Universality and Integrability in Random Matrix Theory and Interacting Particle Systems

Ivan Corwin, Percy Deift, Alice Guionnet, Alexander Its, and Herbert Spohn

In 1999 and 2010, MSRI hosted two highly successful programs focused on the fruitful interface between random matrix theory and other fields — in particular interacting particle systems. The decade since 2010 has seen tremendous progress in these areas, for instance in the robust theory of universality for random matrix eigenvalue statistics, or the rich integrable structure uncovered behind a host of interacting particle systems and random growth models. This fall’s jumbo program is the third in this series: It serves as a chance to educate a new generation in the cutting-edge methods developed over the past decade, and also sets the stage for the next decade of advancement and breakthrough.

Twentieth Century Roots

Random matrix theory has many roots, perhaps explaining why it has so successfully thrived as a research area that bridges mathematics and many other disciplines (such as statistics, physics, computer science, data science, numerical analysis, biology, ecology, engineering, and operations research). In statistics, Wishart began the study of sample covariance matrices in the 1920s.

Tatiana Toro Named Incoming MSRI Director

The Board of Trustees of MSRI is pleased to announce the appointment of Tatiana Toro to be the next director of MSRI. Her five-year term will begin Aug 1, 2022.

Toro is the Craig McKibben & Sarah Merner Professor of Mathematics in the Department of Mathematics at the University of Washington in Seattle; she will maintain her tenure at the University of Washington while she is Director.

Toro’s primary research interest lies in the interface of partial differential equations, harmonic analysis, calculus of variations, and geometric measure theory. The main premise of her work is that under the right lens, objects that at first glance might appear to be very irregular do exhibit quantifiable regular characteristics. Her work establishes unexpected bridges between these areas of mathematics, opening new landscapes for research.
The View from MSRI

Three-Dimensional People!

The big news at MSRI is that we have 75 members in the building — in 3D! — and people seem delighted to be back to something like normal interaction. I see it particularly in the buzz and intense chatting at tea-time, blackboards in full use. It really is different to interact in person! Of course there are advantages to the no-longer-new video communications too, especially for people who cannot or do not want to travel, and also for the environment, air travel’s expense and “footprint” being as large as they are. We do our best to provide a reasonable remote experience; for example, we have new large monitors on both sides of the stage in the Simons Auditorium, so that the audience in the room can see, as well as hear, the distant participants, who are “present” on Zoom.

I wrote “something like” normal advisedly: our COVID precautions are still very present. We admit only those who are fully vaccinated. Our building is permanently locked, so that only members and Berkeley faculty are admitted; there is now a receptionist stationed in the entry foyer, and she checks all incoming members’ symptom screening badges. We ask everyone to mask at all times in the building unless in a private office; and (since you cannot eat and drink while masked!) we eat only outdoors. We bought lots of new tables and sun umbrellas, as well as rolling blackboards, to make this as pleasant as possible (as I write, the weather has been cooperative, and the smoke in the air only occasional and mild). We have ordered MSRI hoodies to keep everyone warm when it does become chilly. We have become a testing center, and we test everyone, members and staff, once a week. I have the sense that most people are now quite used to these precautions, and find living with them much preferable to being on Zoom.

And what will you do, you may ask, when someone tests positive? It’s not an unlikely event, sometime(s) in the semester. We have plans in place for contact tracing if there are few cases, and, alas, for closing the building temporarily if there is a more serious outbreak; we hope to avoid that! It’s the mathematics!

Third Decade of Random Matrices at MSRI

Of course the point of all this is the mathematics! — and it’s in fine form. This semester we have a jumbo program (that is, just one subject occupying the whole building, instead of two parallel programs): Universality and Integrability in Random Matrix Theory and Interacting Particle Systems. MSRI is willing to run a program on a given subject at most once in ten years, and indeed this is the third decennial program in this very exciting field. Although (I believe) the idea first appeared in the work of Wigner on the spectral lines of heavy atoms, there is a sense in which MSRI invented random matrices as a field, with a 1998 program that for the first time brought many of the applications of these probability measures together. The subsequent success of the field is a tribute to the insight of the Scientific Advisory Committee of that day. You can read more in the article by Ivan Corwin, Percy Deift, Alice Guionnet, Alexander Its, and Herbert Spohn in this Emissary — starting on the cover and continuing on page 4.

Microprograms

I have already mentioned one “sticky” change brought about by the pandemic: systematic, interactive live-streaming of seminars. Another that I hope will be here to stay are “microprograms” — one-month events of intense interaction, not necessarily at MSRI. Currently we are planning a few of these to allow direct interaction of mathematicians from programs disrupted by the pandemic, but in the long run they represent an avenue for growth of MSRI’s scientific footprint despite the fact that the MSRI building is now fully utilized. We’ll learn by experience how well this works; but I myself was part of MSRI’s only previous microprogram (organized by then-director Kaplansky) — and it was both exciting and productive.

Mathematics for Everyone

We continue to innovate in ways to present mathematics to the public despite the bumps caused by the pandemic. When we learned that the Washington Convention Center (which we had booked for the 2021 National Math Festival) was being converted to a field hospital, with uncertain date of return to business, we knew that the Festival had to change. Kirsten Bohl and Jenn Murawski rose brilliantly and effectively to the challenge — Bravo! We spread festival events out, starting in December and climaxing in our usual April weekend. All have been online so far, but in-person events are coming in April 2022 as part of the North Carolina Science Festival. We also worked with Cliff Stoll (famous for much, including glass Klein bottles) and Nicole Mullen (then Curator of the SFO museum) on something new: if you pass through Terminal 2 of the San Francisco airport before May 2022, you’ll see a marvelous exhibition of math artifacts. You can read more about the Math Festival and the SFO Museum exhibition on pages 8–9.
A Tribute to Bob Moses


MSRI mourns the passing of US civil rights leader and math educator Robert “Bob” Parris Moses. MSRI Director David Eisenbud shared his reflections on the influence that Bob Moses had on our institute’s work towards a more welcoming and inclusive mathematics community for all ages:

I am deeply sad to mark the passing of a great leader, Bob Moses. He was a hero of the civil rights movement in Mississippi and a tireless crusader to recognize the availability of good teaching in general, and good teaching of algebra in particular, as a civil right, of crucial importance in our day. I met Bob when he agreed to join MSRI’s Educational Advisory Committee many years ago. He spoke often at our Critical Issues in Mathematics Education meetings, always with the voice of a prophet and deeply thought ideas. Bob’s death leaves a void that can never be filled, but his influence will continue in many areas. May the seeds that Bob planted prosper through the years!

You can learn more about Bob Moses’ life and his legacy in civil rights and mathematics education in the book *Radical Equations: Civil Rights from Mississippi to The Algebra Project*, by Robert P. Moses and Charles E. Cobb (2002), as well as on our website.

