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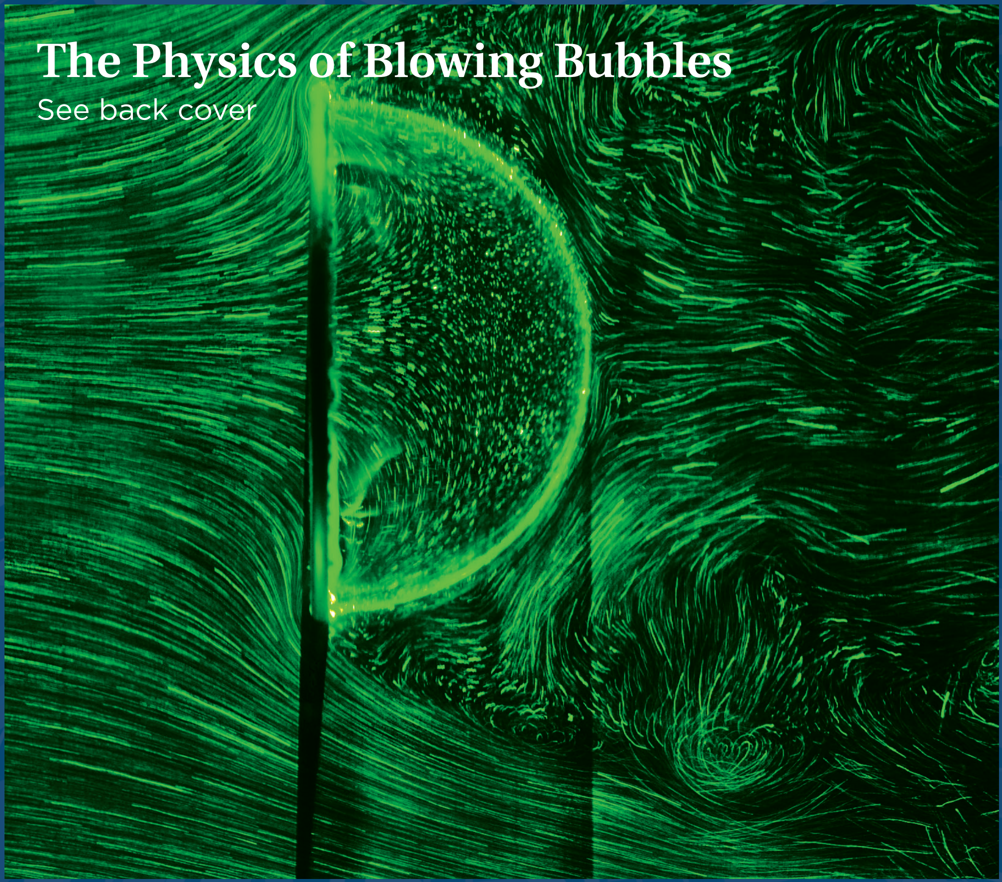
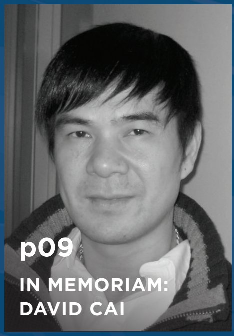


The Physics of Blowing Bubbles

See back cover



ALSO IN THIS ISSUE:

NYU COURANT INSTITUTE OF MATHEMATICAL SCIENCES

Geometric foundations of self-assembly
with Miranda Holmes-Cerfon

by April Bacon

Miranda Holmes-Cerfon has built computational and theoretical tools that hold promise for synthetic self-assembly and broaden our knowledge and means of investigating complex colloidal systems.

Colloids are a mixture of insoluble particles in a medium—in milk, butterfat is dispersed in an aqueous solution of carbohydrates; in blood, cells are suspended in plasma; and in paint, pigment is held within turpentine. For a few decades, theorists and experimentalists have been studying colloids, substances with particles small enough to exhibit erratic Brownian motion but large enough to be observed by light and escape the realm of quantum mechanics.

