# NCTS Newsletter

Vol. 11 Fall 2021

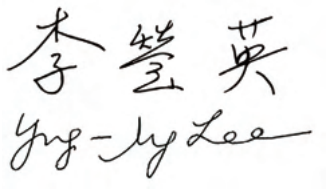
# Director's Message

Dear Friends of NCTS,

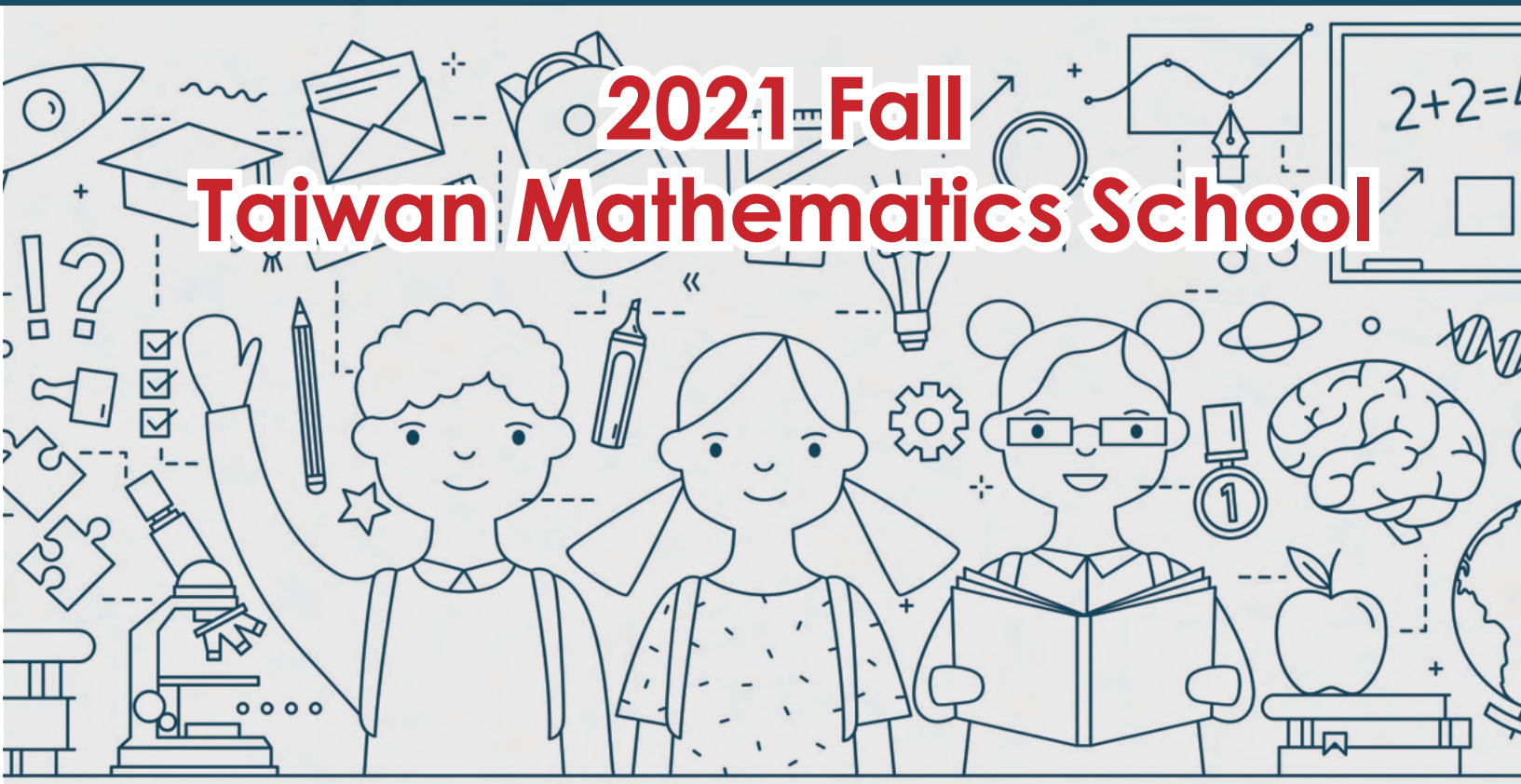
The ongoing pandemic of Covid-19 continues to restrict international travel and disrupt many academic activities. The NCTS Mathematics Division also has been affected by the pandemic substantially. In this difficult time, we strive to make a difference. In collaborations with outstanding mathematicians from different countries, the NCTS is hosting two very successful international online seminars: The NCTS International Geometric Measure Theory Seminar and Seminar of Algebraic Geometry in East Asia, which invite some of the world foremost leading experts in their fields, e.g., the speaker of the iGMT on September 22 this year was Fields Medalist Alessio Figalli. The center's three educational programs, Taiwan Mathematical School (TMS), Undergraduate Research Program (URP) and Undergraduate Summer Research Program (USRP) continue to flourish; more information on them can be found in this issue of newsletter.

We are also very pleased that NCTS center scientist Prof. Chung-Jun Tsai received this year's MOST (Ministry of Science and Technology) Outstanding Award, center scientist Prof. Hsing-Yuan Huang and NCTS Young Theoretical Scientist awardee Prof. Wei-Fan Hu received this year's MOST Wu-Ta-You Memorial Award. We congratulate them for their achievements and honors!

Despite the pandemic, the NCTS postdoctoral program remains strong and continues to attract many outstanding applicants. The program is extremely international. There are 20 postdocs currently employed in the NCTS from many countries like USA, Japan, Italy, Korea, Taiwan, Turkey, Germany, Vietnam etc. We are now calling applications for Postdoctoral Fellows starting appointments either in the spring or fall of 2022. The NCTS also invites applications for Research in Pairs and international exchange program. We warmly welcome you to take a look and apply.




NCTS Mathematics Division, Director
*Prof. Yng-Ing Lee*



# 2021 Fall Taiwan Mathematics School

With the approaching of the new school year, we invite Prof. Eiichi Bannai (Kyushu University) and Prof. Keiji Oguiso (The University of Tokyo) to give lectures on their research for Taiwan Mathematics School; we also have teachers from universities around Taiwan to give courses for TMS. The course plan of this semester is as follows:

## Algebraic Combinatorics (I)

Lecturer: Eiichi Bannai (Kyushu University)

Prof. Bannai is a worldwide well known mathematician. He came to Taiwan to visit NCTS in November of 2020. He taught Algebraic Combinatorics I & II for one school year. This year he continues to stay in NCTS and teaches the same course.

The purpose of this course is to give the audience a chance to explore "algebraic combinatorics" without assuming any previous knowledge of combinatorics. We will try to propose many open problems hoping that some of them are accessible and solvable by the audience. (We encourage and emphasize the discussions on trying to solve these open problems among the audience.)

