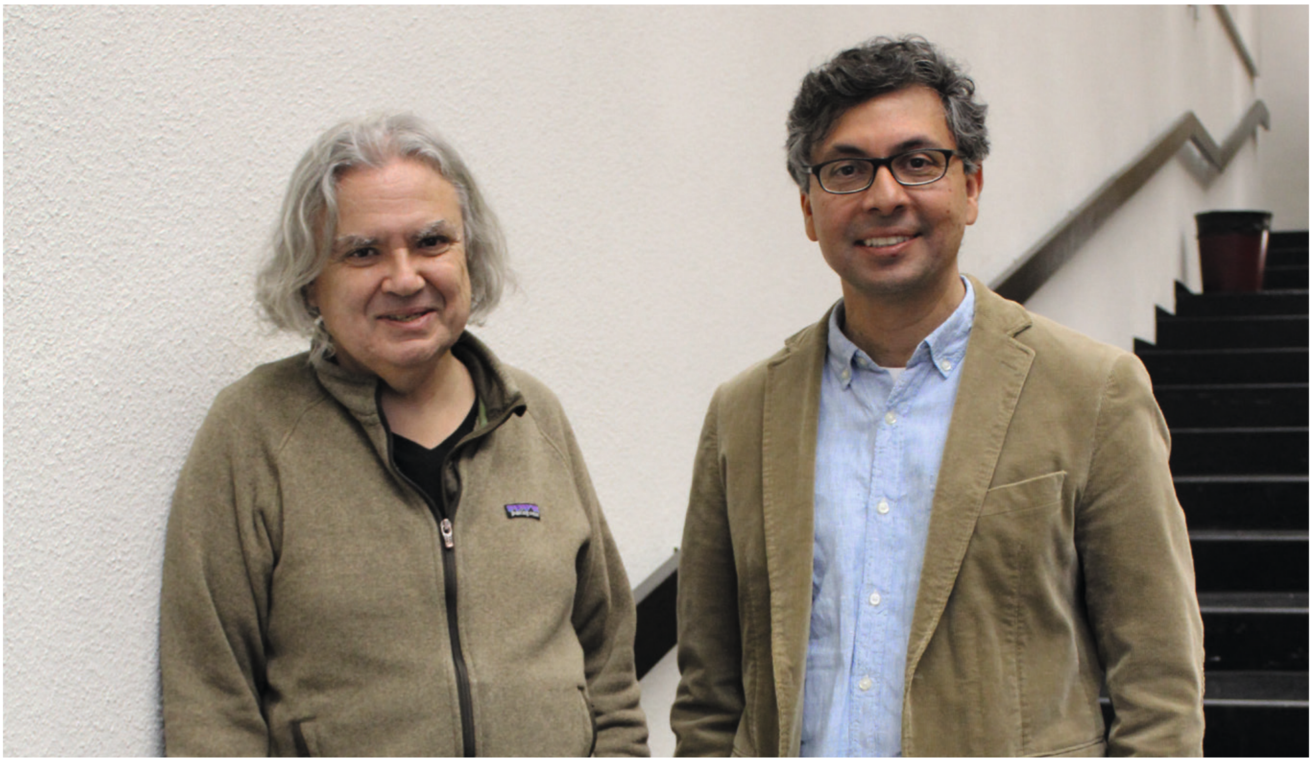
Baladi presented her paper with Magnus Aspenberg and Tomas Persson (started during her first visit at ITS) on the almost sure invariance principle (ASIP) for the quadratic family, at a seminar talk at the ETHZ-UZH Seminar on Ergodic Theory and Dynamical Systems in May 2023, and in the workshop on Regular and Stochastic Behaviour in Dynamical Systems at the Scuola Normale Superiore in Pisa in June 2023. The motivation for this ASIP is to understand the fractional response for the physical measures in the quadratic family, following the path laid out by Amanda de Lima and Daniel Smania in the toy model of piecewise expanding maps. Discussions during visits of Persson and Smania to ITS in May – June 2023 allowed

Daniel Huybrechts discussing with Dietmar Salamon at the ITS Science Colloquium in May 2022.

them to make crucial progress in this project. In addition, Smania gave a talk on deformations of one-dimensional dynamical systems at the ETHZ-UZH Seminar on Ergodic Theory and Dynamical Systems in May.

Baladi's 2022 visit to ITS also led to a paper with Roberto Castorrini on statistical properties of higher dimensional piecewise expanding maps, using ordinary Sobolev spaces. During the 2023 visits of Persson to ITS, Baladi and Persson started to explore the use of Hajlasz-Sobolev spaces associated to a conformal measure, in order to obtain sharper results. This work is still in progress, in particular because it led to the discovery of a flaw in the published literature.

Daniel Huybrechts visited the ITS during the months of February and March. During this time he was concerned with the following projects: His book on cubic hypersurfaces, on which he worked intensively during his visit in 2022, was prepared for publication. The book will appear this summer. His other projects concerned various aspects of elliptic fibrations of K3 surfaces and twisted sheaves. More concretely, in the attempt to define twistor families in positive characteristics, for which the right kind of geometry has still to be introduced, he studied alternative ways of parametrising Tate-Shafarevich twists of an elliptic K3 surface. Related to this he investigated moduli spaces of twisted sheaves with curve support. The strange phenomenon to understand here is that although curves have trivial Brauer groups varying the curves detects Brauer class on the surface. An introduction to this circle of ideas and to first results were presented in the ETHZ moduli seminar.



Alex Eskin and Rahul Pandharipande after the ITS Science Colloquium in March 2023.

During his visit to the ITS, **Alex Eskin** worked on a variety of problems of Dynamical Systems. The first project involved Lyapunov exponents. These are key numerical invariants of a dynamical system which have been studied for over a hundred years. The simplest situation for which the behaviour of Lyapunov exponents is non-trivial is the Furstenberg theory of products of random matrices, where one multiplies matrices which are independent random variables with some fixed probability distribution. This has also been studied extensively since the 1960's. Together with Artur Avila, a faculty member of the University of Zurich at Irchel, and Marcelo Viana, director of IMPA in Brazil and a short-term visitor to the ITS, Eskin completed a long-term project establishing optimal conditions for the continuity of the Lyapunov exponents in this setting.

In an ITS colloquium, Eskin introduced a wider audience to various aspects of the theory of billiards in polygons, and presented connections to other branches of mathematics, including ergodic theory and algebraic geometry. The main results involve leveraging our understanding of dynamics on homogeneous spaces to study more general situations. He summarized the current status of the underlying problem of the classification of SL(2,R) orbit closures and presented some recent developments.

Eskin also used his stay at ITS to continue his long-term project (joint with Aaron Brown, Simion Filip and Federico Rodriguez-Hertz) which aims to bring some of the arguments sketched in the colloquium to a much more general smooth dynamics setting. This would have several applications to problems in dynamics, in particular to the study of random diffeomorphisms and the study of actions on character varieties. Eskin gave a talk at the dynamics seminar at ETH in which he focused on this project and related developments.

While at the ITS, Eskin has also worked on other problems in the area. Together with Çağrı Sert from the University of Warwick and the University of Zurich at Irchel and Uri Shapira from the Technion, Eskin studied the classification of stationary measures on some quotients of the form G/H, where G is a Lie group and H is a closed subgroup. Even though this is a problem in homogeneous dynamics, it seems to benefit from a more general smooth dynamics point of view. There is some hope that this will lead to some improvement on the previous results on this topic.

Kannan Soundararajan spent the months of July and August 2023 as a Senior Fellow at ITS. This was his second visit to ITS, completing his intended visit between 2019 and 2020 which had been cut short in March 2020 by the pandemic. Soundararajan holds a permanent position as the Anne T. and Robert M. Bass Professor of Humanities and Sciences at Stanford University. His research interests are in number theory, and especially in problems with an analytic, combinatorial or probabilistic flavor.