We are grateful to the celebrated author Alice Walker, who has allowed us to share her poem in remembrance of Bob.


New from AMS: Stories of Latinx Mathematicians

*Testimonios: Stories of Latinx and Hispanic Mathematicians*
Edited by Pamela E. Harris, Alicia Prieto-Langarica, Vanessa Rivera Quiñones, Luis Sordo Vieira, Rosaura Us养护, and Andrés R. Vindas Meléndez

*Testimonios* brings together first-person narratives from the vibrant, diverse, and complex Latinx and Hispanic mathematical community. Starting with childhood and family, the authors recount their own individual stories, highlighting their upbringing, education, and career paths. Their particular stories, told in their own voices, from their own perspectives, give visibility to some of the experiences of Latinx/Hispanic mathematicians. This book seeks to inspire the next generation of Latinx and Hispanic mathematicians by featuring the stories of people like them, holding a mirror up to their own community. Among the authors’ connections to MSRI, Andrés R. Vindas Meléndez is a current NSF postdoc in the 2021–22 complementary program, and Pamela E. Harris has been the research leader in the MSRI-UP program in 2019 and 2021. In addition, one of the featured chapters is by incoming MSRI director Tatiana Toro.

Bob Moses 1932–2021
by Alice Walker

Dear Bob Moses,
Before I went to Mississippi
I had heard
You were there
But soon you left.
Your name was Moses
And the people became
Too used to following you.
You were wise enough
Not to want to be followed;
But to want the people
To create their own path
By walking it.
Leading ourselves
As you knew
Is the only way
For us
To finally get somewhere.
What teachings you were kind
Enough
And stubborn enough
To leave behind,
And so I learned to
Share
What I learned from you:
Forget martyrdom,
Leave the fray before
The people begin
To argue over you.
The world is filled
With many vineyards
In which to labor.
Look deeply in the valley
In which your talent and spirit
Have found rest
And energy.
Flow with that as your offering.
Oh our Moses
How you taught us
A freedom of being
Far beyond
The chaos and sadness
Of Mississippi.
You blessed us by being
 Without category.
By being yourself.
The eternal mystery
That all true pioneers
Of spirit
Endlessly are.
Rest in our gratitude.
Alice
Random Matrix Theory & Interacting Particle Systems

(continued from cover)

Quite separately in nuclear physics in the 1950s, Wigner introduced and studied certain Gaussian matrix ensembles invariant under classical symmetry groups (that is, conjugation by orthogonal, unitary, or symplectic matrices — see the figure at top right).

Goldstein and von Neumann came upon random matrix theory at a similar time, from the perspective of numerical analysis and estimation of condition numbers. In number theory, in a surprising development in the 1970s, Montgomery recognized that random matrix statistics described the nontrivial zeros of the Riemann zeta function (see the figure at bottom right). More recently, there have been a host of new motivations and sources for problems in random matrix theory, or new uses of the tools which have been developed in its study. It is this constant growth and expansion of the field which has made it one of the most dynamic and exciting areas of mathematics.

Fruitful Mysteries

While some applications of random matrix theory techniques come quite naturally, others (like the number theory ones mentioned above) come as a surprise and take a while to fully develop. In the late 1990s, such a mysterious link was discovered between random matrix ensembles and a few interacting particle systems, namely the longest increasing subsequence problem for random permutations and the closely related totally asymmetric simple exclusion process (see the temporal evolution figure on the next page). This linked random matrix theory to a vibrant and growing area of probability and nonequilibrium statistical mechanics, and led to a bevy of new problems, methods, and results. The origins of the link have been progressively exposed over time and have further connected these fields to asymptotic representation theory, quantum integrable systems, and algebraic combinatorics.

Foundations of the Fall Program

Interacting particle systems arise as probabilistic models of real world systems such as traffic, queues, and mass transport; and through certain transforms or limits they also relate to random interface growth, random walks in random media, stochastic optimization problems, and stochastic PDEs. These types of systems have been actively studied since the 1970s in probability, as well as in other more applied fields including non-equilibrium statistical mechanics.

Within random matrix theory, and more broadly probability and statistical mechanics, there are often two complementary themes — universality and integrability. Universality refers to the idea that randomness smooths out microscopic difference between systems and hence only certain key phenomenological properties of a system will control the large scale or long time behavior. The simplest instance of this concept at play is the central limit theorem for independent, identically distributed random variables where, after fixing the mean and variance, all sums have the same universal Gaussian limit. Integrability (or sometimes exact solvability) refers to the search for models that enjoy enhanced algebraic structure that

The Gaussian unitary ensemble (GUE) is a measure on $N \times N$ Hermitian matrices in which all diagonal entries are real Gaussian distributed and all off-diagonal entries are complex Gaussian distributed (all Gaussians being independent). The ordered eigenvalues $\lambda_1 \geq \cdots \geq \lambda_N$ are consequently real and random, and their joint density (against Lebesgue measure on $\mathbb{R}^N$) is proportional to $\prod_{k=1}^N e^{-\lambda_k^2/2} \prod_{1<j}^N (\lambda_i - \lambda_j)^2$. For large $N$, the histogram of eigenvalues becomes well approximated by the Wigner semicircle distribution. Zooming in to the resolution of individual eigenvalue, one sees the Dyson sine point process inside the support of the histogram and the Airy point process near the edge. In particular, the distribution of the maximal eigenvalue follows a Tracy–Widom distribution.

The plotted blue curve is $|\zeta(\frac{1}{2} + it)|$, where $\zeta(z)$ is the Riemann zeta function. The zeros form a point process, denoted in red, which is widely believed to share many properties with the zeros of random Hermitian matrices. For instance, recently there has been great interest in comparing the modulus of the zeta function on the critical line to the characteristic function for certain types of random matrices, and relating both to log-correlated Gaussian fields known as Gaussian multiplicative chaos. Based on this comparison, Fyodorov, Hiary, and Keating conjectured a precise asymptotic for the maximum modulus of the zeta function on almost all intervals along the critical axis. Major progress in this direction has come in recent work of Arguin, Bourgade, and Radziwill.
enables exact calculations and precise asymptotics. Indeed, with the central limit theorem example, coin flipping admits exact formulas in terms of binomial distributions, which yielded for the first time the Gaussian distribution (in 1738! — long before it was proved universal around 1900). In a sense, universality says that many systems share a common limit, and integrability identifies precisely what that limit is.

In the context of random matrices, integrable models such as the Gaussian unitary ensemble (GUE, described in the caption to the top figure, previous page), have statistics that can be written exactly in terms of compact formulas which are amenable to asymptotic analysis (generally, as the matrix size grows to infinity). Quite remarkably (as shown in the work of Soshnikov and the works of Erdős, Yau, and co-authors, as well as Tao and Vu), these limiting statistics are quite robust — changing the underlying distribution of matrix entries from Gaussian to other distributions does not change these limiting statistics.