## Continuation Method: Theory and Application

Lecturers: Je-Chiang Tsai (NTHU), Chia-Chieh Jay Chu (NTHU), Yueh-Cheng Kuo (NUK), Te-Sheng Lin (NYCU)

Continuation method is a powerful numerical computation approach. Its prominent features consist of two parts: (1) solutions dependence on system parameters; (2) detection of unstable solutions. Due to these features, continuation method has a variety of applications in physical models, chemical reactions, and biological processes. In this course, we will first set up the theory for continuation method, then move to the software AUTO which implements continuation method, and finally give the application in scientific problems and dynamical systems.

## Arithmetic Dynamics for Rational Dominant Self-maps of Projective Varieties

Lecturer: Keiji Oguiso (University of Tokyo)

In this course, in the first few lectures, Prof. Oguiso will introduce Weil height and the so called Weil Height Machine following M. Hindry and J.H. Silverman. Then he will introduce the notion of arithmetic degree for a self-morphism of a normal projective variety and its basic properties following Kawaguchi-Silverman. Then as concrete important cases, he'll explain the full solution of KSC for an endomorphism of a surface and an endomorphism of an abelian variety (Kawaguchi-Silverman-Sano-Matsuzawa-Shibata) and a self-morphism for hyperkaehler manifold by Leiseutre and Satriano. Then (probably the last one third of lectures) we start to generalize for dominant self-maps or birational self-maps. This part is under progress by many researchers, and, except some basics, the choice of topics will be fixed later.

## Real Analysis I
Lecturer: Ulrich Menne (NTNU)

Lebesgue integration theory is one of the pillars of analysis. The present course and its sequel, Real Analysis II, gives a thorough treatment of the underlying general measure theory, Lebesgue integration, the resulting Lebesgue spaces, related linear functionals, and product measures. It treats Borel regular measures, Radon measures, and Riesz's representation theorem in some depth and includes the theory of Daniell integrals and as well as Riemann-Stieltjes integration. This choice of emphasis facilitates the study of geometric measure theory through planned subsequent courses.

In part I, after establishing the necessary basics from point-set topology, measures and measurable sets (including numerical summation and measurable hulls), Borel sets (Borel families, the space of sequences of positive integers, images of Borel sets, and Borel functions), Borel regular measures (approximation by closed sets, nonnmeasurable sets, Radon measures, and their images), measurable functions (approximation theorems and spaces of measurable functions), and Lebesgue integration (up to and including limit theorems) shall be treated. In part II in the following term, after establishing the necessary background on tensor products and functional analysis, Lebesgue integration shall be completed (Lebesgue spaces), linear functionals (lattices of functions, Daniell integrals, linear functionals on Lebesgue spaces, Riesz's representation theorem, curve length, and Riemann-Stieltjes integration), and product measures (Fubini's theorem and Lebesgue measure) shall be covered. Some of the material on topology and functional analysis will be relegated to the two self-study phases.

## Introduction to Riemann Surfaces
Lecturer: Ching-Jui Lai (NCKU)

The subject of compact Riemann surfaces or algebraic curves has its origin going back to the work of Riemann. Its development requires ideas from analysis, PDE, differential geometry, complex geometry, algebra, and topology etc. This course serves as a introductory course to more general theories of complex manifold and higher dimensional algebraic geometry.

In this course, we will introduce the notion of Riemann surfaces, holomorphic functions, meromorphic functions, differential forms on Riemann surfaces, maps between Riemann surfaces, Riemann-Roch Theorem, Abel-Jacobi theorem. We might discuss the existence of meromorphic functions and the uniformization theorem if time allows.

# Undergraduate Summer Research Program

From July 12 – August 20, 2021 NCTS hosted the Undergraduate Summer Research Program. Due to the pandemic, this year the program was entirely held online, but the participants enjoyed the 6 weeks of their research nevertheless.

**Group 1**, which was supervised by Prof. Chia-Fu Yu (AS) and Prof. Ting-Yu Lee (NTU), looked at Computational problems of certain algebraic tori. An algebraic torus is an algebraic group which is isomorphic to the product of copies of the multiplicative group over a finite extension. There have been many studies of tori in various areas, including algebraic geometry, analysis, number theory and representation theory. Participants are interested in properties of algebraic tori over global fields. Rationality, the local-global principle, weak approximation, class numbers and Tamagawa numbers are important guiding problems for studies of them. In this program they focus on the computational problem of the Tamagawa numbers of multinorm one tori. Using works of Ono, Pollio, Rapinchuk, Demarche-Wei, Lee and her collaborators, they compute the Tamagawa numbers for the products of two linearly disjoint extensions, and those of cyclic extensions.

**Group 2,** which was supervised by Prof. Eiichi Bannai of Kyushu University with teaching assistants Wei-Hsuan Yu and Chin-Yen Li, studied Euclidean and Gaussian designs. In this program, mentor introduced the problems of the existence of tight designs in low dimensions to the students. Students learned the notion of designs, in particular for Euclidean designs, Gaussian designs and coherent configurations. In the end, they prove that tight Gaussian 6- and 8-designs with constant weight do not exist in any dimensions.

The project of **Group 3** consists of two parts: a short course and a hands-on research. In the first two weeks, students built up the knowledge of convergence theory of solutions of elliptic equations. Prof. Chih-Wei Chen (NSYSU) and Prof. Kuo-Wei Lee (NCUE) introduced Holder norm, harmonic coordinates and elliptic regularity to students, so that students can have better convergence results than just applying Arzela-Ascoli theorem. For instance, the mentors obtained the regularity of Einstein metrics. They further introduced the notion of weak derivatives and Sobolev embedding theorem. This gives the up-to-date and general technique for dealing with regularity problems.

For the second part of this project, mentors encouraged students to learn M. Gage's result on long-time existence and convergence for the curve shortening flow on sphere. Students learned how to use maximum principle and some standard inequalities to prove $C^\infty$-convergence of the curvature. On the other hand, mentors proposed two hands-on projects for students to practice all the skills they have just learned. Both projects focus on the singularity analysis of the Ricci flow. The first one is to estimate the size of the Type

II set. They wish to show that the set of Type II points is relatively small. The second one is to blow up a singularity along "secondary" points. Through these two projects, students learned how to rescale Riemannian metrics so that one can find a convergence subsequence of these metrics. Some fundamental theorems, such as Shi's estimate, Hamilton's compactness theorem, Perelman's no local collapsing theorem and pseudo-locality theorem, arise naturally in this investigation. Students should have a comprehensive understanding and a practical experience on the blow-up procedure along the Ricci flow.