During his visit, he interacted regularly with Emmanuel Kowalski at ETH, with whom he had begun a number of projects during his first visit to ITS, as well as with Raphael Steiner and Özlem Imamoglu. He gave talks at conferences in Bristol and Oxford, and benefitted from the excellent working conditions at ITS to make progress on several projects. These include work with Ben Green on covering integers using positive definite binary quadratic forms; work with Harper and Xu on central limit theorems for random multiplicative functions; work with Angelo and Xu on Dirichlet characters with non-negative partial sums; and work with Radziwill on central limit theorems for the logarithms of central values of L-functions.

Advanced Fellows

In September 2022, **Michael Borinsky** commenced his second year as an Advanced Fellow at the ITS. His innovative research involves using quantum physics tools to address mathematical problems. Moreover, he leverages unique mathematical methodologies to streamline quantum mechanical computations crucial to high-level experiments, such as those conducted at CERN's Large Hadron Collider (LHC).

A standout moment in Borinsky's career took shape in the publication of an extensive research project with Karen Vogtmann in January 2023. Their paper revealed the unexpectedly complex shape of the moduli space of graphs, a geometric structure that holds significant interest in numerous areas of mathematics and theoretical physics. More specifically, they demonstrated that this structure's Euler characteristic, a broad indicator of a geometric object's complexity, escalates quickly with the size of the graphs. This research was featured in a recent article in Quanta Magazine.

Another notable accomplishment was the 'Tropical and Convex Geometry and Feynman integrals' workshop

Michael Borinsky

Michael Borinsky enjoying the beautiful surroundings at Lake Sils (Engadin) in January 2023.

Borinsky orchestrated alongside Erik Panzer at the ITS with the invaluable assistance of the ITS staff. The event was a vibrant confluence of researchers exploring the tropical and convex geometric approach to Feynman integrals.

During a month-long stint at the Max-Planck-Institute for Mathematics in Bonn, Borinsky further delved into his research on moduli spaces and graph complexes. Currently, he is drafting a new paper that investigates the Euler characteristic of a compactified version of the moduli space of graphs, a version that also finds applications in the moduli space of curves – a significant object in algebraic geometry and string theory.

In May 2023, Borinsky was an invited visitor at the renowned Institute of Advanced Studies in Princeton, US, where he discussed the tropical approach to Feynman integrals with several institute members. These stimulating conversations are currently guiding Borinsky to broaden the scope of the tropical approach, incorporating the domain of Feynman amplitudes. These Feynman amplitudes are considered even more foundational than Feynman integrals. They describe the quantum mechanical probability of a particles interacting in space and time.

Mentoring the future generation of researchers, Borinsky guided a Master's thesis project in theoretical particle physics. The student was educated in the tropical geometric approach to Feynman integration, an approach pioneered by Borinsky in 2020. The student successfully applied this methodology to a wide array of examples and inferred new insights on the asymptotic behavior of Feynman amplitudes. After a successful project, the student is now a PhD candidate at ETH Zurich.

The productive year of 2022, which saw Borinsky publish six research papers, can also be attributed to the excellent research environment provided by the ITS.

Since September 2022, Borinsky has been invited to share his research at various prestigious venues. These include the Newton Institute in Cambridge, Bonn University in Germany, Stanford University in the US, McMaster University, Waterloo University and Perimeter Institute in Canada, DESY Zeuthen in Germany, Max-Planck Institute in Leipzig, Institute of Advanced Studies in Princeton, and Warwick University in the UK. Moreover, Borinsky gave the Nico van Kampen colloquium at Utrecht University.

Gramoz Goranci joined the ITS as an Advanced Fellow in September 2022. He is broadly interested in theoretical computer science, with a particular focus on the design and analysis of (dynamic) graph algorithms and data structures.

Goranci's first work during his time at ITS was on the dynamic edge connectivity problem on undirected graphs. Edge connectivity is a fundamental graph measure that quantifies the robustness of graphs and has been extensively studied in combinatorial optimization. Together with Monika Henzinger, Danupon Nanongkai, Thatchaphol Saranurak, Mikkel Thorup, and Christian Wulff-Nilsen, Goranci showed the first dynamic algorithm for exact edge connectivity that runs in sub-linear time (in the size of the input graph) per edge insertion or deletion. Their result answered in the affirmative a 20-year open question, which was central to this research area and led to a publication to the 34th ACM-SIAM Symposium on Discrete Algorithms (SODA 2023). Goranci attended the conference in Florence, Italy to present this work.

Goranci continued his work on dynamic graphs on two other projects. The first project considered the dynamic complexity of the maximum flow problem, and was accepted to the 50th International Colloquium on Automata, Languages and Programming (ICALP 2023) shortly after he left ITS. Together with Maximilian Probst Gutenberg (ETH) and Arnold Filtser (Bar-Ilan University), Goranci's main focus has been on the problem of obtaining efficient data structures for the dynamic shortest path problem on a structured family of graphs. Despite the fact their approach seemed promising in the beginning, they have been facing several technical challenges that make the final outcome of this ongoing work rather unclear. If successful, this result would constitute a major breakthrough in the area of dynamic graph algorithms.

In addition to projects on dynamic graphs, Goranci also found some time to think about one of his favorite projects, namely understanding the power of spectral graph theory and numerical linear algebra in the design of algorithms with provable guarantees. Together with his collaborators, Goranci showed that a collection of carefully reweighted electrical flows leads to an algorithm that can serve any arbitrary routing requests in an oblivious manner while paying only a poly-logarithmic factor loss in quality when compared to the optimal solution in hindsight. Compared to the state-of-the-art, this result achieved a faster algorithm that also admits an efficient parallel implementation. The preliminary manuscript of this work appears as a preprint on arXiv.

The high concentration of excellent researchers at ETH made Goranci's experience at ITS very enjoyable. In particular, he is thankful for the opportunity to interact with Prof. Rasmus Kyng, Dr. Bernhard Häupler, and their group members, on several occasions. He attended the Dagstuhl Seminar on "Dynamic Graph Algorithms" in Schloss Dagstuhl, Germany, and also delivered an invited talk during the event. On the service front, he was a member of the program committee for the 34th ACM-SIAM Symposium on Discrete Algorithms (SODA 2023).

After a brief but wonderful stint at ITS, Goranci left the institute to take up a tenure-track professorship at the University of Vienna, Austria. He greatly acknowledges the excellent support of the administration team at ITS and hopes to visit the institute again in the future.

Sylvain Lacroix joined the ITS as an Advanced Fellow in September 2021. His research topics concern the development of exact methods for the study of physical systems, in particular in the context of field theories. The approach that he follows is mostly based on algebraic and geometric methods, putting his field of research at the frontier between physics and mathematics. During the last year, Lacroix's research focused on a class of field theories called sigma-models, which appear in various domains of physics, such as string theory, high-energy physics and condensed matter systems.

In a first project, he studied a large family of sigma-models which have the additional property of being conformal, meaning in particular that they are invariant under changes of scale (in other words, the physical phenomena described by these conformal theories do not change when we zoom or dezoom in space-time). The sigma-models investigated in this project are built in terms of certain mathematical objects called current algebras (which more technically take the form of infinite-dimensional Lie algebras) and all possess the property of being conformal/scale-invariant at the classical level, i.e. when neglecting quantum effects. These quantum effects generally break the conformal invariance, resulting in what is called a scale anomaly. Based on their underlying algebraic formulation, Lacroix found a condition which ensures that these theories stay conformal at the quantum level, at least at the first order in the quantum loop expansion. The class of theories which satisfy this condition includes some previously known models such as gauged

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Advanced Fellow Sylvain Lacroix in the ITS garden.

Wess-Zumino-Witten ones but also contain new examples. Moreover, Lacroix studied the space of chiral fields of these theories and their classical Poisson brackets, which is the first step for their exact all-loop quantisation using the language of Operator Vertex Algebras. This constitutes a very natural perspective for further developments, which Lacroix plans to explore in the future. Such results also open the way for a more systematic study of the quantum integrable structures of sigma-models, which was one of the main motivation for this project and a long-term goal of Lacroix's research program.