The temporal evolution of the height function for the totally asymmetric simple exclusion process is shown. Initially, the height function looks like |x|. Every local minimum can grow into a local maximum after independent exponentially distributed waiting times. Remarkably, the distribution of this process can be exactly linked to the distribution of the largest eigenvalue from the Laguerre unitary ensemble (LUE), a measure on complex sample covariance matrices. Figure by Leonid Petrov.

Other Classes of Random Matrices

Besides changing the distribution of matrix entries, there are many other natural classes of random matrices to consider. For instance, in spectral graph theory one seeks to understand the eigenvalues of adjacency matrices for large classes of random graphs (see the figure at right). One challenging conjecture which now seems within reach is to prove that for a randomly chosen d-regular graph on N vertices, the eigenvalues in the bulk of the spectrum (that is, away from the edges of the support) are universal and independent of d, down to the minimal nontrivial value of $d = 3$. For the d-regular random graph model as well as the Erdős–Reyni random graph model, there remain many such compelling questions, despite great progress over the past few years.

Another form of universality deals with studying matrix ensembles that are still invariant under the action of classical symmetry groups, but for which individual entries are not Gaussian. This form of universality was established in work in the early 2000s of many authors, including Bleher, Deift, Gioev, Its, Kriecherbauer, Lubinsky, McLaughlin, Pastur, Scherbina, Venakides, and Zhou. Yet another direction is to move away from invariant ensembles to the realm of $\beta$-ensembles and log-gases, in which case universality has come from various works, including those of Bekerman, Borodin, Bourgade, Dumitriu, Edelman, Erdős, Figalli, Gorin, Guionnet, Leble, Ramirez, Rider, Serfaty, Sutton, Virag, Valko, and Yau.

The temporal evolution of the height function for the totally asymmetric simple exclusion process is shown. Initially, the height function looks like |x|. Every local minimum can grow into a local maximum after independent exponentially distributed waiting times. Remarkably, the distribution of this process can be exactly linked to the distribution of the largest eigenvalue from the Laguerre unitary ensemble (LUE), a measure on complex sample covariance matrices. Figure by Leonid Petrov.

Two random graphs on N = 300 vertices. Both graphs have average degree 10, though the one on the top is uniformly chosen from 10-regular graphs while the one on the bottom is chosen according to the Erdős–Reyni measure on graphs.

Landscapes and Tilings

Besides the intrinsic value in their study, random matrices also pop up in many remarkable applications. One such example is the subject of this fall’s Chancellor Professor course delivered by Gérard Ben Arous. Random nonlinear functions of many variables arise in many contexts. Examples include Hamiltonians of disordered models like spin glasses (in statistical mechanics), or landscapes of inference problems in high-dimensional statistical estimation (in data science).
A fundamental problem in both contexts is to understand the complexity of the topology of the landscapes of such random nonlinear functions of many variables (see the figure below for such a complex landscape in two dimensions). This landscape complexity is closely linked to the efficiency of natural exploration or optimization algorithms in these landscapes. If there are many valleys of differing heights, separated by large saddle points, it will take these algorithms a long time to find the global minimum (or near-minimum). In high dimensions, the landscape complexity is controlled by the behavior of the Hessian, which itself is a random matrix. Thus, the toolbox of results and methods from random matrix theory become vital.

Though the main interest is in high-dimensional complex landscapes, here we see a 2-dimensional complex landscape where there are many valleys, saddle points, and hills. Figure by Benjamin McKenna.

### Random Tilings

The tools and statistics that arise in the study of random matrices also play an important role in the study of many other probabilistic systems. One prime example is found in the realm of random tilings. In the figure at right, one starts with a hexagonal domain with a diamond cut out from the inside and then fills it with three types of rhombuses: $\diamond$ and its $2\pi/3$ and $4\pi/3$ rotations. There are many (in fact, exponential in the system size) admissible tilings and one is chosen uniformly at random among these.

Remarkably, for large system sizes the behavior of the tiling is quite stable to first order (that is, there is a limit shape), and then shows smaller scale fluctuations. Recent work of Aggarwal has proved that the local statistics describing the tiling inside the limit shape are universal (with respect to changing the boundary of the domain) and related to discrete versions of point processes (such as the Dyson sine process) arising in random matrices. Other properties, such as Gaussian free field global fluctuations of the height function around the limit shape, have been shown in some special domains by Bufetov, Gorin, Kenyon, and Petrov, though this type of result for general domains remains open. At the edge of the disordered region, Aggarwal and Huang have shown that the Airy process arises quite generally as well.

### KPZ and Quantum Systems

In the 2010 MSRI program, the Kardar–Parisi–Zhang stochastic partial differential equation (or KPZ equation for short) featured prominently. Work of Amir, Calabrese, Corwin, Le Doussal, Rosso, Sasamoto, Spohn, Tracy, and Widom revealed that statistics could be computed exactly for this paradigmatic model for nonlinear stochastic interface growth. In the decade since then, the KPZ equation has attracted immense interest, both from the perspective of its exact solvability and from the perspective of its solution theory (in the spirit of work of Hairer, Gubinelli, and Perkowski). The exact solvability of the KPZ equation and related models has been put into a more general context in the development of the field of integrable probability, featuring work of Borodin, Corwin, and collaborators on Macdonald processes and stochastic vertex models. Another set of notable developments in this area is the construction of the KPZ fixed point in work of Matetski, Remenik, and Quastel, and of the directed landscape in work of Dauvergne, Ortmann, and Virag.

At the heart of integrable probability theory and the exact solution to the KPZ equation lies tools of quantum integrable systems such as the Yang–Baxter equation, the Bethe ansatz, and associated families of symmetric functions (for example, Macdonald, Hall–Littlewood, Whittaker, and Schur). These tools have been used in the study of quantum spin chains and two-dimensional equilibrium statistical mechanics for many decades, with origins in works from the 1930s–1970s of Baxter, Bethe, Lieb, Sutherland, and Yang, and subsequent developments in the 1980s of Faddeev and collaborators, as well as Drinfeld and Jimbo in the form of quantum group theory. The figure at the beginning of the article (on the cover) illustrates the colored stochastic vertex model introduced and studied recently by Borodin and Wheeler, relying on these tools.

### Riemann–Hilbert Techniques and Integrable Systems

Classical integrable systems have also long been known to relate to the asymptotic statistics that arise in the study of stochastic interface growth models, interacting particle systems, and random matrices.
However, over the past few years there are some quite surprising links that have emerged; these are a subject of study in the current MSRI program.

The modern theory of classical integrable systems has its origin in the remarkable work of Gardner, Green, Kruskal, and Miura in 1967 and has since expanded to connect to the analysis of exactly solvable quantum field and statistical physics models, the theory of integrable nonlinear PDEs and ODEs, and quantum and classical theories of dynamical systems integrable in the sense of Liouville. Over the years, integrable system theory has emerged as one of the principal sources of new analytical and algebraic ideas for many branches of contemporary mathematics and theoretical physics.