**Group 4**, which was supervised by Prof. Hao-Wei Huang of NTHU, studied free probability theory and random matrix theory. The former theory was launched by Voiculescu around 1985 with the intention of classifying the free products of algebras. In this summer research program, participants explored this theory from the analytical aspect. They acquired that the notion of freeness of random variables performs the analog character of the classical independence. They also learned that free harmonic analysis operate essential implements in investigating this area, and proved various known consequences analytically. In addition to the exploration of free probability theory, participants studied the connection of free probability theory to random matrix theory, such as asymptotical freeness of GUE and other types. By inspecting the simulation of the eigenvalue distribution of matrices of suitable sizes, they linked more known matters to strong convergence of random matrices. In the end, participants presented what they have learned in this subject.

**Group 5**, which was supervised by Prof. Hsin-Yuan Huang of NYCU, were interested in topics in Integrable System. The inverse scattering transform (IST) is a method for solving some non-linear partial differential equations in the integrable systems. The method is a non-linear analogue of the Fourier transform. This method was introduced by Gardner-Greene-Kruskal-Miura for the Kdv equation, and soon extended to the nonlinear cubic Schrodinger equation, the Toda lattice equation and so on.

In this project, Prof. Huang introduced the IST for Kdv and defocusing nonlinear Schrodinger equation, and the connection between IST and Riemann-Hilbert problem in the first three weeks. Students were required to study the IST for Toda lattice equation and its connection with the Riemann-Hilbert problem in other three weeks. The Riemann-Hilbert Method is a modern technique developed by Deift and Zhou to study the asymptotic behaviors of some integrable systems. After the experience of USRP, we believe the students are ready to study the Riemann-Hilbert method for the integrable systems in the future.

**Group 6** was supervised by Prof. Jung-Chao Ban of NCCU and Prof. Chi-Hung Chang of NUK and their research topic is "nonautonomous dynamical systems (NDS)," focusing on symbolic aspects. NDS is a relatively new topic in the field of dynamical systems. Most results in classical autonomous dynamical systems do not hold. There were four students, including one research assistant who is a graduate student in this group. One of the members is a senior student of the department of mechanical engineering. Although he was not well-trained compared with the others, he worked very hard to catch up during the whole program. His achievement demonstrates that no one is limited. Furthermore, as he is not that familiar with "mathematical thinking," his seeking provided the group a different viewpoint of the investigation. This turns out to be good stimulation for all members.

Due to the pandemic, the whole program was running online, which made the discussion a little harder than usual. One of the most seen situations was one's presentation was interrupted by another since the latter thought the other had done talking. It was kind of interesting and eased the atmosphere sometimes. Like the saying, "life finds a way." For the second half of the program, we expressed ourselves and exchanged ideas quite smoothly. Moreover, the final results, which were demonstrated totally by the students themselves, were much better than we expected initially.

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**Group 7** was supervised by Prof. Wei-Fang Hu of NCU. The research topic of Group 7 is "Applications of Deep Learning for Scientific Computing". During the consecutive six weeks of lecturing, the students learned the mathematical backgrounds of machine learning and methodologies to various training methods. Each student has his/her own interest research topic, including finding problem parameters using data-driven recovery model, developing a black-box formula for the computation of mean curvature on a triangular mesh, and solving partial differential equations using neural network learning machine. Although some of students did not achieve their goals due to some computer programming issues, they still gain fruitful knowledge about the problem that they were tackling with. Joining the USRP program would definitely be a good experience for the students and they will be able to proceed with the related studies in the future.

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Two students participating in **Group 8**, which was supervised by Prof. Pengwen Chen of NCHU, studied the recovery from underdetermined measurements. In the first two weeks, Prof. Chen provided 12 hours of lectures on convex optimization, including the L1-sparse problem and some well-known algorithms such as ISTA and FISTA. This provides a warm-up for the research on non-convex optimization of the subject phase retrieval. In these two weeks, students also practiced some coding skills. In the third/fourth week, Prof. Chen introduced some related academic literature on this topic and explained the relevant knowledge of a few papers. Then he chose a suitable research topic for participants: the realization of two-dimensional ptychography. This task is not easy but doable for them. In the past two weeks, they have held nearly ten meetings on a regular basis to clarify some theoretical misunderstandings and provide some help in coding. In the end, the students stood up to the pressure and finished the project in a relatively short period of time.

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Professor Chia-Jay Chu (NTHU) and Prof. Cheng-Fang Su (NYCU) organized **Group 9** on "Study on data analysis and dimensionality reduction". In the first two weeks, mentors gave lectures to introduce some dimensionality reduction methods, including principal component analysis (PCA), diffusion maps, and multidimensional scaling (MDS). The students not only learned the procedure of the methods but also investigated the mathematical foundations of these methods. For the rest of the weeks, the students focused on studying "split and combine multidimensional scaling" (SC-MDS), a speed-up version of MDS, and improved the method.

During the program, they read many literatures and novel papers. They shared the discovery from these literatures and discussed the progress of their research. The students found that, in the original paper, the authors have not established the reasoning of why SC-MDS could obtain the same results as MDS. They have stated the assumptions for SC-

MDS to work correctly and fulfilled the proof of their theorem. They also observed that SC-MDS may generate a worse result than the result obtained from MDS. They investigated the factors that may cause such issues and tried to resolve them. They proposed a modified version of SC-MDS that is more stable and efficient. They also demonstrated several numerical experiments to support their theories. Their research built some mathematical keystones for SC-MDS and gave a better understanding of the methodology.

At the final stage of the research program, the undergraduates gave a presentation to discuss their findings. All in all, the participants benefited greatly from high-quality mentorship and enriching mathematical research experience provided by NCTS USRP, and some of them will keep on doing their research under the support of NCTS URP from October 2021 to June 2022.

## Undergraduate Research Program

The Undergraduate Research Program (URP) is the fall and spring semester counterpart of the Undergraduate Summer Research Program (USRP). Recognizing the importance of beginning to do original research at an early stage, these programs target highly motivated undergraduate students who plan to pursue a career in scientific research. The difference of these programs is mainly in their durations: the URP is a 9-month, while the USRP is a 6-week program. Both programs can be complementary to each other: on several occasions a URP program serves as a precursor of a USRP program and vice versa. Usually, such a program consists of group of 2-4 students and 1-2 faculty members whose task is provide guidance to the students to reach a stage capable of investigating (and ultimately solving) original research problems. In the past, topics studied by these research groups include many directions in pure to applied mathematics. These two programs are an integral part of NCTS' commitment to play an active role in training the next generation of scientists in Taiwan.