The second project was the subject of the Master Thesis of Anders Heide Wallberg, prepared under the supervision of Sylvain Lacroix during the last year. It concerns the study of integrable elliptic sigma models. Here, the adjective integrable means that the model under investigation possesses an infinite number of symmetries and conserved quantities, which can in particular be used to extract some exact results. Such a property is often established by finding a generating function for these conserved quantities, which depends on an auxiliary complex variable called the spectral parameter. Mathematically speaking, this parameter belongs to what is known as a Riemann surface. Most known examples of integrable sigma-models are associated with the simplest of these surfaces, namely the Riemann sphere: the conserved quantities are then built using rational functions of the spectral parameter and these models are called rational. In their project, Lacroix and Wallberg developed new methods to construct integrable sigma-models based on a more complicated Riemann surface, namely the torus. In this case, the conserved quantities are built using elliptic functions and the resulting models are then said to be elliptic. Moreover, they have studied various properties of these elliptic models, including their renormalisation group flow at one-loop, verifying some conjectures proposed in the literature on this subject. These various results will be the subject of several scientific publications, which are currently under preparation. Moreover, they open the way for further explorations, in particular generalisations to higher-genus Riemann surfaces. Interestingly, some of these subjects have shown some unexpected relations with other domains of mathematics, for instance with moduli spaces of abelian differentials and their Rel-flow. These various perspectives are subjects that Lacroix would like to explore in his future projects.

Yunan Yang

Yunan Yang successfully finished the Zurich Marathon on 23 April 2023.

In addition to his research activities, Lacroix was a co-organiser of the conference "Integrability in Gauge and String Theory 2023", which took place at ETH Zürich from the 19th to the 23rd of June. He also participated in various academic activites in the Physics and Mathematics departments of ETH (journal clubs, reading groups, ...) and presented his results in several seminars, workshops and conferences (both online and in presence).

Yunan Yang has served as an Advanced Fellow at the ITS since January 2022. Her research primarily focuses on inverse problems, optimization, optimal transport, and machine learning. Over the past academic year at ITS, she has made substantial progress in these areas.

Inverse problems pose the challenge of identifying a cause from a set of observable effects. In a fixed model, the cause often manifests as the model parameter, and the observed effects constitute the data. The complexity of an inverse problem can be gauged by its well-posedness, including factors such as existence, uniqueness, and stability. Ill-posed problems typically present issues with stability. Yang, in collaboration with her undergraduate mentee at MIT, examined the stability of inverse problems in relation to varying metric spaces for data and parameter domains. Their study, published in the journal "Inverse Problems," revealed that the stability of inverse problems is not absolute and can be improved by selecting appropriate metric spaces for parameters and data. This insight can guide practitioners in computational problem-solving, allowing for the choice of different objective functions and gradient flows to enhance the stability of the inverse problem.

In addition to her individual research, Yang has engaged in collaborative efforts with professors and students from the Seminar of Applied Math (SAM) at ETH Zürich. Working alongside Roberto Molinaro, Siddhartha Mishra, and Björn Engquist, Yang proposed the use of Neural Inverse Operators (NIO), parameterized by neural networks (*see Figure 1*), to solve a broad range of inverse problems for PDEs. These problems involve outputs in the form of model parameters and data inputs via Dirichlet-to-Neumann or Albedo operators. The proposed neural network architecture effectively approximates the inverse map, an operator mapping another operator to a function. The results derived from the use of NIO are promising, showing superior performance compared to traditional methods (*see Figure 2*). This work has been accepted for presentation at the 40th International Conference on

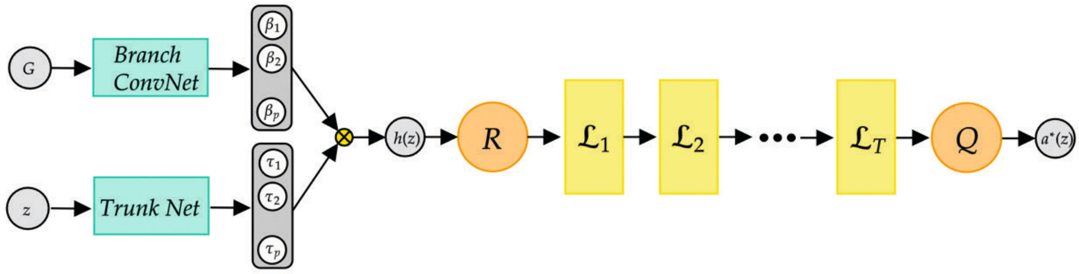


Figure 1: Schematic representation of Neural Inverse Operator (NIO) architecture, which composes two exist-ing architectures, DeepONet and FNO.

Yunan Yang

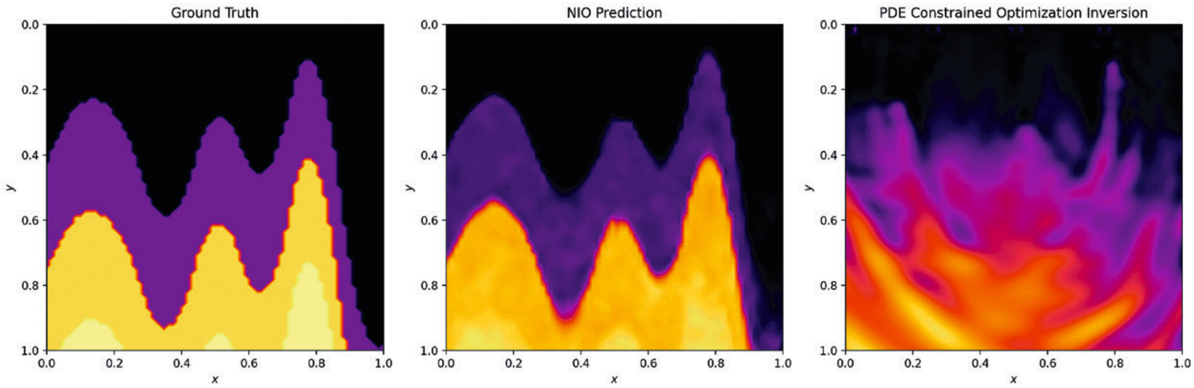


Figure 2: Waveform inversion results: ground truth (left), NIO reconstruction (middle), and reconstruction with the PDE-constrained optimization method (right) for an out-of-distribution test sample.

Yunan Yang

Machine Learning (ICML 2023). Yang is also involved in an ongoing project with Rima Alaifari from SAM, focusing on phase retrieval from the magnitudes of short-time Fourier transform (STFT) measurements.

Yang's commitment to student mentorship is also noteworthy. In the past year, she co-mentored a master's student at the University of Bonn who graduated in April 2023. She is currently co-mentoring two master's students at ETH Zürich with Prof. Rima Alaifari. Additionally, Yang is advising three doctoral students and two undergraduate students at Cornell University, as well as an undergraduate student at New York University.

Yang has also been actively involved in organizing conferences and workshops. She co-organized the BIRS workshop Banff on "New Ideas in Computational Inverse Problems" in October 2022 and the 18th Annual Conference on Frontiers in Applied and Computational Mathematics (FACM'23) held at the New Jersey Institute of Technology in May 2023. More recently, in June 2023, she organized a workshop on Optimal Transportation at ITS in collaboration with Alessio Figalli from ETH Zürich and Lénaïc Chizat from EPFL. The workshop was highly successful, featuring a strong lineup of speakers leading in their respective areas and providing support to early career researchers.

Apart from enhancing her research portfolio, Yang has been invited to deliver talks at various institutions, including the Fields Institute in Toronto, the University of Wisconsin-Madison, the University of Minnesota Twin Cities, the University of Warwick, the University of Manchester, the University of Edinburgh, Eindhoven University of Technology, and the Max Planck Institute at Leipzig. After an industrious 18 months at ITS, Yunan Yang transitioned to a tenure-track assistant professorship at Cornell University.