The evolution of a stochastic interface at different times (indicated through different colors). Figure by Alexandre Krajenbrink.

A key ingredient of the analytic part of the theory of integrable systems is the Riemann–Hilbert method, which reduces the problem at hand to a certain Riemann–Hilbert problem of analytical factorization of a jump matrix defined on some appropriate contour in the complex plane. As a result, the solution of the original, usually nonlinear, problem is given in terms of the solution of the Riemann–Hilbert problem. A generic matrix Riemann–Hilbert problem cannot be solved explicitly in terms of contour integrals. It can, however, always be reduced to the analysis of a linear singular-integral equation.

One may think of a Riemann–Hilbert representation of the solution of the original problem as a non-abelian analog of the integral representations of classical special functions, such as Bessel functions or Legendre functions. The great benefit of reducing an originally nonlinear problem to the analytic factorization of a given matrix function comes to the fore in the asymptotic analysis of the problem at hand when one can exploit the nonlinear steepest descent method. This method was introduced in 1992 by Deift and Zhou as a culmination of some twenty years of significant efforts of several authors in the development of an efficient scheme for the asymptotic analysis of oscillatory Riemann–Hilbert problems.

In the past two decades, several new areas have fallen under the realm of integrable systems. Among these areas, an important place is occupied by random matrix theory. Indeed, the use of integrable techniques, notably the Riemann–Hilbert method, has made it possible to solve some of the longstanding problems of the theory, such as universality for invariant matrix ensembles. In a reciprocal fashion, the involvement of integrable theory into random matrix theory has extended the methods of integrable systems even further into areas which previously have never been considered as integrable systems, and which include string theory, enumerative topology, random permutations, and number theory. In turn, these new directions have posed new challenges to the analytical apparatus of integrable systems itself.

Setting the Stage for “MSRI Random Matrices, Part IV” (in 2032!)

Some of these new challenges are among the topics of concentration for this MSRI semester. Of a particular interest is the extension of Riemann–Hilbert techniques to the study of the KPZ equation and the general-\(\beta\) Tracy–Widom distributions. The possibility of applying Riemann–Hilbert methods is based on the very recent discovery of the remarkable integrable structures of Korteweg–de Vries- and Painlevé-type behind these subjects. The Riemann–Hilbert setting that arises is quite unusual, and involves operator-valued and block matrix Riemann–Hilbert problems. Another subject of great interest in the program deals with the study of hydrodynamic limits for integrable systems with infinite conservation laws, such as the Toda chain, as well as correlation functions for quantum spin chains, all of which relate to both random matrix ensembles and statistics coming up in the study of the KPZ equation.

The topics highlighted above are just a sampling of the subjects of intense study this semester at MSRI. The overarching theme, as reflected in the program’s title, is the use of methods from integrable systems to compute exact statistical properties of special classes of random matrices and interacting particle systems (broadly interpreted) as well as more probabilistic tools to show that these statistics are universal with respect to varying microscopic properties of these systems. We expect that this program will set the stage for the breakthroughs of the next decade, and that we will return in 2032 to MSRI for the fourth instance of this program.
National Math Festival

The 2021 National Math Festival started with live online Mathical Book Prize readings in December 2020, and continued with the NMF Live Performance Series (also online) in January through March of 2021. There was juggling, rap concerts, a Numberphile YouTube appearance, a play focused on the lives of female mathematicians through the ages, and a game show featuring mathematicians of color, instigated by the Young People’s Project. You can see event videos at tinyurl.com/21nmf-video.

The NMF Live Online Weekend, April 16–18, 2021, drew thousands of attendees from around the US and around the world to celebrate math with joyful, hands-on activities thanks to the efforts of two dozen math organizations and individual presenters. The weekend included five film panels with live Q&A, six talks about the math behind the way the world works presented by some of the country’s most fascinating mathematicians, and dozens of puzzles, games, mini-workshops, and many more instances of live interactive math play. The program details are at tinyurl.com/21nmf-schedule.

Together, these activities drew an estimated 17,800 live attendees, both children and adults, including many students and teachers during the pandemic. Presenters during the NMF events included 68% women and 64% people of color. MSRI is grateful to the partners who made this possible through their generous leadership and participation in building the program.

The year also saw the creation of two new, ongoing programs: the NMF Weekly Puzzle Newsletter, coordinated by James Tanton, with puzzles (and answer keys!) for elementary, middle-grade, and high school students; and the Math Moms and Math Dads Facebook group, a community of interested caregivers who come together and find inspiration and a more joyful approach to math.

NMF 2021 Continues!

The 2021 Festival activities continue this fall with the IMAGINE MATH CLASS video contest for U.S. students aged 13–18 to share their vision of a math class centered on youth, freedom, and color — and free, online events including Australian math educator, Mathematical Book Prize author (of It’s a Numberful World), and YouTuber Eddie Woo presenting “Mathematics: The Key to a Hidden World” in September 2021. View the event video at tinyurl.com/woo-nmf.

The National Math Festival will continue in Spring 2022 with special events at the North Carolina Science Festival. There will also be selected online events for a national audience of kids and adults.

NMF Appreciates...

The National Math Festival is a labor of love, time, and energy by multitudes. Here we share a few key expressions of gratitude.

Organizers. The 2021 National Math Festival is organized by the Mathematical Sciences Research Institute (MSRI) in cooperation with the Institute for Advanced Study (IAS) and the National Museum of Mathematics (MoMath)

Sponsors. The 2021 National Math Festival thanks its sponsors for their generous support: the Simons Foundation, Alfred P. Sloan Foundation, National Science Foundation, Schmidt Futures, the Kavli Foundation, American Mathematical Society (AMS)

2021 NMF Lecturers. Jesús De Loera, Robbert Dijkgraaf, Erica Graham, Raegan Higgins, Emilie Davie Lawrence, Candice Price, Steven Strogatz, Joseph Teran, Shelby Wilson


Friends of the Festival: Gifts in Kind. American Mathematical Society (AMS), Association for Women in Mathematics (AWM), Mathematical Association of America (MAA), National Association of Mathematicians (NAM), National Council of Teachers of Mathematics (NCTM), Society for Industrial and Applied Mathematics (SIAM).

Public Understanding of Mathematics Updates

Mathical’s Growing List

The Mathical Book Prize, now in its eighth year, recognizes math-inspiring kids’ literature for ages Pre-K through high school. It will continue adding to a growing list of great honorees with the upcoming Spring 2022 awards.

Award winners and honor books join the growing Mathical List of books intended to spark a love of math in the world around us. You can find the Mathical List in interactive form at mathicalbooks.org/portfolio/books/, and on PDF flyers grouped by grade levels at mathicalbooks.org/printables/.

Two Mathical partnerships, each in their second year in 2021–22, are putting many more books directly into the hands of kids in need.