Miranda Holmes-Cerfon, an Assistant Professor of Mathematics at Courant who also attained her Ph.D. through the Institute's Center for Atmosphere Ocean Science (2010), was named a 2018 Sloan Fellow for her work on the subject. She explains that colloids are about the same scale as the wavelength of visible light, making them potentially a unique tool for designing new synthetic materials.

"One of the most popular applications to cite is an invisibility cloak. Obviously we haven't gotten there yet," she says, gesturing to her own visibility—"If I had an invisibility cloak I would be wearing it! Right now, a lot of the interest is in just understanding general principles of physics from colloids that could be used in material science, but there is a lot of potential for compelling applications."

Those applications include self-healing, self-replicating, and self-assembling synthetics. Miranda is most compelled by self-assembly—i.e. the ability to spontaneously organize into a desired form, a property with game-changing possibilities in medicine and nanotechnology. A piece of the puzzle is designing a system architecture that would enable the property to emerge, and so the question is in part geometric.

A number of phenomena can be in part explained by the geometric arrangement of particles, including water freezing, gels forming, and glass melting. There are also geometric underpinnings to the ability of certain biological systems (such as proteins and viruses) to fold, replicate, and assemble themselves. The synthetics have to be designed so that the system starts at a higher energetic state than the desired result, and so that there aren't any traps that would make the system assemble in a different way while en route.

Her first ventures into the area began as a Postdoc at Harvard in fall 2010. In the labs of chemical engineer and physicist Vinothan Manoharan and applied mathematician Michael Brenner, Miranda and collaborators calculated the rate at which colloid particles transition from one cluster arrangement to another, as seen modeled with sphere clusters in Figure A and imaged through a microscope in Figure B.

Colloids exhibit Brownian motion—that is, their particles move around erratically and incessantly due to constant bombardment by molecules coming from their surrounding medium. Much the way shaking a bucket of sand will flatten its surface, this constant jiggling forces the colloids from one geometric configuration to the next.

In order for the team to calculate the rate at which these systems of interacting particles change states, Miranda first needed to develop a way to mathematically represent their energy landscapes—a plot of the energy of the system—because traditional methods for doing so don't work effectively for colloids.

Whereas the energy landscape of other systems can be graphed as a surface of gentle hills, for colloids the landscape is a flat line with narrow spikes and valleys. This means that trying to describe the landscape by certain "critical points" doesn't provide enough information. "You somehow need to incorporate more global information about the whole geometry (shape, size, etc) of each flat piece of the landscape," says Miranda.

To get around this, Miranda used the sticky sphere limit, which simplifies the landscape by shrinking the range of interaction between particles down to exactly zero. She offers the analogy of two tennis balls stuck together with velcro. Unlike a pair of magnets, which will interact over a wider distance, two tennis balls Velcro-ed together only interact so long as they are exactly stuck together.

"What happens in the sticky limit is that the basic shape of the energy landscape is determined by the shape of the particles, and all the other parameters (interaction potential, temperature, etc, which are usually not known very accurately for colloidal systems) collapse into just one or two parameters. Therefore, you can change interaction potentials but the basic shape of the landscape doesn't change, so once you calculate the complicated geometrical properties of it, you can use them to understand the system over a wide range of conditions."

Figure A

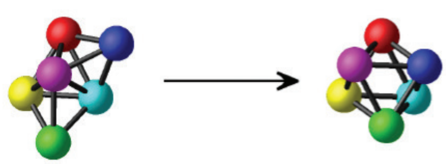
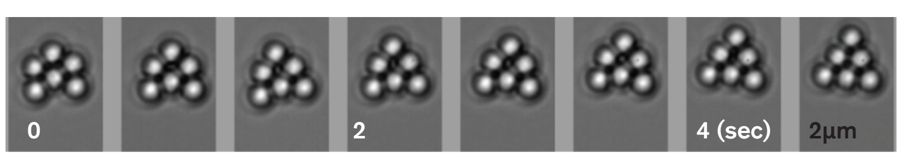


Figure B



"I'm hoping that looking at the energy landscape in this different way might lead to more efficient ways to solve certain kinds of problems. There are highly developed optimization algorithms that I could throw at the problem, but I'm also hoping to discover some kind of fundamental structure, a more general property [within statistical mechanics]."