Deeksha Adil

Junior Fellow Deeksha Adil during her trip to Michigan in Fall 2022.

Junior Fellows

Deeksha Adil joined the ITS in January 2023. She completed her PhD in computer science from the University of Toronto a few months earlier after which she was visiting the University of Michigan for a few months. Her research interests lie in the design of fast algorithms with provable guarantees for problems in optimization, machine learning and theoretical computer science. During her PhD, she focussed on fast algorithms for the p-norm regression problem, developing state of the art algorithms, both in theory and practice. She also worked towards understanding acceleration schemes to speed up algorithms, thus generalizing the algorithms for p-norm regression to a broader class of optimization problem.

Since then, Adil has worked on developing fast algorithms for a broader class of problems. Along with Brian Bullins, Arun Jambulapati and Sushant Sachdeva, she has worked on fast algorithms for higher-order smooth, monotone variational inequality problems. The variational inequality framework is a generalization of convex optimization which also includes bilinear saddle point problems. For such problems, Adil and her collaborators developed simple, fast algorithms and have shown matching lower bounds, thus concluding that faster algorithms with provable guarantees are not possible.

From her time at Michigan, Adil has also worked on some dynamic optimzation problems. Along with Thatchaphol Sararunak, she has explored how to quickly maintain certain solutions of some cases of positive semi-definite programs when the input matrices undergo increasing and decreasing updates.

Adil and her collaborators, have also been working towards understanding and developing fast algorithms via interior point methods, problems in non-convex optimization, and understanding how krylov space methods work in finite precision, and among others.

Adil was invited to present her research at the SIAM Conference on Optimization in Seattle and the Einstein Institute in Berlin. She has also given talks in the Fellows seminar at the ITS and the theory seminar at the Institut de Recherche en Informatique Fondamentale (IRIF) in Paris in the past year.

Rhea Palak Bakshi standing in front of a sculpture of the framed Borromean rings. The Borromean rings are a three component link, which is topologically linked, but removing one of the components causes the remaining two components to no longer be linked together.

Rhea Palak Bakshi has been a Junior Fellow at ETH-ITS since September 2021. Her research interests lie at the confluence of low-dimensional topology, quantum topology, and knot theory. In particular, she focusses primarily on the study of skein modules and skein algebras of 3 – manifolds, the Witten – Reshetikhin – Turaev 3 – manifold invariant, and Topological Quantum Field Theories. Skein modules are invariants of 3-manifolds and generalize the skein theory of all the polynomial link invariants in the 3-sphere to arbitrary 3-manifolds. Over time, skein modules have evolved into one of the most important algebraic objects in knot theory and quantum topology, having strong ties with many fields of mathematics, a few of which are algebraic geometry, hyperbolic geometry, quantum cluster algebras, representation theory, and Chern-Simons theory.

The structure of the Kauffman bracket skein module over the ring of Laurent polynomials with integer coefficients has long been elusive to skein theorists. Connected sums of 3-manfolds cause much of the obstruction in understanding the structure. Characterising the exact set of handle sliding relations is the trickiest part of the calculations. In collaboration with Xiao Wang and Seongjeon Kim, Bakshi undertook research to compute the Kauffman bracket skein module of the connected sum of two copies of the product of the circle with the 2-sphere. Bakshi and her coauthors discovered the precise set of handle sliding relations needed to fully determine the structure of the skein module. They also showed the presence of torsion in the skein module, which reflects the presence of the essential 2-spheres in the 3-manifold.

On the classical knot theory side, in collaboration with Huizheng Guo, Gabriel Montoya-Vega, Sujoy Mukherjee, and Józef H. Przytycki, Bakshi showed that the generalized Kauffman-Harary (GKH) conjecture is true. The GKH conjecture states that if D is a reduced alternating diagram of a prime link L, then different arcs of D represent different elements of the first homology of the double branched cover of the 3-sphere, branched along the link L. The tools used to prove this conjecture involve the theory of Fox k-colourings and pseudo-colourings of links and their relations to the double branched covers of the 3-sphere, branched along those links.

This year, Bakshi also expanded her research to the study of the AJ conjecture, which relates the coloured Jones polynomial and the A-polynomial. The A-polynomial describes how the Sl(2,C)-characters of a knot lie inside the Sl(2,C)-characters of its boundary torus. It is known that the A-polynomial can be related to the Alexander polynomial of the knot and to the structure of essential surfaces in the complement of the knot. This year, along with Dionne Ibarra, Bakshi is undertaking research to compute the quantum A-polynomial, a noncommutative generalization of the A-polynomial, of twist knots and double twist knots.

Bakshi was a visiting fellow for two weeks in May 2023 at the George Washington University in the USA and is scheduled to visit Jilin University in China in July 2023 to further her research collaborations. Bakshi was invited to present her research at several conferences and seminars, including the Nearly Carbon Neutral Geometric Topology Conference, the AMS Fall Western Sectional Meeting in Utah, the Quantum Topology Seminar, the Zurich Topology Seminar, Knots in Wahsington, Journées de Topologie Quantique (Quantum Topology Days) in Dijon, the Moab Topology Conference, the AMS Spring Western Sectional Meeting in California, and the GW Topology Seminar. Bakshi organised a Special Session on Knots, Skein Modules, and Categorification at the AMS Spring Southeastern Sectional Meeting in Atlanta in March 2023. She has also been invited to participate in the Quantum Invariants and Low-Dimensional Topology workshop at the American Institute of Mathematics in Pasadena in August 2023.

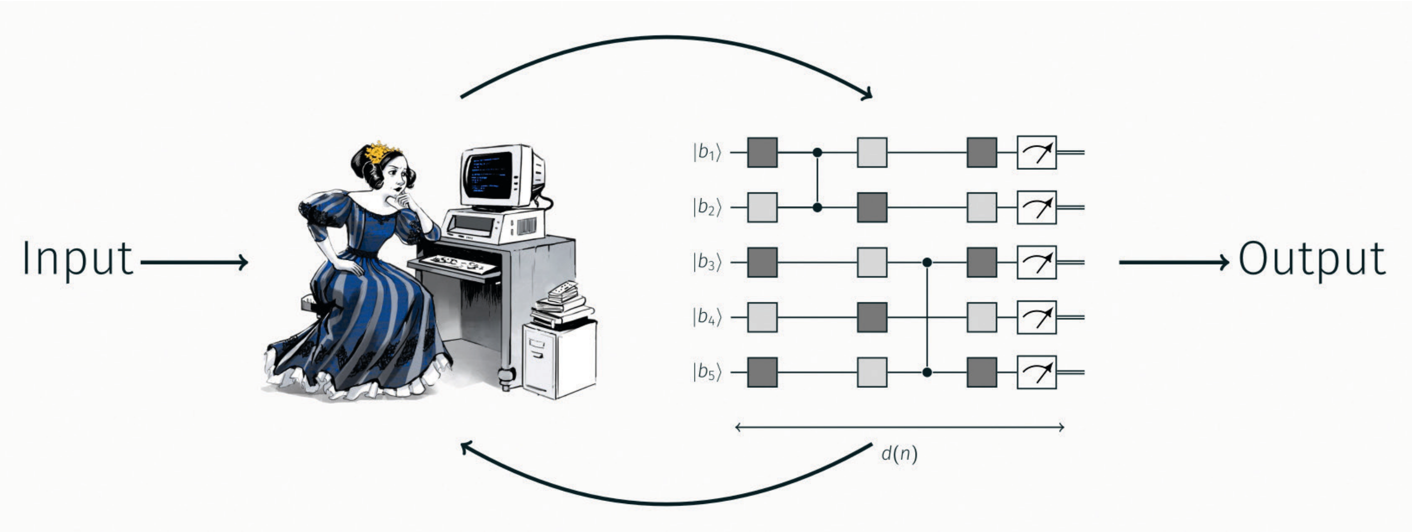
On the teaching front, Bakshi was invited to deliver a second lecture series on 'Skein modules and Relations to Algebraic and Hyberbolic Geometry' at Jilin University in Spring 2023. The course was delivered online and the audience consisted of graduate and advanced undergraduate students, and some research faculty from China and Korea. Once again, Bakshi looks forward to continue contributing to the scholarly activities at ITS and the endless possibilities that the coming academic year presents.