The National Council of Teachers of Mathematics (NCTM) and the National Council of Teachers of English (NCTE) each administered ten grants of $750 to teachers in Title I schools to weave Mathical List titles into their classrooms.

The School Library Journal (SLJ) administered 25 grants of $700 each to librarians in Title I schools to integrate selected books from the Mathical List into their classrooms.

These two programs join the longstanding partnership between MSRI and First Book, which places new Mathical titles into the hands of educators in the Bay Area.

The Mathical Book Prize is generously supported by the Firedoll Foundation and Joan and Irwin Jacobs.

Math + Art at SFO

Beginning in 2019, MSRI reached out to the San Francisco International Airport Museum to propose a collaboration on a mathematics exhibition. This took well over two years to develop, with the design and execution of the exhibition led by Nicole Mullen, Curator of the SFO Museum, and by mathematician, astrophysicist, and Klein bottle manufacturer Cliff Stoll.

Mathematics: Vintage and Modern features objects from the past, when calculation and computation required mechanisms and tables. It also highlights teaching tools that help students learn arithmetic, geometry, and calculus, as well as toys that mirror modern physics, such as quantum mechanics, general relativity, and the physics of the early universe. It also explores the music that mirrors modern physics, such as quantum mechanics, general relativity, and the physics of the early universe, and how innovations in physics have been and can be inspired from “improvisational logic” exemplified in jazz performance and practice.

Jazz of the Spheres

On November 18, Stephon Alexander presented a public lecture in downtown Berkeley on “Jazz of the Spheres,” in conjunction with the 2021 Blackwell-Tapia Conference at MSRI. In his critically acclaimed book, The Jazz of Physics, Alexander explores new ways music, in particular jazz music, mirrors modern physics, such as quantum mechanics, general relativity, and the physics of the early universe, and how innovations in physics have been and can be inspired from “improvisational logic” exemplified in jazz performance and practice.

New from Math Circles Library

Mathematics via Problems: Part 2: Geometry, by Alexey A. Zaslavsky and Mikhail B. Skopenkov

Like its predecessor, Part 1: Algebra, this Mathematics via Problems volume is a translation from Russian and features sequences of problems that allow high school students (and some undergraduates) with strong interest in mathematics to discover and recreate much of elementary mathematics and start edging into more sophisticated topics such as projective and affine geometry, solid geometry, and so on, thus building a bridge between standard high school exercises and more intricate notions in geometry. Part 3: Combinatorics will be released soon.


Math Out Loud recounts the authors’ experiences from the first ten years of running a Math Hour Olympiad at the University of Washington in Seattle. In an oral olympiad, students spend several hours thinking about a few difficult and unusual problems. They then present a solution orally to a pair of friendly judges. It is a personal and engaging mathematical experience that introduces students to the true nature of mathematical proof and problem solving. The major part of the book is devoted to problem sets and detailed solutions, complemented by a practical guide for anyone who would like to organize an oral olympiad for students in their community.
Focus on the Scientist: Alice Guionnet

Alice Guionnet is one of the organizers and Clay Senior Scholars for this semester’s program on Universality and Integrability in Random Matrices and Interacting Particle Systems. Her outstanding research contributions span all aspects of this program and, in general, probability — with seminal work on free probability, random matrix universality, matrix integrals, large deviations, and spin glasses. Growing up in France, Alice initially intended on becoming an engineer. After two years of classes préparatoires, she was accepted to both the École Normale Supérieure de Paris (ENS), as well as the École Polytechnique. Though the latter is known for its role in preparing engineers, Alice opted for ENS to avoid the compulsory military service at Polytechnique.

Once at ENS, Alice’s eyes were opened to the rich structure of mathematics and the potential route to pursue it as a livelihood. Within two years, she started working on her Ph.D. with Gérard Ben Arous, and within another two years, she was hired by the Centre national de la recherche scientifique (CNRS) into a permanent position at Université Paris-Sud. Since then, Alice has also held positions at Imperial College, the Courant Institute, ENS Paris, UC Berkeley, and MIT. She currently is a CNRS research director at the ENS Lyon and headed the department there from 2016–2020.

Alice’s Ph.D. work dealt with the fascinating question of the dynamics of spin glasses. The Ising model is a basic object in statistical mechanics, and models the alignment of particles (for example, magnetic dipoles) that have specific types of interactions (for example, either all energetically reward, or all energetically punish alignment). Spin glasses generalize this type of model and arise when there is a mixture of types of particles, some of which like to align and some of which prefer the opposite. The interaction is often modeled by random matrices, and thus to better understand the properties of spin glasses, Alice was led to study the behavior of random matrices. This, as it turns out, has become one of her central research areas, and a few years ago, with Anderson and Zeitouni, she wrote a widely celebrated book on the subject.

Among the many research problems on her mind, Alice is still quite obsessed with questions of understanding the non-commutative entropy of Dan Voiculescu. The field of free probability has benefitted from a fruitful interaction with random matrix theory (as it relates to the limit of large matrices). Alice’s work on large deviations for the spectra of random matrices enabled her to extend the large deviation principle to the context of Voiculescu’s free probability theory, and in collaboration with Cabanal-Duvillard, Capitaine, and Biane she proved an inequality between the two notions of free entropy given by Voiculescu, settling half of an important conjecture.

In general, Alice is quite excited by the analysis of rare events and large deviations, as they require a deep understanding of the random object under consideration. Her analysis of matrix models and the study of Dyson–Schwinger allowed her, together with Jones and Shlyakhtenko, to construct matrix models for towers of factors and the Potts models on random graphs for any possible index.

Alice is a worldwide leader in mathematics, a top level mentor and a model for many younger female mathematicians. For her immense impact, Alice has been recognized with a still-growing list of awards, including the Oberwolfach prize, the Rollo Davidson Prize, a Miller Fellowship, the Loeve Prize, the Medaille d’argent du CNRS, Chevalière de la légion d’honneur, a Simons Investigator grant, and the Blaise Pascal Medal.