With this tricky variable pinned down, Miranda and the team at Harvard developed a model that determines the rate at which a system will transition from one state to another, the different paths a system may take, and the likelihood of any given arrangement appearing. While former methods approaching this latter problem produced results that couldn't resolve the fine differences between states, Miranda's results are far more precise and, further, have been experimentally verified within acceptable limits of error.

Miranda realized her model offered solutions for another problem as well: enumerating rigid sphere packings. Some of the theoretical work surrounding colloids requires knowing a total set of the way the spheres can be arranged, or packed. Miranda took an algorithmic approach to this question: What are all the ways to form a rigid cluster? Starting with a single cluster, the algorithm breaks one point of contact (i.e. one side of a bar in Figure A), making the cluster "floppy" instead of "rigid." A rigid cluster can't rearrange itself—it can only jiggle its bonds slightly. But once a bond is broken, the newly floppy cluster can form new arrangements by two of its spheres coming into contact and forming a new bond. The algorithm does just that, deforming and locking into new arrangements until it exhausts all possible paths, searching for unique arrangements one dimension at a time.

The approach has produced ample new data unreached by other methods and, remarkably, has revealed clusters that mathematicians believed were possible but had no examples for, and which physicists didn't believe could exist.

"When my algorithm started outputting these clusters I thought there was a bug in it," says Miranda. "I spent a week trying to debug it and then I realized they were real!"

Miranda explains that such computational approaches to geometric problems are becoming increasingly useful. "We have this huge range of building blocks," she says. "Experiments can't possibly search through the whole space, but on a computer we can guide the search."

"One thing that is nice about this question [of enumerating rigid sphere packings] is that it's such a simple question to formulate," she says. She has done demonstrations with both high school teachers and students, including at cSplash, Courant's day-long program for high schoolers that Miranda co-founded in 2006 as a doctoral student. "I give [participants] these toys and ask them to come up with an algorithm, and they usually do. They usually figure out what some of the rigid clusters are. It's a great question for teaching people about mathematics research and getting them engaged in solving problems."

In new work, Miranda has been looking at problems related to physical properties of colloidal systems, such as the effects of friction and the effects of coating colloidal particles with DNA strands.

Adding friction is challenging because friction itself is not well understood. Miranda gives an example of its complexity introduced to her by Tadashi Tokieda (Stanford). Place a few small balls in a circular container and move the container around in a circle. At first, the balls move in the same direction as the container. But as more balls are added, at some critical point they begin to go in the opposite direction.

"The only way this can happen is because of the friction between the balls and some collective property of how they're interacting," says Miranda. "This is an example of a simple experiment that you can do at home that shows how complicated friction can be, even with a small number of particles." Miranda and then-undergraduate student John Ryan (now a Ph.D. student at Cornell) studied this within a computational model.

"The nice thing about code is you can turn off and on certain properties of the system that you can't do in experiments. It's hard to do this experiment with discs, but we did it with discs in code. You can't just turn off friction in the experiments, but we turned off friction in our code."

Miranda is also studying DNA-coated particles, which interact in ways that are complex but within the realm of prediction, so they increase the range of synthetic design possibilities.

"Experimentalists can program which particles attach to which other particles by choosing the right choice of DNA strands," says Miranda. "They can make a very complicated interaction matrix with different kinds of interaction for different kinds of particles. And they can do this purely by coating particles with strands of DNA."

With Postdoc Emilio Zappa, Miranda is looking at the information-theoretical part of DNA-mediated systems—i.e. questions such as how DNA can be used to program the particles to assemble in different ways, what structures can be formed by mixing particles of different types, and if a system's energy landscape places constraints on what structures it can form. She is also building computational models with several collaborators. For example, With Jonathan Goodman and Nawaf Bou-Rabee, "I'm developing algorithms to efficiently sample and simulate dynamics on sticky energy landscapes. With Steven Gortler [Harvard] and Louis Theran [St. Andrews], I'm developing algorithms to better understand the geometrical properties of the landscapes."