François Bienvenu attending the ITS Tea Time in Spring 2023.

During his second year as a Junior Fellow, **François Bienvenu** kept focusing on phylogenetic networks and developing the research program that he started upon coming to ITS. The goal of this research program is to develop the mathematical tools required to study reticulate evolution – i.e. to understand the evolutionary history of species in situations where phenomena such as hybrid speciation or horizontal gene transfers make it impossible to use trees to represent that history. Last year, Bienvenu and his collaborator Jean-Jil Duchamps had focused on understanding the consequences of the existence of a large-scale tree structure in phylogenetic networks (for instance, how that structure can be characterized and leveraged to simplify the study of the network). This year, they tried to understand when and why those large-scale tree structures emerge in networks. To do so, they considered various models of random phylogenetic networks and tried to obtain either necessary or sufficient conditions for the emergence of a tree structure as the size of the networks increases.

Besides this, Bienvenu has worked on the evolution of multicellularity and apoptosis, in collaboration with a group of researchers including biologists and mathematicians. The evolution of multicellular organisms is one of the major transitions in evolution, and given the intricacies needed to get a group of cells to function as a coherent entity, this topic has been and will remain an endless source of study. However, despite the large body of work on the subject, several fundamental questions remain not fully answered – for instance, when and how does it become beneficial for some cells to stay grouped? This simple question opens the door to game-theoretic considerations, because for this to happen not only should the benefits of multicellularity exceed its costs; the proto-organism should also be resilient to the evolution of "free-riders" (cells that would try to reap the benefits of multicellularity without paying its cost), at every stage of its evolution. There can therefore be conflicts between what is beneficial to the proto-organism and to the individual cells. One extreme example of such conflict is apoptosis, a type of controlled cell death in which some cells "voluntarily" sacrifice themselves to ensure the functionality of the organism. Apoptosis plays a central role in the embryonic development and growth of organisms, but also in their maintenance in adult life. To study how apoptosis can evolve, Bienvenu and his colleagues have introduced a dynamic random graph that models the growth and fragmentation of snowflake yeast, a proto-multicellular organism used as an experimental model for the study of multicellularity.

This year, Bienvenu has been invited to present his work at the Stochastic Geometry Days in Dijon (France) and at the Mathematics of Evolution workshop in Singapore.



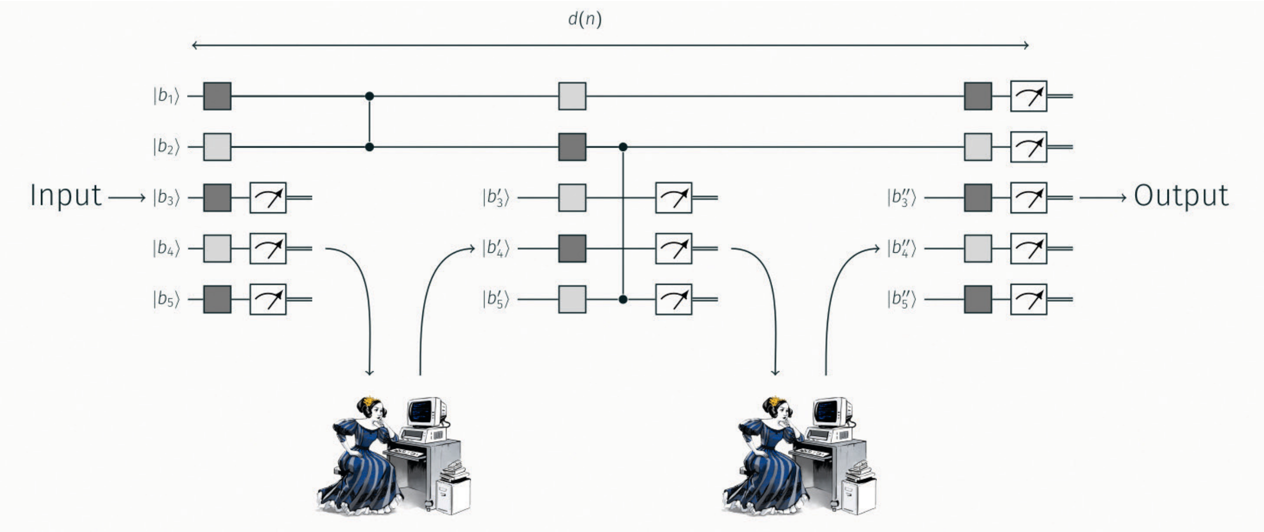
Alexandru Gheorghiu

A classical computer invoking a short depth quantum circuit several times.

In his last year at the ITS, **Alexandru Gheorghiu** continued his research into quantum computational advantage and quantum complexity theory.

One of the major challenges of quantum computing, particularly with near-term devices, is to be able to demonstrate quantum advantage in a way that is efficient to certify. That is, it should not only be that a quantum computer performs classically intractable computations, but that the result of those computations can be verified efficiently. So far, this has proven difficult to realize. A promising approach is the use of so-called "proof of quantumness" (also called "test of quantumness") protocols. These are protocols between a classical computer (referred to as the verifier) and a quantum computer (referred to as the prover). The verifier sends challenges to the prover which only a quantum computer can answer correctly. One of the main difficulties in implementing such a protocol in practice is the interaction between the verifier and the prover – the fact that the two have to exchange messages consisting of challenges from the verifier and responses from the prover. In recent work, Gheorghiu together with collaborators from Caltech, the University of Maryland, Duke, NIST and IonQ performed a proof of principle demonstration of a test of quantumness with an ion-trap quantum computer. What distinguishes this from previous such demonstrations, is that the test of quantumness they implemented is non-interactive. In other words, the test involves a single challenge from the verifier and a single response from the prover. While this was merely a small-scale demonstration of the protocol, the hope is that this approach can be scaled up and lead to efficient and practical tests of quantum advantage. The work was presented at Quantum Computing Theory in Practice (QCTIP) 2023 and is available as a preprint on the arXiv (2209.14316).

On the more theoretical side, Gheorghiu has worked on understanding the strengths and limitations of shallow quantum circuits when combined with classical computation. Shallow, in this context, means quantum circuits of very short depth. Many important quantum algorithms (such as Shor's algorithm for factoring integers) are known to be implementable with short depth quantum circuits, combined with (high depth) classical computation. It was not known, however, whether all problems that are efficiently solvable by quantum computers can also be solved using only shallow quantum circuits. Gheorghiu, together with Arora, Coladangelo, Coudron, Singh and Waldner gave the first instantiations of problems solvable with high depth quantum circuits that are not solvable with short depth quantum circuits, even when



A short depth quantum circuit interspersed with classical computation.

Alexandru Gheorghiu

augmented with classical computation. This resolved an open question posed by Aaronson almost 20 years ago. They also showed that the way in which quantum and classical computation are combined can lead to different classes of problems being efficiently solvable. Finally, they devised a protocol for certifying the "depth capabilities" of a quantum computer (i.e. verifying that a quantum computer can perform computations of a certain minimum depth).

This work was accepted at the Symposium on the Theory of Computing (STOC) 2023 and Theory of Quantum Computation (TQC) 2023 conferences. It is also available as an arXiv preprint (2210.06454).

Since leaving the ITS, Gheorghiu has started an assistant professor position at the Computer Science and Engineering department of Chalmers University of Technology, in Gothenburg, Sweden.

André Guerra started as a Junior Fellow in September 2022, after having spent a year at IAS in Princeton. He works in the Calculus of Variations, a field at the interface of analysis, geometry and physics. During this academic year, he focused on three different projects.