# Highlights of Events

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| 4/24 | NCTS Student Workshop on Scientific Computing |
| 4/30 | NCTS (Central Taiwan) computational mathematics workshop |
| 5/1 | The 21st Taiwan Geometry Symposium |
| 6/28 | NCTS Symposium on Applied Mathematics |
| 7/1 – 7/2 | Statistics Symposium in Memory of Wen-Chen Chen |
| 9/2 | Machine learning on solving partial differential equations |
| 9/4 | Interfacing Mathematics and Physical Sciences through Machine Learning |
| 9/10 – 9/11 | 2021 NCTS Online Workshop on Computational Mathematics and Scientific Computing for Young Researchers |

# Taiwan Mathematics School: Upcoming Courses

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| 9/15 – 2022/1/21 | Introduction to Riemann Surfaces |
| 9/24 – 2022/1/21 | Continuation Method: Theory and Application |
| 9/24 – 2022/1/21 | Real Analysis I |
| 9/24 – 2022/1/21 | Algebraic Combinatorics I |
| 10/4 – 12/6 | Arithmetic Dynamics for Rational Dominant Self-maps of Projective Varieties |

**September 10-11, 2021**

**I. Workshop Aim & Introduction**

The purpose of this workshop is to provide scholars with an opportunity to share their research and research interests in the field of computational mathematics and related topics. In particular, senior scholars not only presented their research, but also talked about their experiences and their careers that will inspire more collaboration and interaction between senior and young scholars. Therefore, the workshop aimed to provide participants an opportunity to:

- To report on recent developments in the representation theory of recent research and its related topics in computational mathematics.
- To foster discussions and interactions in computational mathematics.
- To explore and engage in number of topics related to emerging research topics, discussion or research to expose young scholars to the work of computational mathematics and scientific computing.
- To hear from some applied mathematics experts about how recent developments in computational mathematics.
- For senior scholars to share their experiences about working in this field, as well as some anecdotes from their work and careers.

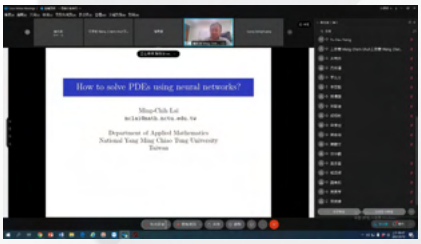
**II. Accomplishment Summary**

Our invited speakers were Peng-Wen Chen, Ming-Chih Lai, Matthew M. Lin, Wei-Jie Liang, Li-Ren Lin, Ching-Sung Liu, Chung-Lin Tseng and Mei-Heng Yueh. In particular, there were approximately 40 scholars and students enrolled in this workshop, including faculty from national and private universities and their students.

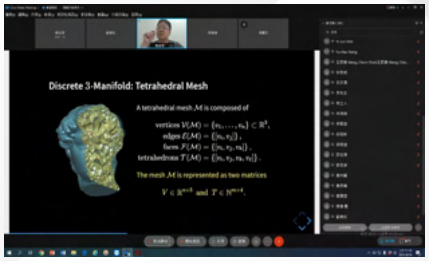
# 2021 NCTS Online Workshop on Computational Mathematics and Scientific Computing for Young Researchers

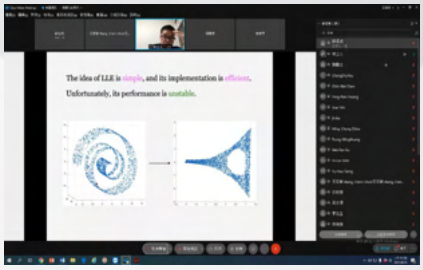
The topics of the talks are diverse and challenging in the fields of computational mathematics such as solving PDEs by using machine learning, introduction to quantum computing, image processing, numerical optimization problem, and numerical partial differential equations.

Continuing to support such kind of workshops or activities, can lead to a new concept, spurring both scholars and students, to investigate it further on their own, or can demonstrate and encourage the practice of actual methods and giving them a chance to practice and receive feedback on techniques and concepts they already know.

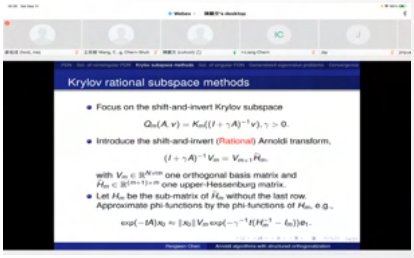


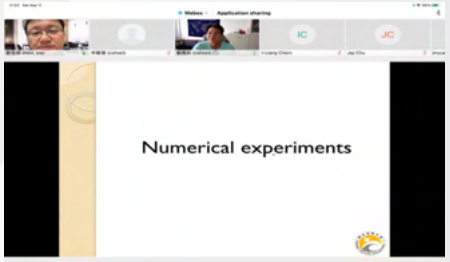


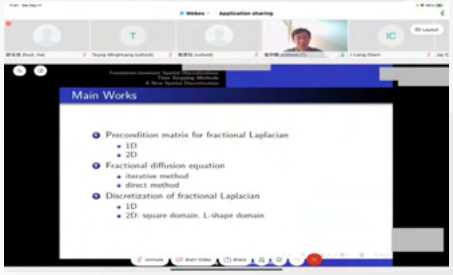






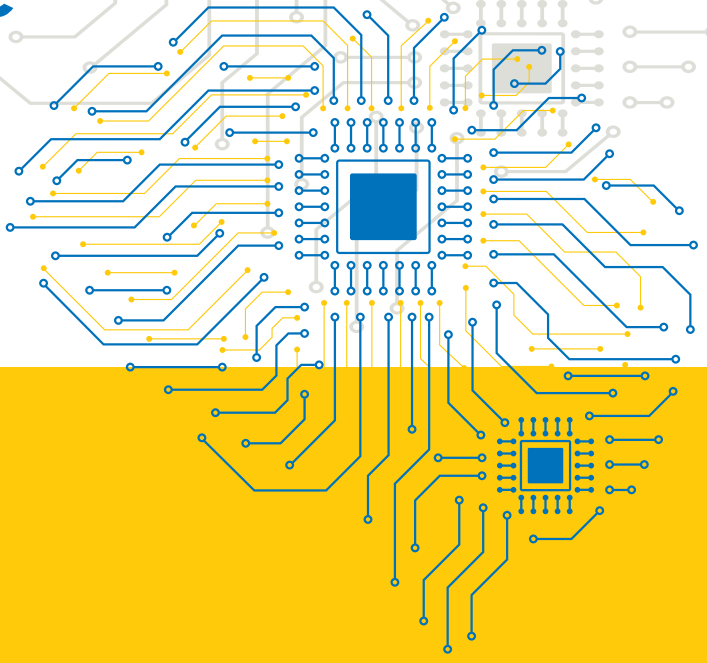



National Center for Theoretical Sciences

# Interfacing Mathematics and Physical Sciences through Machine Learning

September 4, 2021



The boundaries of research are constantly changing. Cross-disciplinary research has become the mainstream of scientific development in recent years. Initiated by the Discipline of Mathematics, Physics, and Statistics, the conference was jointly organized by MRPC, PRPC, and NCTS. Experts in the fields of Physics and Mathematics were brought together to discuss related theoretical research, such as Machine Learning and Big data analysis which gradually develops in recent years.