"My hope is that all these tools will one day be useful for other kinds of systems as well," she says. The ideas she has been using to study colloids have connections to other systems that are wonderfully broad—from protein folding and virus assembly to robotics and origami, each with the essential feature of being a system with objects that move stochastically, subject to certain constraints.

Much of the work is also linked by randomness and geometry. On what draws her to the research, she says: "There's this really difficult and beautiful mathematical topic of geometry and also a counterintuitive topic of stochastic [i.e. random] process and they seem to be related in certain systems. That's something I find fascinating."

As a doctoral student within Courant's Center for Atmosphere Ocean Science program, Miranda developed stochastic models for studying the impact of small-scale, internal waves on the large-scale flow of the ocean. "It also turned out to have a geometrical flavor to it," she says. "One of the questions I looked at was, how does the shape of the bottom of the ocean impact larger tides and waves?"

"Geometry is really important in many stochastic processes that occur in the real world," says Miranda. "The way that objects are shaped has a major impact on how they behave." ■

Randomness and Cryptography
with Yevgeniy Dodis

by April Bacon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Across two decades, Yevgeniy Dodis has explored theoretical limits of randomness generation and extraction, and devised ways to illuminate and fortify its foundation, entropy.

"Randomness in cryptography is like the air we breathe. You can't do anything without it," says Yevgeniy Dodis, Professor of Computer Science at Courant. "It's needed for everything: generation of keys, cryptographic protocols, masking—you name it."

It is fundamental to the field because secrets are fundamental to the field; cryptography is only possible when a secret can be kept safe from a potential attacker, and a secret that isn't random to that attacker isn't truly secret. Yevgeniy, a Courant alum (B.S., 1996) who joined the Institute as a faculty member in 2001, has gone deep and wide into the subject.

There are many ways a computer can attempt to find randomness for cryptographic purposes. For example, it can create a sequence of numbers mathematically or collect bits by tracking physical processes such as the processor's temperature, interrupt timing, or the movement of a computer mouse. While the possibilities for how to generate bits are as wide as a cryptographer's imagination, these sources are not guaranteed—nor even likely—to produce perfect randomness. Luckily, such imperfect sources can still be sufficient for real-world applications of cryptography. Much of Yevgeniy's work on randomness consists of characterizing the precise conditions when a source is "good enough" for a given application and, when these conditions are met, devising the most efficient way to use that source.

A source doesn't have to be perfectly random because randomness is not an on and off switch, it's a spectrum. Between true randomness and complete predictability (such as the sequence "0000") lies a mathematical concept called entropy. The entropy of a given source tells us just how unpredictable—and therefore secure—it is. A one-hundred-bit source, for example, can have entropy ranging from zero (totally predictable) to one hundred (truly uniform) bits; twenty bits of entropy guarantees that the source cannot be guessed with probability better than 2^{-20}, which is less than one in a million. Secrets require at least a few hundred bits of entropy, otherwise they can be easily guessed. This measurement alone does not tell the whole story, as 100 truly random bits appears to be much more useful than a million-bit source with 100 bits of entropy "scattered" throughout otherwise predictable bits.

In early work, Yevgeniy investigated formally what degree of entropy is sufficient for different cryptographic tasks. He showed that even very scattered entropy is likely sufficient for authentication tasks such as digital signatures. But in a series of cornerstone papers in the early 2000s, he and various co-authors demonstrated that such is not the case for privacy tasks (such as encryption), which cannot be based on entropy alone. Even more surprisingly—and of great philosophical importance to understanding the role of randomness in cryptography—these privacy tasks require true randomness.