In a first collection of works, Guerra studied variational problems related to conformal maps: i) with K. Astala, D. Faraco, J. Kristensen and A. Koski, he completed a work concerning optimal integrability properties of quasiconformal maps; ii) with E. Prywes, he studied configurations of linked curves in S^3 with least conformal capacity, showing that the standard Hopf link is a local minimum; iii) with X. Lamy and K. Zemas, he proved that the conformal group of the sphere is stable in a strong, quantifiable manner.

A second ongoing project, with A. Figalli, S. Kim and H. Shahgholian, aims to study harmonic maps into manifolds with boundary. In this problem, the boundary of the manifold acts as an obstacle, and it is interesting to study the corresponding free boundary. More precisely, we are studying the way in which the harmonic map singularities interact with the free boundary.

Junior Fellow André Guerra (black shirt) attending the ITS Science Colloquium of Mihalis Dafermos in Spring 2023.

Finally, with J. Gómez, J. P. Ramos and P. Tilli, Guerra studied uncertainty principles for the Short-time Fourier Transform (STFT). The STFT is an operator which attempts to localize a given signal simultaneously in time and in frequency. There is a limit to how much signals can be localized, and we have obtained optimal quantitative bounds on this limit.

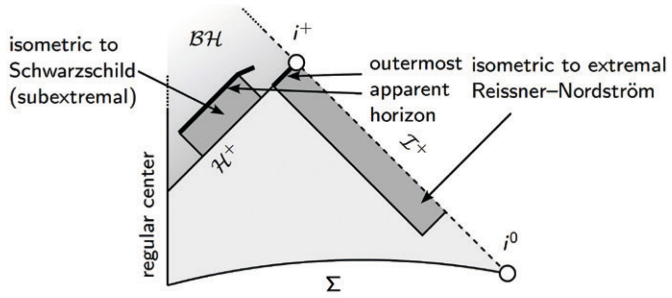
During this year, Guerra also presented his research in several different venues, including seminars at the University of Oxford, the MPI in Leipzig, Universidad Autónoma de Madrid, and at conferences in Banff, Bonn and Konstanz. He also participated in a special trimester program at the HIM in Bonn.

Besides the above research activities, Guerra has also mentored two ETH master students on semester papers in Calculus of Variations (joint with Prof. A. Figalli).

Christoph Kehle returned to ITS as a Junior Fellow in August 2022 after he spent one year as a member at the Institute for Advanced Study in Princeton. His research interests lie at the interface of analysis, geometry and partial differential equations. Specifically, he focuses on a rigorous mathematical understanding of foundational questions and phenomena in gravitational physics within the mathematical theory of general relativity formulated by Albert Einstein.

In the academic year 2022 – 2023, Christoph Kehle focused on three different research projects.

His first research project is motivated by the study of extremal (zero temperature) black holes. In influential work from 1973, Bardeen-Carter-Hawking conjectured that such extremal black holes cannot form from collapsing matter in nature. This conjecture has been disproved in 2022 by Kehle in joint work with Ryan Unger (Princeton): they show that certain matter configurations do collapse under their own gravitational attraction to form extremal black holes as depicted in the *Figure*. The work of Kehle–Unger further suggests that some extremal black holes feature a novel critical phenomenon: they lie exactly at the threshold of forming a black hole and the failure to do so. In the future, they plan to advance the understanding of this novel critical phenomenon linked to extremal black holes.



Christoph Kehle

Figure: Penrose diagram illustrating the counterexample to the third law of black hole thermodynamics.

Christoph Kehle

Christoph Kehle and his guest Georgios Moschidis in front of Lenin's Zurich residence in November 2022.

Kehle's second project concerns black holes in the presence of a negative cosmological constant. Such black holes have taken a very prominent role in high-energy physics, but a rigorous understanding of their nonlinear dynamics has remained elusive due to wave turbulence phenomena suggested by heuristics. In fact, based on these heuristics, it is debated whether to expect stability or instability for these black holes. In upcoming joint work with Georgios Moschidis (EPFL), they prove that solutions to certain model nonlinear wave equations on these black holes do exhibit turbulent instabilities.

Kehle's third project is in collaboration with his mentor Alessio Figalli, in which they study solutions to the prescribed Gauss curvature equation for hypersurfaces in higher dimensions – a fully nonlinear hyperbolic Monge-Ampère equation. Their work establishes the local theory and provides obstructions and insights on certain global aspects by analyzing the corresponding linearized equations.

Christoph Kehle was invited to present his research on various occasions, including research seminars at Princeton, Vienna, Rutgers, Columbia, Caltech, Stanford, Paris, Leipzig, and at international conferences in Bejing (virtual), Oxford, Victoria and the Erwin Schrödinger Institute in Vienna. Kehle is also one of the organizers of the monthly GAuS seminar on Analysis and PDE. In June 2024, he will organize a conference on "Gravitational physics and its mathematical analysis" at the SwissMAP research station in Les Diablerets together with Peter Hintz and Georgios Moschidis.

In addition to his research activity, Kehle actively engaged in teaching at ETH. In the spring term 2023, he taught a Master's level course on "Nonlinear wave equations with applications to general relativity", and supervised semester papers.

Johannes Knörzer started his second year at the ITS in February 2023. His research interests lie at the intersection of quantum information science, condensed-matter physics, and quantum optics. In the past year, he has been working on several projects related to quantum simulation of condensed-matter physics, the verification of quantum computations in quantum networks and quantum machine learning.

Junior Fellow Johannes Knörzer (on the left) organized the group hike around the Wägitalersee in Spring 2023.

Cross-platform verification

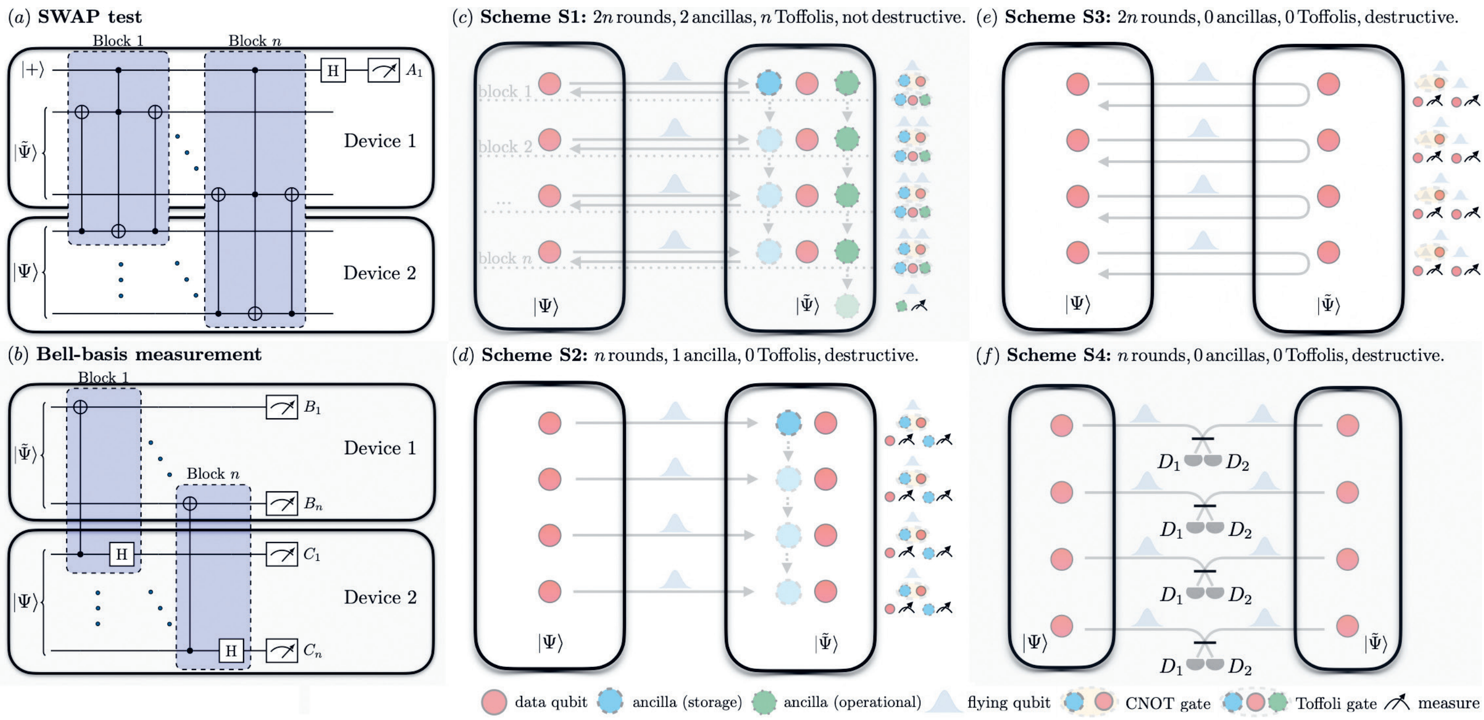
Quantum technologies are becoming more mature and dozens to hundreds of qubits are now within experimental reach. These machines may soon be used to solve computational problems that are intractable with current classical hardware. To gain trust in the output of a quantum device, however, they need to be benchmarked and their output verified. For small quantum devices, this may be achieved by resorting to a predict-and-verify paradigm in which both a quantum and a classical computer simulate a problem, upon which their solution is simply compared. Unfortunately, this usage of a classical computer is not possible for larger systems, due to a prohibitive exponential scaling of resources with system size. On the other hand, even to fully characterize the state of a quantum computer becomes impossible for larger systems, since the standard method, i.e., quantum state tomography, also requires exponentially many measurements in the number of qubits.