— Ivan Corwin

Named Positions, Fall 2021

**Chern, Eisenbud, and Simons Professors**

- Pavel Bleher, Indiana University–Purdue University Indianapolis
- Ivan Corwin, Columbia University
- Percy Deift, NYU Courant
- Philippe Di Francesco, Northwestern University
- Pablo Ferrari, University of Buenos Aires
- Alexander Its, Indiana University–Purdue University Indianapolis
- Mariya Shcherbina, B. Verkin Institute for Low Temperature Physics and Engineering

**Named Postdoctoral Fellows**

- *Gamelin*: Milind Hegde, University of California, Berkeley
- *McDuff*: Alexandre Krajenbrink, International School for Advanced Studies (SISSA)
- *Uhlenbeck*: Chiara Franceschini, Instituto Superior Técnico
- *Viterbi*: Emma Bailey, City University of New York

**Named Program Associates**

- *S. Della Pietra*: Sayan Das, Columbia University
- *S. Della Pietra*: Hindy Drillick, Columbia University
- *Vitulli*: Weitao Zhu, Columbia University

**Chancellor Professor 2021–22**

- Gérard Ben Arous, NYU Courant

**Clay Senior Scholars**

- Alice Guionnet, École Normale Supérieure de Lyon
- Herbert Spohn, Technische Universität München

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**MSRI is grateful for the generous support that comes from endowments and annual gifts that support members of its programs each semester. The Clay Mathematics Institute awards its Senior Scholar awards to support established mathematicians to play a leading role in a topical program at an institute or university away from their home institution.**
Tatiana Toro To Become MSRI Director in August 2022

(continued from cover)

Building on a Strong Relationship with MSRI

As MSRI Director, Toro will build upon her longstanding relationship with the institute to continue its mission to support mathematical research, foster talent, and further the appreciation of mathematics by the general public, in the US and abroad.

In addition to her research, Toro’s career path has included a strong focus on service to the mathematical community, including extensive mentoring of students at the undergraduate, graduate, and postgraduate levels. Toro’s commitment to addressing issues of equity and inclusion of underrepresented groups in the mathematical sciences is a guiding principle in each of these settings.

Toro’s involvement with MSRI began during her graduate education at Stanford in the 1980s, when she participated in one of MSRI’s first summer graduate schools. Since 1997, she has been deeply involved in the institute’s research programs, including co-organizing a semester-long research program and topical workshops. She was appointed the UC Berkeley Chancellor’s Professor in the Harmonic Analysis program in 2017. She has also served on MSRI’s guiding Scientific Advisory Committee since 2016, as co-chair since 2018.

Bio & Honors

Toro was born in Bogotá, Colombia and received her B.S. equivalent from the Universidad Nacional de Colombia. She earned her Ph.D. from Stanford University in 1992 under the supervision of Leon Simon, and held positions at the Institute for Advanced Study, UC Berkeley, and the University of Chicago before joining the University of Washington faculty.

Her honors and awards include a Sloan Research Fellowship, a Guggenheim Fellowship, and two Simons Foundation Fellowships. She was an invited session speaker at the International Congress of Mathematicians in 2010 in Hyderabad, India. She is a fellow of the American Mathematical Society (AMS), a member of the American Academy of Arts and Sciences and of the Academia Colombiana de Ciencias Exactas, Físicas y Naturales. Toro is the recipient of the 2020 Blackwell–Tapia Prize and of the 2019 Landolt Distinguished Graduate Mentor Award from the University of Washington. Her research has been continuously supported by the National Science Foundation since 1994.

Continuity in Leadership

Toro will be the sixth director in the MSRI’s 40-year history. She will succeed David Eisenbud, who will have served in the role for 20 years, from 1997–2007 and 2012–22. Eisenbud plans to continue his teaching and research as a professor at UC Berkeley, where he looks forward to having more time to participate in the rich academic culture of the campus.

“When I became director of MSRI in 1997, the very first program I oversaw was on Harmonic Analysis, and I noted with interest the important role played by a promising young researcher: Tatiana Toro. Since then she has returned to MSRI in many different roles, most recently as a leader of MSRI’s Scientific Advisory Committee, which determines all the major scientific activities of the institute,” said Eisenbud. “I have enjoyed working with Professor Toro over the years, and have deeply appreciated her scientific acumen, wide knowledge, and high standards. I believe that she will continue the best of MSRI’s traditions and lead it in exciting new directions, and look forward to watching these developments!”

Toro’s appointment as director of MSRI follows an international search led by a committee of the institute’s trustees, chaired by Edward Baker. “It is a pleasure to congratulate Dr. Toro on her appointment as Director of MSRI,” said Robert Stacey, dean of the University of Washington College of Arts and Sciences. “Dr. Toro is an outstanding mathematician and a widely admired leader in the mathematical community. I cannot imagine a better choice to lead MSRI, one of the premier mathematical institutions in the world.”

MSRI’s Next Documentary Film

MSRI is currently in production on our next joint project with Zala Films. With the working title Journeys of Black Mathematicians, the documentary aims to share the largely untold history of African-Americans in science and mathematics, featuring interviews with prominent, contemporary Black mathematicians and showcasing innovative educational programs in math for Black students from grade school through postsecondary and postdoctoral levels. The project aims to inspire young people, particularly African-Americans, to pursue careers in the mathematical sciences.

The film’s release is anticipated in January 2024. The production of this film is supported by the Simons Foundation and the Hilde Mosse Foundation.
Named Program Associates — Fall 2021

This is the first semester that we have Named Program Associates at MSRI! Program Associate fellowships support current graduate students to take part in our research programs, thanks to the generosity of MSRI donors Marie Vitulli, Kristin Lauter, Stephen Della Pietra and Pamela Hurst-Della Pietra, and The Salgo-Noren Foundation. While MSRI already hosts a number of advanced graduate students in each program, until now these opportunities have been largely self-funded. Thanks to the new fellowships, graduate students will receive financial support to remain in residence at MSRI for the entire semester with their advisor, fully integrated into the semester’s research program.

S. Della Pietra

Sayan Das is a Della Pietra Program Associate in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. He is currently a fourth-year graduate student at Columbia University, advised by Ivan Corwin. Prior to Columbia, Sayan received Bachelor’s and Master’s degrees at the Indian Statistical Institute. Sayan works on large deviations and fractal properties of stochastic PDEs, interacting particle systems, and discrete random matrix ensembles.

S. Della Pietra

Hindy Drillick is a Della Pietra Program Associate in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. She is currently a third-year graduate student at Columbia University, advised by Ivan Corwin. Prior to Columbia, Hindy received a Bachelor’s degree at SUNY Stonybrook. Hindy works on exceptional times for the temporal evolution of stochastic PDEs, as well as positivity results for stochastic PDEs.

Vitulli

Weitao Zhu is a Vitulli Program Associate in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. She is currently a fourth-year graduate student at Columbia University, advised by Ivan Corwin. Prior to Columbia, Weitao received a Bachelor’s degree at Williams College. Weitao works on large deviations of interacting particle systems and directed polymer models, as well as fluctuations of Gibbsian line ensembles.

Call for Proposals

All proposals can be submitted to the Director or Deputy Director or any member of the Scientific Advisory Committee with a copy to proposals@msri.org. For detailed information, please see the website msri.org.

Thematic Programs

The Scientific Advisory Committee (SAC) of the institute meets in January, May, and November each year to consider letters of intent, pre-proposals, and proposals for programs. The deadlines to submit proposals of any kind for review by the SAC are March 1, October 1, and December 1. Successful proposals are usually developed from the pre-proposal in a collaborative process between the proposers, the Directorate, and the SAC, and may be considered at more than one meeting of the SAC before selection. For complete details, see tinyurl.com/msri-progprop.