The conference consisted of three sessions: High-dimensional Data Analysis, Machine Learning in Practice, and Dimension Reduction and Manifold Learning. In addition to people from Math, Physics and Statistics, invited speakers also included experts from Astronomy and Chemistry. The topics ranged from AI in healthcare, the interpretation of Higgs boson in Particle physics, Active galactic nucleus (AGN), image recognition and processing to Riemannian manifolds and Harmonic matrices. It is clear from their talks that machine learning is a powerful tool and it has brought a great impact on many areas; mathematics must play a fundamental role in the research on machine learning. We hope to take this opportunity to seek potential collaborations of Mathematics and Physics and stimulate some new ideas for further research in these fields.

# Machine leaning on solving partial differential equations

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| Date | **September 2, 2021** |
| Venue | Online Conference |
| Time | 10:00-12:00 |

In the past ten years, deep learning has achieved great success in different scientific disciplines and many practical applications in our daily lives. For the mathematics community, an important question is whether deep learning can bring breakthroughs to our own research topics, or how artificial intelligence can help us conduct our own research. The purpose of this seminar is to answer this question through a specific example, namely, machine learning on solving partial differential equations.

In this special lecture, Prof. Ming-Chi Lai and his collaborators, Prof. Wei-Fan Hu and Prof. Te-Sheng Lin, gave an example of using machine learning methods to solve partial differential equations, especially when PDEs become difficult to handle with traditional numerical methods (such as finite difference, finite element or spectral methods). The lecture started by introducing some fundamental mathematical backgrounds for machine learning and the methodologies to solve PDEs. Then, the shallow neural network model to solve the elliptic interface problems was explained in detail. Some remaining open questions and future directions were also be raised.

This two-hour lecture was conducted online, from 10:00 am to 12:00 pm, with about 70 people attending. After the speech, there was a lively discussion for about 30 minutes. We sincerely hope that, through this seminar, more scholars engaged in mathematics research will know about deep learning and artificial intelligence, and will be able to use this tool to bring breakthroughs in their research topics.

# Statistics Symposium in Memory of Wen-Chen Chen

## July 1-2, 2021

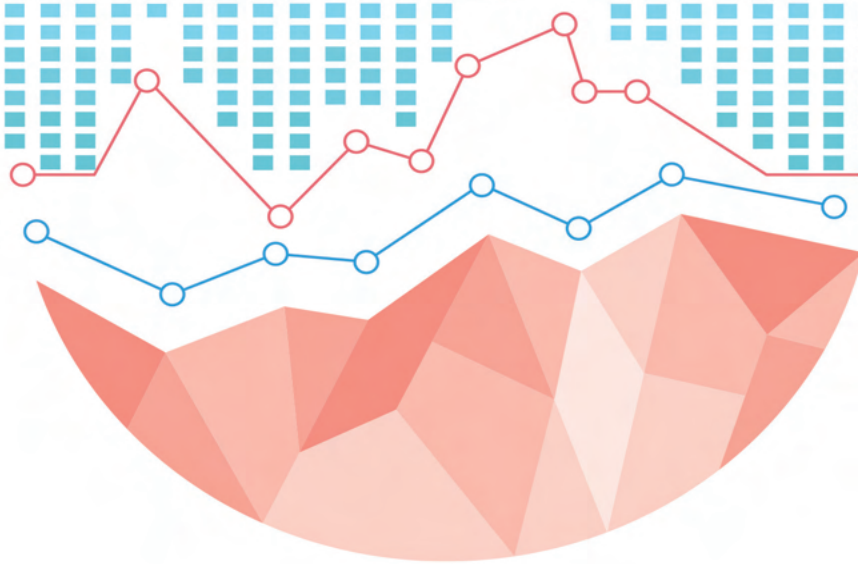
Dr. Wen-Chen Chen, Assistant Professor of Statistics at Carnegie Mellon University, died at the young age of 31 in Taipei, Taiwan, at the dawn of his promising career. The Statistics Symposium in Memory of Wen-Chen Chen was held on July 1-July 2, 2021, at NCTS. This Symposium is organized by Department of Mathematics, National Taiwan University, NTU Math Alumni Association, and sponsored by the National Center for Theoretical Sciences, Taipei, Taiwan, the Institute of Statistical Science, Academia Sinica, Taipei, Taiwan, and the Department of Statistics and Data Science, Carnegie Mellon University, Pittsburgh, Pennsylvania, USA. The main organizers of this symposium are Professor Chii-Ruey and Professor Naihua Duan, Professor Chin-Tsang Chiang, Professor Su-Yun Huang, Professor Wen-Han Hwang and Professor Ching-Kang Ing.

Due to the COVID-19 outbreak, we couldn't have a traditional symposium to honor Dr. Wen-Chen Chen. With the help of technology, we had audiences from abroad to gather online to attend this very special symposium.

NTU President Chung-Ming Kuan and Wen-Chen Chen Foundation President Maysing Yang gave opening speeches to welcome all the participants. There were several special speakers in this symposium. In 1978, Professor Jay Kadane hired Dr. Wen-Chen Chen as an assistant professor in the Carnegie Mellon Department of Statistics. He gave a talk on "Wen-chen Chen at Carnegie Mellon University: Before and After His Death". Professor Joel Greenhouse gave a talk "On Becoming a Bayesian: The Influence of LJ Savage". He is the academic brother of Dr. Wen-chen Chen at University of Michigan. Professor Liza Levina ( Chair of the Department of Statistics, University of Michigan) gave a talk on " Wen-Chen Chen at the University of Michigan". She shared with us that Dr. Chen finished his thesis work by the end of second year, but stayed for the third year. Dr. Chen was remembered by all contemporaries for his warmth. His adviser Professor Bruce Hill said that " he is an outstanding student – the best that I'd seen in statistics in 21 years." We also had Professor Anne Chao from Tsing Hua University. She invited Dr. Chen to give a talk at Tsing Hua University one week before his death. Professor Chao gave a talk "A Review of Professor Wen-Chen Chen's Statistical Research—Marking the 40-Year Remembrance of his Martyrdom". There were also many speakers and guests here who are the recipients of Dr. Wen-Chen Chen's Statistics Scholarship. This symposium was a very special event to honor Dr. Wen-Chen Chen's life and his academic accomplishment.

# NCTS Symposium on Applied Mathematics

## Date: June 28, 2021



This one-day symposium is to provide researchers and students progresses in some research topics of applied mathematics such as quantum state tomography, dynamics based on equation-free modelling, and the analysis of traffic problems. The symposium focused on the key idea of research topics, so the speakers were encouraged to give more details in their presentations. Specifically, Prof. Yen-Huan Li explained the set up of quantum state tomography, the relation to quantum computing devices, and how the Cover's method from investment discipline came into play. Without constructing models, Dr. Chun-Wei Chang applied the embedding Takens theory to time series data to predict the evolution of ecosystem, and extract the causation between species. His researches also proposes some challenge problems in dynamics systems. Dr. Shis-Hsun Hung used data analysis techniques to analyze city illegal parking, and take Tainan city as an example to derive interesting conclusions.