One of the practical approaches to this problem consists in cross-platform verification of quantum machines. In this approach, different quantum platforms are compared against each other after performing a given task. In recent years cross-platform verification protocols have been put forward which rely on local operations and classical communication. While they have a significantly improved scaling when compared to full state tomography, the required resources still scale exponentially. Together with colleagues from Munich, Knörzer investigated cross-platform verification schemes that involve quantum communication, i.e., the transmission of quantum information between distant quantum machines. In theory, these schemes do not suffer from the devastating exponential scaling but require only linear resources. Besides the comparison of different quantum states, as Knörzer and colleagues show, this approach also allows for efficient protocols for comparing quantum computations performed on distant devices. Their work is available as a preprint on arXiv [arXiv:2212.07789]. In the future, such protocols will become important, to gain trust in quantum machines and verify their output. In a related line of research, with colleagues from Germany, Sweden and the US, Knörzer has recently started investigating how techniques from quantum machine learning may help to improve cross-platform verification protocols.

Chain mappings for ultra-strong and relativistic light-matter interactions

Quantum optics deals with the physical description and understanding of interactions between light and matter, using the formalism of quantum physics. The research field has had very productive last decades and is at the core of many modern-day quantum technologies. It provides various toy models for studying light-matter interactions, that agree well with observations in the laboratory. At weak light-matter couplings, often simplifying solutions can be found that are either analytically or numerically available. However, at strong couplings, solutions are typically more difficult to find. Strong-coupling regimes require non-perturbative

Johannes Knörzer



Schematic depiction of cross-platform verification protocols in a quantum network. Reproduced from Fig. 1 in preprint arXiv:2212.07789.

methods, for example, to calculate the radiation emitted from an atom. Together with his collaborators, Knörzer recently investigated how star-to-chain transformations may be utilized for such tasks, when combined with methods based on matrix product or Gaussian states, respectively. Being well known in the study of open quantum systems, they demonstrated that the approach allowed them to also treat field observables – both in vacuum and thermal states of the field.

As an application of this method, Knörzer and a team of colleagues first considered giant atoms in the ultra-strong coupling limit. This work has recently been published in Physical Review A [PRA 106, 013702 (2022)]. In that publication, the team studied the time evolution of a giant artificial atom coupled to a waveguide. Giant atoms have recently emerged as an interesting toy system for unraveling novel quantum effects in the laboratory. In September 2023, Knörzer is co-organizing an international workshop on "Quantum Optics with Giant Atomic Emitters" which will be hosted by the Institute for Theoretical Studies in Zurich. Giant atoms permit the study of systems in which the electric dipole approximation breaks down and pronounced non-Markovian effects become important. While previous studies of giant atoms mainly focused on the realm of the rotating-wave approximation, Knörzer and his colleagues performed a numerically exact analysis of giant atoms strongly coupled to their environment, in regimes where counterrotating terms cannot be neglected. To achieve this, they utilized the abovementioned framework of star-to-chain transformations, combined with matrix-product state simulations. This approach yields access to a wide range of system-bath observables and to previously unexplored parameter regimes. Based on the relatively low computational costs of these simulations, their study paves the way for other numerical investigations of ultra-strong light-matter coupling.

In another recent study, Knörzer and one of his collaborators employed chain-mapping methods to achieve a numerically exact treatment of the interaction between a localized emitter and a scalar quantum field. In that work, they made use of what is sometimes referred to as the thermal double construction that allowed them to treat inertial systems coupled not only to the vacuum, but also to thermal field states. With that analysis, they extend the application range of chain-mapping techniques and put emphasis on the dynamics of field observables, such as the emitted energy density, for cases that are not captured by perturbation theory. As an illustrative physical example, they considered uniformly accelerated systems in the context of the Unruh effect. The corresponding preprint is currently under preparation and will presumably be uploaded to the arXiv in June 2023.

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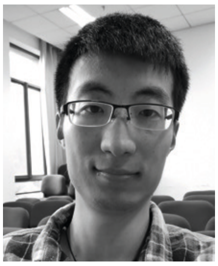
Outlook

Next to Viviane Baladi, who will join us again from January to April 2024, we are also happy to welcome back Gilles Brassard as Senior Fellow at the ETH-ITS for a third time.

1 **Gilles Brassard,** Professor of computer science at Université Montréal, is a researcher in quantum information science. He was among the founders of this discipline, having coauthored some of the fundamental papers in the subject. For example in his 1984 paper with C. H. Bennett he introduced the first quantum cryptography protocol and in 1993, Brassard and collaborators discovered the principle of quantum teleportation. His present research interests are at the boundary between quantum physics and computer science. He joined the ETH-ITS as a Senior Fellow in June 2014 for six months and again in April 2019 for three months. He received the Wolf Prize in Physics in 2018 and the Breakthrough Prize in Physics in 2023. Gilles Brassard is expected to visit the ETH-ITS again in Spring 2024.

The ETH-ITS has increased by one new Advanced Fellow in Summer 2023.

2 **Peter Koymans** received his PhD in mathematics from Leiden University under supervision of Jan-Hendrik Evertse and Peter Stevenhagen, and later held postdoctoral positions at the Max Planck Institute for Mathematics and the University of Michigan. His research is in various areas of number theory with his main field being arithmetic statistics. He has worked on Diophantine equations, unit equations, the circle method, the distribution of class groups and the negative Pell equation. His work on the negative Pell equation was covered by Quanta Magazine. He is currently working on Chowla's non-vanishing conjecture, Malle's conjecture and Greenberg's conjecture.



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In the new academic year, three new Junior Fellows will join the institute. Yuval Wigderson has started in late Summer. Weiming Feng and Chiara Meroni are expected to be ETH-ITS members as of early 2024.

3 Weiming Feng received his PhD in Computer Science from Nanjing University in 2021 under the supervision of Prof. Yitong Yin. His research interests lie in Theoretical Computer Science, with a particular focus on sampling algorithms for high-dimensional distributions. His research work includes studying the mixing times of Markov chains, understanding the relation between sampling and the Lovász local lemma, as well as developing new algorithms for distributed and dynamic sampling problems.