Hot Topics Workshops

Each year MSRI runs a week-long workshop on some area of intense mathematical activity chosen the previous fall. Proposals should be received by March 1, October 1, and December 1 for review at the upcoming SAC meeting. See tinyurl.com/msri-htw.

Summer Graduate Schools

Every summer MSRI organizes several two-week long summer graduate workshops, most of which are held at MSRI. Proposals must be submitted by March 1, October 1, and December 1 for review at the upcoming SAC meeting. See tinyurl.com/msri-sgs.

Call for Membership

MSRI invites membership applications for the 2022–23 academic year in these positions:

Research Members by December 1, 2021
Postdoctoral Fellows by December 1, 2021

In the academic year 2022–23, the research programs are:

Floer Homotopy Theory
Aug 22 – Dec 21, 2022
Organized by Mohammed Abouzaid, Andrew Blumberg, Kristen Hendricks, Robert Lipshitz, Ciprian Manolescu, Nathalie Wahl

Analytic and Geometric Aspects of Gauge Theory
Aug 22 – Dec 21, 2022
Organized by Laura Fredrickson, Rafe Mazzeo, Tomasz Mrowka, Laura Schaposnik, Thomas Walpuski

Algebraic Cycles, L-Values, and Euler Systems
Jan 17 – May 26, 2023
Organized by Henri Darmon, Ellen Eischen, Benjamin Howard, David Loeffler, Christopher Skinner, Sarah Zerbes, Wei Zhang

Diophantine Geometry
Jan 17 – May 26, 2023
Organized by Jennifer Balakrishnan, Mirela Ciperiani, Philipp Habegger, Wei Ho, Hector Pasten, Yunqing Tang, Shou-Wu Zhang

MSRI uses MathJobs to process applications for its positions. Interested candidates must apply online at mathjobs.org. For more information about any of the programs, please see msri.org/scientific/programs.
Focus on the Scientist: Herbert Spohn

Herbert Spohn is one of the organizers and Clay Senior Scholars for this semester’s program on Universality and Integrability in Random Matrices and Interacting Particle Systems. His outstanding research contributions span all aspects of this program and in general mathematical physics, with seminal work on hydrodynamic limits, kinetic equations, stochastic growth models, and universal processes in random matrix theory. Herbert was born in Tübingen, a small university town in southern Germany. He and his two brothers grew up in the home of their grandfather, who was a professor of mathematics. So from a very young age he viewed mathematics with great admiration.

For his university education, mostly at the University of Munich. Herbert studied physics, with strong interests in mathematical physics. He came to the US to do a postdoc with Joel Lebowitz at Yeshiva University and then Rutgers (after YU’s graduate program abruptly closed). For a period of sixteen years he was professor of condensed matter physics at the University of Munich. In 1998, he moved to the nearby Technical University and became a chair in applied probability, now in the mathematics department.

It was during a program in nonequilibrium statistical physics at IHÉS in Paris that Herbert became interested in the subject of interacting stochastic particle systems. There he met Claude Kipnis, a well-trained probabilist, who convinced him that interacting stochastic particle systems — in particular their hydrodynamic limit — is a fascinating topic that serves as an accessible illustration of the very generic phenomenon of emergent macroscopic behavior. Herbert not only learned this subject, but also wrote one of the canonical references on it.

Back in 1986, from a theoretical physics perspective, Herbert began to study growth processes jointly with Joachim Krug. Their connection to combinatorics and probability theory was accomplished through the work of Baik, Deift, and Johansson on the length of the longest increasing subsequence of random permutations. Together with Michael Prähöfer, Herbert realized that the spatial statistics of a growing surface could be figured out. They baptized this fundamental probabilistic object as the “Airy process.” About ten years later, jointly with Tomohiro Sasamoto, Herbert made another splash, in the study of the scaling properties of the Kardar–Parisi–Zhang stochastic PDE.

In recent years, Herbert has been studying the statistical mechanics of classical integrable systems with many degrees of freedom — an essential input to an understanding of the hydrodynamic scale. This direction, which has proved fruitful, brings together many of the topics studied this fall at MSRI.

For his immense impact in the above-mentioned areas, Herbert has been recognized with a still-growing list of awards, including the Max-Planck Award, the Eisenbud Prize, the Heineman Prize, the Georg-Cantor-Medaille, the Henri Poincare Prize, the Max-Planck Medal, and the Boltzmann Medal. Herbert is also a longtime editor for *Communications in Mathematical Physics* and the *Journal of Statistical Physics*.

— Ivan Corwin

Forthcoming Workshops

| Oct 18–22, 2021: | Integrable Structures in Random Matrix Theory and Beyond |
| Nov 16–18, 2021: | Chern-Simons and Other Topological Field Theories |
| Nov 18–20, 2021: | Blackwell Tapia Conference 2021 |
| Jan 20–21, 2022: | Connections Workshop: The Analysis and Geometry of Random Spaces |
| Feb 3–4, 2022: | Connections Workshop: Complex Dynamics — From Special |
| Feb 7–11, 2022: | Introductory Workshop: Complex Dynamics — From Special Families to Natural Generalizations in One and Several Variables |
| Mar 7–11, 2022: | Hot Topics: Foundations of Stable, Generalizable, and Transferable Statistical Learning |
| Mar 21–25, 2022: | Hot Topics: Regularity Theory for Minimal Surfaces and Mean Curvature Flow |
| Mar 28–Apr 1, 2022: | The Analysis and Geometry of Random Spaces |
| May 2–6, 2022: | Adventurous Berkeley Complex Dynamics |

Summer Activities

| June 6–July 15, 2022: | Summer Research in Mathematics |
| June 20–July 1, 2022: | African Diaspora Joint Mathematics Workshop (ADJOINT) |

For more information about any of MSRI’s scientific activities, please see msri.org/scientific.
Named Postdocs — Fall 2021

Viterbi

Emma Bailey is the Viterbi Postdoctoral Fellow in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. She received her Masters in Science degree in 2016 at the University of Bristol on the subject of the Riemann zeta-function, probabilistic models, and branching random walks, under advisor Jon Keating. Staying on in Bristol, she received her Ph.D. in 2020 and spent one year as a Heilbronn Research Fellow before coming to her current position at MSRI. After MSRI, she will start a postdoc at the Graduate Center for the City University of New York. Emma focuses on connections between random matrix theory, number theory, probability, and combinatorics. The behavior of characteristic polynomials for random matrix ensembles has been an important focus area of her recent work. The Viterbi postdoctoral fellowship is funded by a generous endowment from Dr. Andrew Viterbi, well known as the co-inventor of Code Division Multiple Access based digital cellular technology and the Viterbi decoding algorithm, used in many digital communication systems.