NCTS
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# The 20th Taiwan Geometry Symposium

Date : *2021/5/1*

Venue : Lecture Room B, 4th Floor,
The 3rd General Building, NTHU

The "Taiwan Geometry Symposium" is a one-day workshop which is hosted twice or three times per year since 2010 by NCTS. This event is initiated by Professor Yng-Ing Lee (National Taiwan University), Nan-Kuo Ho (National Tsing Hua University), and River Chiang (National Cheng Kung University). The purpose is to foster discussions and interactions within the geometry community in Taiwan. It provides an opportunity to introduce different aspects of geometry to interested students. It is also an event that the differential geometry society can get together to discuss about the plan for the future activities.

We try to have the speakers at different stages of the career. This time we invited 3 one-hour speaker: Yuan-Pin Lee (Academia Sinica) talked about quantum cohomology, Hsuan-Yi Liao (National Tsing Hua University) talked about derived differential manifolds, and Andrea Galasso (National Center for Theoretical Sciences) talked about quantization under group actions. The event was held in the National Tsing Hua University, and there were about 40 participants. The symposium next time is expected to be held during the fall of 2021, and in southern Taiwan.

# NCTS (Central Taiwan)
# Computational Mathematics Workshop

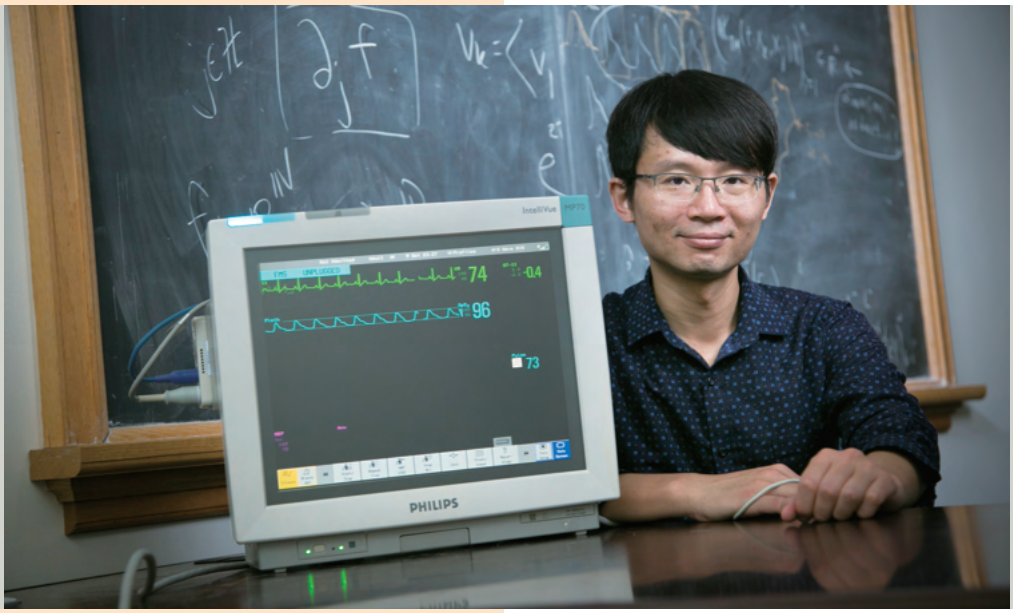
Date | April 30, 2021
Venue | U501, NCHU


It is our pleasure to organize the computational workshop at NCHU in Taichung. This workshop aims to provide one opportunity to communicate some research idea to research scholars as well as students. On 4/30, we had three talks, related to Krylov subspace methods in computing matrix exponential and quadratic eigenvalue problems. In addition to three professors from the local university, the audience included Tsungming Huang, Fengnan Hwang, Yungta Li, Yuehcheng Kuo and more than 10 graduate and undergraduate students.

The motivation of this workshop is to introduce a few open problems in the application of Krylov subspace method in circuit simulations and model reduction. During the workshop, we had many interesting discussions between audience and speakers. A few questions were proposed to clarify the setting of the matrix structure, e.g., low rank or positive definite, symmetric. The workshop venue chosen at NCHU gave one big benefit to local students. We are glad that local undergraduate students attended this workshop and asked a few interesting questions. This experience of academic discussions would bring some impact to these local undergraduate students. We expect that more students could be motivated to the field of computational mathematics.

# NCTS Research Spotlights
# A sensor fusion challenge toward learning physicians' decision making

**Prof. Hau-Tieng Wu is an associate professor in Department of Mathematics and Department of Statistical Science at Duke University. His research interests lie in applied harmonic analysis, signal processing, time-frequency analysis, machine learning, manifold learning, high-dimensional statistics, high-frequency physiological data, etc.**




Physicians view a patient as an integrated system. To make a clinical decision, physicians need different pieces of information from the patient from different dimensions. There are various resources for gathering necessary information, ranging from family history, medical records, physical examinations, lab tests, medical imaging, next-generation sequencing results, to questionnaires, and the gathering process is usually iterative and time consuming. Usually, physicians also count on waveforms (or time series, signals) collected from multimodal equipment, for example, patient monitor in the operation room and emergency room, intensive care unit, and polysomnogram in the sleep lab. In the past decades, thanks to the meteoric innovations in technology, many novel biosensors providing various long-term physiological waveforms (or time series, signals) are available for physicians, like 14 days electrocardiogram (ECG) recording, video or radar monitoring, accelerometer or pressure sensing, noninvasive continuous blood pressure monitoring,

etc. We shall emphasize that compared with the snapshot information, like that from the chest X-ray, questionnaire, or blood test, the information contained in (multimodal) waveforms is about dynamics, which is complementary to the snapshot information. Both types of information play a key role in physicians' decision making process.

Each piece of the above-mentioned tools physicians can access only encode partial information of the patient's overall system, and it is physicians' daily practice to assemble available information to make a decision. This process is far from being linear, and it involves synthesizing and deciphering different pieces of information in a nonlinear way, which depends on different clinical scenarios and usually also clinical experience. While this process is encoded in physicians' daily practice, it is challenging to "teach" an intelligent system how a physician integrates relevant partial information from multimodal and heterogeneous datasets, particularly when an interpretable intelligent system is desirable. While a lot of efforts have been invested in the past decades, there is still a bottleneck, particularly fusing heterogeneous dynamic information from multimodal waveforms. There have been many attempts, and many of them count on a direct concatenation of highly simplified waveform information on a coarse scale with learning algorithms under simplified model. By doing so, information might be missed, and the structure cannot be fully captured, or might be distorted. Recently, black-box algorithms like deep neural networks have become popular and offer various opportunities, while these algorithms provide limited interpretability and have other limitations. To our knowledge, a lack of tools with mathematical support to fuse available information from multimodal sensors, particularly from waveform sensors, is still a challenge to data scientists.