4 Chiara Meroni received her PhD in Mathematics in 2022 from the Max Planck Institute for Mathematics in the Sciences in Leipzig, where she conducted research under the supervision of Rainer Sinn and Bernd Sturmfels. Afterwards, she held postdoctoral positions at ICERM and Harvard University. Her research focuses on convex and real algebraic geometry, with a particular interest in exploring multiple directions and viewpoints, including optimization and quantum physics. More specifically, she investigated the boundary structure and behavior of convex sets defined by nonlinear polynomials.

5 Yuval Wigderson received his PhD in mathematics from Stanford University in 2022 under the supervision of Jacob Fox. His research interests are in extremal combinatorics and Ramsey theory, namely the study of the constraints and interrelationships between various properties of discrete structures. He is interested in applying techniques from algebra, analysis, and probability to such combinatorial problems. His website includes lecture notes and expository articles about many areas and results in and around combinatorics.

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Rahul Pandharipande

Administration
Livia Kürsteiner
Melanie Borer

Board of Patrons
Martin Haefner, Walter Haefner Foundation
Dr. Max Rössler
Prof. Dr. Ralph Eichler

Advisory Committee

2013 – 2017
ETH members
Gianni Blatter, Matthias Gaberdiel, Rahul Pandharipande, Tristan Rivière, Angelika Steger, Nicola Spalding*
External members
Noga Alon (Tel Aviv and Princeton), Luis Alvarez-Gaumé (CERN), Artur Ekert (Oxford), Shafira Goldwasser (MIT and Weizmann Institute), Gerhard Huisken (MFO), Elon Lindenstrauss (Hebrew University), Martin Hairer (Warwick)
*replaced by Ueli Maurer in 2015

2017 – 2019
ETH members
Alessio Figalli, Matthias Gaberdiel, Ueli Maurer, Rahul Pandharipande, Manfred Sigrist, Angelika Steger
External members
Noga Alon (Tel Aviv and Princeton), Robert Brandenberger (McGill), Artur Ekert (Oxford), Gerhard Huisken (MFO), Elon Lindenstrauss (Hebrew University), Martin Hairer (Imperial College), Claire Voisin (Collège de France)

2019 – 2022
ETH members
Alessio Figalli, Renato Renner, Manfred Sigrist, Olga Sorkine-Hornung, David Steurer, Tanja Stadler
External members
Robert Brandenberger (McGill), Ben Green (Oxford University), Albrecht Klemm (University of Bonn), Nathan Linial (Hebrew University of Jerusalem), Madhu Sudan (Harvard University), Corinna Ulcigrai (University of Zurich), Claire Voisin (Collège de France)

2023 –
ETH members
Marina Marinkovic, Svitlana Mayboroda, Renato Renner, David Steurer, Tanja Stadler
External members
Ben Green (Oxford University), Albrecht Klemm (University of Bonn), Nathan Linial (Hebrew University of Jerusalem), Madhu Sudan (Harvard University), Corinna Ulcigrai (University of Zurich), Anna Wienhard (University of Heidelberg)

Fellows 2014–2024

Senior Fellows

Terry Hwa, UC San Diego	02.2014 – 09.2014 and 04.2015 – 08.2015
Gilles Brassard, Université de Montréal	06.2014 – 12.2014 and 04.2019 – 06.2019 and 03.2024 – 06.2024
Henryk Iwaniec, Rutgers University	08.2014 – 05.2015 and 06.2016 – 07.2016
Dmitry Chelkak, St. Petersburg	09.2014 – 08.2015
Alex Lubotzky, Hebrew University	02.2015 – 07.2015 and 02.2016 – 08.2016
Adi Shamir, Weizmann Institute	02.2015 – 07.2015 and 02.2016 – 07.2016
Eugene Demler, Harvard University	05.2015 – 06.2015 and 09.2015 – 12.2015
Robert Brandenberger, McGill University	08.2015 – 07.2016
Walter Schachermayer, University of Vienna	08.2015 – 08.2016
Riccardo Barbieri, SNS Pisa	11.2015 – 10.2016
Alexander Balatsky, Nordita and LANL	02.2016 – 04.2016 and 07.2016 – 03.2017
Eitan Tadmor, University of Maryland	08.2016 – 07.2017
Vadim Kaloshin, University of Maryland	09.2016 – 08.2017
Jean-Michel Coron, Université Pierre et Marie Curie	01.2017 – 12.2017
Claire Voisin, Collège de France	01.2017 – 12.2017
Gerhard Huisken, MFO	02.2017 – 09.2017
Leonid Glazman, Yale University	05.2017 – 12.2017 and 05.2018 – 08.2018
Sandu Popescu, University of Bristol	10.2017 – 12.2017 and 03.2018 – 12.2018
Yakov Eliashberg, Stanford University	06.2019 – 09.2019 and 04.2022 – 06.2022
Ivan Cherednik, University of North Carolina at Chapel Hill	07.2019 – 06.2020
Nicolai Reshetikhin, UC Berkeley	07.2019 – 07.2020
Ming Yuan, Columbia University	09.2019 – 08.2020
Kannan Soundararajan, Stanford University	09.2019 – 03.2020 and 07.2023 – 08.2023
Albrecht Klemm, University of Bonn	08.2021 – 03.2022
Mikhail Lyubich, Stony Brook University	08.2021 – 01.2022
Viviane Baladi, CNRS	04.2022 – 06.2022 and 04.2023 – 06.2023 and 01.2024 – 04.2024
Daniel Huybrechts, University of Bonn	04.2022 – 06.2022 and 02.2023 – 03.2023
Sanjeev Arora, Princeton University	08.2022 – 10.2022
Alex Eskin, University of Chicago	03.2023 – 05.2023

Junior Fellows (with current affiliation of former Junior Fellows)

Emily Clader, University of San Francisco	09.2014 – 07.2016
Zur Luria, Azrieli College of Engineering	09.2014 – 09.2017
Alessandro Carlotto, University of Trento	09.2015 – 08.2016
Maria Colombo, EPF Lausanne	09.2015 – 08.2018
Lavinia Heisenberg, University of Heidelberg and ETH Zurich	09.2015 – 09.2018
Titus Lupu, CNRS	09.2015 – 12.2017
Aline Ramires, Paul Scherrer Institut	09.2015 – 08.2018
Ran Tessler, Weizmann Institute	09.2015 – 10.2018
Shoham Letzter, University College London	09.2016 – 12.2019
William Sawin, Columbia University	09.2016 – 07.2018
Ulrike Rieß	09.2017 – 09.2021
Johannes Noller, ICG Portsmouth	09.2017 – 03.2020
Pierrick Bousseau, University of Georgia	09.2018 – 09.2020
Nina Holden, New York University	09.2018 – 12.2020
Fanny Yang, ETH Zurich	09.2018 – 09.2019
Yi-Jun Chang, University of Singapore	07.2019 – 08.2021
Stefan Glock, University of Passau	09.2019 – 08.2022
Dominik Schröder, ETH Zurich	09.2019 – 08.2022
Christoph Kehle	09.2020 – 08.2021 and 08.2022 – 07.2024
Alexandru Gheorghiu, Chalmers University	09.2020 – 09.2022
Rhea Palak Bakshi	09.2021 – 08.2024
François Bienvenu, CNRS	09.2021 – 01.2024
Sándor Kisfaludi-Bak, Aalto University	09.2021 – 12.2021
Johannes Knörzer	02.2022 – 01.2025
André Guerra	09.2022 – 08.2025
Deeksha Adil	01.2023 – 01.2026
Yuval Wigderson	09.2023 – 08.2026
Weiming Feng	01.2024 – 12.2026
Chiara Meroni	02.2024 – 01.2027

Advanced Fellows (with current affiliation of former Advanced Fellows)

Marvin Künnemann, TU Kaiserslautern	04.2021 – 03.2022
Michael Borinsky	09.2021 – 08.2026
Sylvain Lacroix	09.2021 – 08.2026
Yunan Yang, Cornell University	01.2022 – 06.2023
Gramoz Goranci, University of Vienna	09.2022 – 01.2023
Peter Koymans	08.2023 – 07.2028

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