Uhlenbeck

Chiara Franceschini is the Uhlenbeck Postdoctoral Fellow in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. She completed her undergraduate education in 2014 at the University of Modena and then received a Masters degree in 2016 at the University of Wisconsin, Madison under advisor Timo Seppäläinen. Returning to Modena for her Ph.D., Chiara studied under Cristian Giardinà and received her Ph.D. in 2018. Prior to coming to MSRI, Chiara served as a postdoctoral fellow in Lisbon, Portugal. While her Ph.D. work focused mainly on stochastic dualities for interacting particle systems, especially those related to orthogonal polynomials, since moving to Portugal, Chiara has also become involved in the study of scaling limits and hydrodynamic limits for interacting particle systems. The Uhlenbeck fellowship was established by an anonymous donor in honor of Karen Uhlenbeck, a distinguished mathematician and former MSRI trustee. She is a member of the National Academy of Sciences and a recipient of the 2019 Abel Prize, the AMS Leroy P. Steele Prize, and a MacArthur “Genius” Fellowship.

Gamelin

Milind Hegde is the Gamelin Postdoctoral Fellow in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. He completed his undergraduate education at the Indian Institute of Science in 2016 before moving to Berkeley for his Ph.D. Milind just completed his Ph.D. in 2021 under advisor Alan Hammond. After his time at MSRI, he will move to Columbia University for another postdoctoral fellowship. Milind studies stochastic growth models, last passage percolation, and the Kardar–Parisi–Zhang universality class. He employs a mixture of geometric and probabilistic tools in conjunction with inputs from integrable probability. The Gamelin postdoctoral fellowship was created in 2014 by Dr. Ted Gamelin, Emeritus Professor of the UCLA Department of Mathematics. The Gamelin fellowship emphasizes the important role that research mathematicians play in the discourse of K-12 education.

McDuff

Alexandre Krajenbrink is the McDuff Postdoctoral Fellow in the Universality and Integrability in Random Matrices and Interacting Particle Systems program. He completed his undergraduate education in 2016 at École Polytechnique, in conjunction with a Part III at Cambridge. Alexandre received his Ph.D. in physics from the École Normale Supérieure, Paris in 2019, under advisor Pierre Le Doussal. Prior to coming to MSRI, he spent two years as a postdoc at SISSA, in Trieste, Italy. His research has focused on disordered and out-of-equilibrium systems, interface growth, optimization in directed polymers, random matrices, and cold fermions. In particular, he has recently studied large deviations for the Kardar–Parisi–Zhang equation and universality class and uncovered remarkable and new connections to integrable systems. The McDuff fellowship was established by an anonymous donor in honor of Dusa McDuff. She is an internationally renowned mathematician, a member of the National Academy of Sciences, and a recipient of the AMS Leroy P. Steele Prize (2017). She is also currently a trustee of MSRI.

Does group theory have to be so puzzling? (Part of MSRI’s exhibit in collaboration with the SFO Museum).
1. Describe all the natural numbers that can’t be expressed as a sum of two or more consecutive odd numbers.

2. A piece of bread is floating in water. It is known that 1/5 of it is under the water and 4/5 above the water. A fish starts nibbling on the bread under water with a speed of 60 grams per minute. At the same time, a bird starts nibbling on the bread above the water with the speed 120 grams per minute. What fraction of the bread will the fish get to eat?

3. Draw a regular 10-gon in the plane, including all its sides and diagonals. How many “shapes” of triangles can you find — that is, what is the largest number of triangles that you can find so that no two are similar?

4. Find the smallest 10-digit natural number n such that both n and n/2 have distinct digits.

5. A regular right polygon has all sides equal and all angles equal to 90 degrees. The only regular right polygon in the plane is of course a square. For which n do regular right n-gons exist in \(\mathbb{R}^3\)?

6. Find a real number p between 0 and 1 such that a “Bernoulli” coin that comes up heads with probability p can be used to simulate, in a guaranteed finite number of flips, both a fair coin and a coin that comes up heads with probability 1/2. This means that you should specify an m together with a set of outcomes of m flips of a p-Bernoulli coin that has probability 1/2, and an n together with a set of outcomes of n flips that has probability 1/2.

7. Let \(H_n\) be an n-dimensional hypercube, that is, the graph of \(2^n\) binary strings of 0’s and 1’s where two vertices are connected by an edge if and only if they differ in exactly one coordinate. A 2-dimensional face of \(H_n\) consists of four points \(t, u, v, w\) such that \(u\) and \(v\) are adjacent to \(t\), and \(w\) is adjacent to both \(u\) and \(v\). Find a subset \(S\) of \(H_n\), containing about a third of the points, such that \(S\) intersects every 2-dimensional face of \(H_n\). ⬤

Comments and sources for these problems will appear with the solutions at msri.org/emissary.

Upcoming Summer Schools 2022

Jun 6–17, 2022: Integral Equations and Applications (MSRI)

Jun 20–Jul 1, 2022: New Directions in Representation Theory (AMSI, Brisbane, Australia)

Jun 20–Jul 1, 2022: Geometric Flows (Athens, Greece)

Jul 5–15, 2022: Random Graphs (MSRI)

Jul 5–15, 2022: Algebraic Theory of Differential and Difference Equations, Model Theory, and their Applications (St. Mary’s College, Moraga, CA)

Jul 11–22, 2022: Metric Geometry and Geometric Analysis (Oxford, United Kingdom)

Jul 11–22, 2022: Séminaire de Mathématiques Supérieures 2022: Floer Homotopy Theory (Vancouver, Canada)

Jul 17–Aug 6, 2022: 2022 Joint PCMI School: Number Theory Informed by Computation (Park City, Utah)

Jul 18–29, 2022: Recent Topics in Well Posedness (Taipei, Taiwan)

Jul 25–Aug 5, 2022: Topological Methods for the Discrete Mathematician (St. Mary’s College, Moraga, CA)

Jul 25–Aug 5, 2022: Sums of Squares Method in Geometry, Combinatorics, and Optimization (Alberta, Canada)

Aug 1–12, 2022: Tropical Geometry (St. Mary’s College, Moraga, CA)

For more information about any of MSRI’s scientific activities, please see msri.org/scientific.
Individuals can make a significant impact on the life of the Institute, on mathematics, and on scientific research by contributing to MSRI.

Make a Donation to MSRI

Happy 110th Birthday, Shiing-Shen Chern

In celebration of the 110th birthday of co-founder Shiing-Shen Chern, MSRI hosted a three-day conference on Chern–Simons and Other Topological Field Theories on November 16–18, 2021. Among the featured speakers was Jim Simons (pictured), who discussed the origins of the Chern–Simons theory.

— Join us! —
For two events at the 2022 JMM in Seattle

Mathematical Sciences Institutes Open House & Reception
Thursday, January 6
6:00–8:30 pm
Sheraton Grand Seattle
Grand Ballroom C & D (2nd Floor)

MSRI Reception for Current & Future Donors
Friday, January 7
5:00–6:30 pm
Sheraton Grand Seattle
Boren Room (4th Floor)