One of my research focuses is how to handle the heterogeneity of information captured by multimodal waveform sensors and fuse them efficiently. The goal is not only to mimic physicians' daily practice but also to quantify hidden dynamic information that might be difficult to be directly accessed by physicians. There are two challenges. The first one is how to quantify information encoded in each channel, and the second one is how to assemble information from different sensors. Below we briefly discuss the second challenge. Take sleep dynamics as an example. When a subject is sleeping, both electroencephalograms (EEG), ECG, airflow and many other sensors reflect the sleep stage, while they reflect different aspects of the sleep dynamics. For example, EEG contains the cortical activity, airflow contains the subcortical activity, and ECG contains the heart rate variability that reflects the autonomic system activity. The sleep dynamics is on the other hand influenced by the subject's disease history, like sleep apnea, drug history, like benzodiazepine, etc. In other words, these sensors contain the common information about sleep dynamics, but they also contain specific information that can only be captured by the specific channel. This fact has been long known qualitatively and practiced by medical experts. While several efforts have been made to capture the common information, it is still challenging to quantify what is exceptionally owned by each channel, not to mention how to assemble the heterogeneous dynamic information from waveforms to recover the sleep dynamics. Recently, my team managed to handle this challenge from two aspects. First, we develop a theoretically solid algorithm to quantitatively capture what is different among two sensors, in addition to what is common [1]. In brief, we developed a kernel-based manifold learning algorithm, the S operator that captures the common information, and its companion A operator, which captures the different information that is shared by two sensors. These operators have been applied to develop an automatic sleep stage annotation system [2,3]. Second, we directly model how the sleep experts read

different waveforms and fuse information to annotate sleep stages. This idea has led to an automatic hospital quality evaluation system that can help sleep education [4], thanks to the recently developed Taiwan Integrated Database for Intelligent Sleep (TIDIS) [5] under the support of National Center for Theoretical Sciences (NCTS).

There is still a long way to go to better depict what dynamic information is hidden in a waveform, and better learn how physicians make a decision by assembling available information. The challenge is not simply collecting a large amount of data and developing an intelligent system. The challenge is multifront, and the main one from my opinion is constructing the core – what information is essential and how the information should be assembled from the scientific perspective with solid scientific foundations. For young talents having interest in applied mathematics in a broad sense, this is a gold mine with rich unsolved interesting mathematical problems. For physicians, your medical knowledge and clinical experience are the key to guide the whole process. We should work together toward this goal.

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(2) T. Shnitzer, R.R. Lederman, G.-R. Liu, R. Talmon, H.-T. Wu, "Diffusion Operators for Multi-Modal Data Analysis", Handbook of Numerical Analysis: HNA Volume 20, 2019

(3) G.-R. Liu, Y.-L. Lo, J. Malik, Y.-C. Sheu, H.-T. Wu, "Diffuse to fuse EEG spectra – intrinsic geometry of sleep dynamics for classification", Biomedical Signal Processing and Control, 55, 101576, 2019

(4) G.-R. Liu, T.-Y. Lin, H.-T. Wu, Y.-C. Sheu, C.-L. Liu,; W.-T. Liu, M.-C. Yang, Y.-L. Ni, K.-T. Chou, C.-H. Chen, D. Wu, C.-C. Lan, K.-L. Chiu, H.-Y. Chiu, Y.-L. Lo, "Large Scale Assessment of Consistency in Sleep Stage Scoring Rules among Multiple Sleep Centers Using an Interpretable Machine Learning Algorithm", Journal of Clinical Sleep Medicine, 17(2), 159-166, 2020

(5) TIDIS: https://tidis.org

## Postdocs all over the world

We have several postdoc fellows joining us in summer, 2021.

**Dr. Brian Harvie just completed his Ph.D. at University of California, Davis in this June. His research interests lie in differential geometry and geometric analysis.**

I grew up in Massachusetts then travelled across the United States to California for graduate school. Although the pandemic is complicating things, I look forward to travelling even further this time to begin my postdoc in Taiwan in person! In addition to my research interests in differential geometry and mathematical relativity, I also enjoy outdoor activities like hiking. Between the many geometric analysis researchers at NCTS and the natural beauty of Taiwan, I am sure both of these interests will be thoroughly satisfied.

**Dr. Simon-Raphael Fischer completed his Ph.D. at the University of Geneva and Claude Bernard Lyon 1 University (a dual Ph.D. programme, called cotutelle), and he is now joining the NCTS. His research is in differential geometry and theoretical and mathematical physics in general, while his current focus lies on gauge theory in the sense of Yang-Mills-Higgs gauge theory.**

I was born in Germany and got my high school diploma in Flensburg, Flensburg lies at the border to Denmark. While I studied physics, I was always also interested into the rigorous formulation of (fundamental) physics. Hence, I started studying physics for my bachelor at the university of Ulm, but then I switched to the master study programme of theoretical and mathematical physics in Munich at the Ludwig Maximilians University. For my Ph.D. I finally moved abroad and researched at two countries, France (in Lyon) and Switzerland (in Geneva), as part of my dual Ph.D. programme. My supervisors were Anton Alekseev and Thomas Strobl.

I am very excited about to finally move to Taipei for my first postdoc position. However, due to the pandemic, my move to Taiwan got delayed and we are currently still waiting for that Taiwan's borders are opening again. As an intermediate solution I will start my work as a long distance work, my home office being in Germany. Thanks to Peggy Lee for their great help in making this possible and for their support in the last months.

My current research is about curved Yang-Mills-Higgs gauge theories, a generalized gauge theory developed by Alexei Kotov and Thomas Strobl. In my Ph.D. thesis I generalized certain aspects and found statements about whether or not this theory may introduce new physical phenomena. There are still a lot of open question which I may study now while I am a postdoc at the NCTS.

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**Dr. Kuan-Hsiang Wang completed his Ph.D. at the National Cheng Kung University in July 2017. Before joining NCTS, he was a postdoctoral fellow at National University of Kaohsiung. His current research focuses on quasilinear elliptic systems.**

I received my Ph.D. at the National Cheng Kung University. My advisor is Professor Yung-fu Fang.

Under the guidance of Professor Fang, I began to study the quantum Zakharov system. By using Fourier transform, Harmonic analysis and fixed point theory, we investigate local and global well posedness of the quantum Zakharov system.

After that I worked as a postdoctoral fellow under the research project of Professor Tung-fu Wu in National University of Kaohsiung. Hence, I began to contact and study elliptic problems, for example, Schrodinger-Poisson system, Kirchhoff equations, coupled Schrodinger systems, and quasilinear elliptic systems.

Now, I am a postdoctoral fellow at NCTS. This is a good place because there are many outstanding research scholars coming from different backgrounds.

Hence, I am excited to work at NCTS.

**Dr. Seonghyeon Jeong just received his PhD degree from Michigan State University this summer. His research area are optimal transport and related PDEs.**

I have done my Ph.D. in Michigan State University, and I have studied optimal transportation and Monge-Ampere type euqations with my advisor Jun Kitagawa. Specifically, I have studied about regularity theory of the solutions of optimal transportation problems and generated Jacobian equations. In NCTS, I am going to study applications of optimal transportation to data science with Prof. Chih-Wei Chen from NSYSU and Prof. Hau-Tieng Wu from Duke. Also, I will study some pure mathematics topics that I have in mind, especially about gradient flow structure in the Wasserstein space. I am really excited to start my job in NCTS. Due to the pandemic, I will start my work outside Taiwan, but I hope that I can enter Taiwan soon.

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**Dr. Yen-An Chen completed his Ph.D. at the University of Utah. His research interests are mainly in algebraic geometry, in particular, the minimal model program and moduli theory.**

I am interested in the theory of foliation, especially how much information on foliation we could get from its canonical sheaf. My Ph.D. thesis concerns the boundedness of the canonical models of the foliated surfaces of general type for fixed Hilbert function. I am glad to work at NCTS, which is one of the best institutes for me to pursue my research. Under the pandemic, NCTS provides a comfortable physical/virtual environment for everyone so that we can still focus on

our research. Moreover, even in this difficult time, we still have many opportunities to get connections with many experts. I am looking forward to having more conversations and collaborations here at NCTS.

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**Dr. Oguz Gezmis completed his PhD in Texas A&M University in 2019. His research interest is the arithmetic of function fields, Drinfeld modules, special values of L-functions and modular forms.**

Although it is my first year in NCTS, I started to live in Taiwan two years ago to work as a postdoctoral fellow in National Tsing Hua University. Thanks to the enormous help of my mentor Prof. Chieh-Yu Chang and my colleagues here, settling down has become much easier. Now as a new member of NCTS, I really enjoy the working environment here and I am also grateful to Peggy Lee for her guideline during my moving to Taipei. I believe that working in NCTS will be valuable

to improve my research via communicating with other postdocs coming from different backgrounds and learning new viewpoints from them.

**Dr. Jun-Wen Wayne Peng received a Ph.D. from the University of Rochester in 2020, under the direction of Prof. Thomas Tucker. Before joining NCTS, he was a Proposal Author of ROMYS Bridge Research Project. His research interests include algebraic and arithmetic dynamical systems and number theory.**

I graduated from the University of Rochester in 2020. After a half year of searching and wandering for my next position, I decided to move back to Taiwan. My research interest is arithmetic dynamics. It is a field that amalgamates number theory and dynamical systems. Among many exciting questions in this field, I am triggered by the arboreal representation. You can understand it as the questions about the Galois group of the iterated polynomials simply. Although the question is easy to understand and explain, there are still many open questions in the field waiting to be answered.

About my personal life, I enjoy many outdoor activities. Sometimes I still miss the experiences of camping in the States. I played ultimate frisbee regularly. If you happen to play this game, too, I can show you some local pick-up games.

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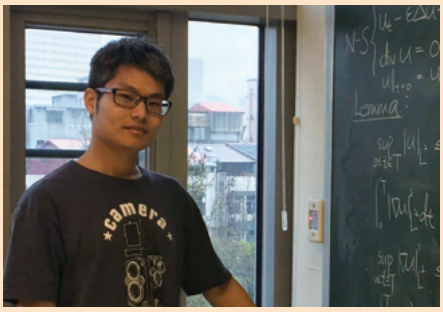
**Dr. Shih-Hsin Chen received his Ph.D. in National Taiwan University. Currently, his research topics includes partial differential equations and synchronization theory.**



I completed my Ph.D. in National Taiwan University. In my dissertation, I investigate the synchronization theories for bidirectionally coupled Kuramoto model, which is extensively applied in networks, generators and power systems. This is the join work with Prof. Chun-Hsiung Hsia and Prof. Ming-Cheng Shiue. Currently, I work in NCTS as a postdoc. I believe that NCTS provides a good working environment so that I have many opportunities to communicate with different experts. I am looking forward to meeting new friends here and figuring out good ideas together to benefit our researches.

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**Dr. Yoshinori Kamijima received his Ph.D. from Hokkaido University this June. His main research interests are Probability Theory and Statistical Mechanics, and his current research focuses on oriented percolation and the quantum Ising model.**

I was born in Nagano prefecture, Japan. I belonged to the Department of Physics, Niigata University when I was a bachelor student. In graduate school, I was indebted to my supervisor Prof. Akira Sakai at the Department of Mathematics, Hokkaido University. I have moved my living area to the north, so that it is the first time to live in a warmer land than my hometown. Although I cannot go to Taiwan yet due to the pandemic, I am looking forward to living in Taipei city and to continuing research with my collaborator (my mentor in Taiwan) Prof. Lung-Chi Chen. I also expect that research activities in NCTS are a great opportunity for me to explore several areas of Mathematical Physics.

# NCTS is calling for...

## 2022 Postdoctoral Fellows

The NCTS accepts applications for postdoctoral fellows from Oct. 1, 2021 to Feb. 28, 2022. The appointment starts from August 1, 2022, for 1 or 2 years, extendable up to 3 years. Every talent pursuing academic excellence is welcome. Priority will be given to the following areas: Algebraic Geometry, Differential Geometry and Geometric Analysis, Differential Equations and Stochastic Analysis, Scientific Computing.

## Research Pairs

The goal of the Research in Pairs Program at the National Center for Theoretical Sciences (NCTS) is to bring together outstanding scholars with similar research interest to the NCTS to jointly conduct cutting-edge research. A Research Pair consists of 2-4 researchers of different affiliations. Each member in a pair is expected to spend 2-4 weeks at the NCTS for research collaborations, and will be supported as a visiting scholar by the NCTS.

## 2022 International Exchange Program

National Center for Theoretical Sciences (NCTS) provides the most important platform for collaboration and interaction among Taiwanese and international mathematicians. Among the missions of the NCTS since its foundation are to facilitate scholarly exchange in mathematical sciences and cultivation of mathematical talents. With this in mind the NCTS has signed agreements with several partner institutions that give selected mathematicians affiliated with Taiwanese institutions the possibility to visit these institutions for a duration of 1-3 months for the purpose of international academic exchange. We are pleased to accept for applications to these exchange programs.

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