There are ways to meaningfully overcome this fact, such as with privacy amplification, an area first developed in the late 80s. The technique combines two initial sources—one perfect public source and one imperfect secret source—to extract a new, nearly perfect and secret source. In other words, public perfect randomness can be used to "purify" imperfect secret randomness. The success of the process is measured in minimizing its "entropy loss." Entropy loss is the difference between the entropy of the secret source given as input, and the length of the nearly perfect randomness that is extracted from it. Prior work on privacy amplification achieved entropy loss of 128 bits for "industry-grade" security 2^{-64}. This is a high price to pay because entropy is already scarce in many cases, such as when taken from biometric data (as discussed below).

In a series of recent works, Yevgeniy and co-authors achieved the same level of security with strikingly lower entropy loss: just 10 bits for any authentication and 64 bits for most privacy applications (including encryption). The result has important practical implications; as Yevgeniy puts it, "If you need randomness to produce cryptographic keys, you don't need as much entropy as for full randomness extraction."

In work that has over 2500 citations and which this year was selected for a Eurocrypt Test-of-Time award for the year 2004, Yevgeniy and co-authors tackled the question of securely extracting cryptographic keys from biometrics and other noisy data, such as fingerprints and retina scans. Specifically, such data is not only imperfect in terms of its entropy, but also noisy: repeated readings of the same data will likely be close, but not identical. The resulting cryptographic primitive is called a fuzzy extractor. As Yevgeniy explains, "First I measure my fingerprint to derive the key. That's the true secret. The next time I measure my finger, it's going to be close but not exactly the same. So how do I reliably extract the same key from close-but-noisy readings?"

Yevgeniy's approach is to decouple the issue of noise and extraction. With the first reading, helper information is created through another primitive he developed, known as "secure sketch." The original reading maintains most of its entropy, even if the helper information is public, so the helper information can be stored without risk of exposing the key. The next time a noisy reading is taken, the helper information allows the exact initial reading to be reproduced, and so the same key is derived the second time around.

One of the rewarding experiences from this work on fuzzy extractors was that it found so many unexpected applications beyond biometrics, such as differential privacy and physically unclonable functions. As Yevgeniy says, "If you do something clean and elegant, science will be kind to you."

Another important area of Yevgeniy's research on randomness is his influential work on random number generators (RNGs). Random number generators are tools built into computer operating systems to produce, as Yevgeniy says "randomness on steroids." From a small amount of randomness in their secret state, RNGs repeatedly produce plentiful amounts of "pseudo-randomness" in the foreground for any process that requires it. Although this pseudo-randomness is not perfect, no efficient attacker can tell it apart from true randomness. The foreground part of this process has been well understood since the late 80s for cases in which the source in the secret state is random to begin with. A far less understood process happens in the background, where an RNG repeatedly incorporates fresh entropy from various imperfect entropy sources (e.g., timing of computer interrupts, etc.) into their small state. This background process should "work like a sponge," says Yevgeniy, looking for entropy everywhere and absorbing it like water. Like a sponge, the generator will "mix up" the entropy that it takes in, without necessarily knowing how much it has or where it might be located. This rapid entropy accumulation safeguards the RNG in face of a computer reboot or potential state compromise—without it, the foreground process of pseudo-randomness generation will lack enough initial entropy and will provably fail.

Yevgeniy was the first to formalize the process of entropy accumulation, which is at the heart of all existing RNG designs. Formerly, "random number generators inside computers were all ad hoc," he explains. RNGS are "complex and hard to understand; as such, they're hard to attack. And because they're hard to attack, the theory behind them was lacking. I wanted to change that—to bring this important area of cryptography on par with encryption and authentication." In particular, Yevgeniy reduced part of the problem of sound entropy accumulation to an online randomness extractor and then made several constructions of such online extractors.

Yevgeniy has applied his theory to real-world RNGs, revealing theoretical weaknesses in the RNG used by the Linux operating system. By comparison, Windows has a very secure random number generator, and macOS is somewhere in between. His work attracted several high-profile discussions on the subject and ongoing interest from Microsoft and Apple, which Yevgeniy hopes will influence their future RNG releases.

Randomness extraction—applying methods to an imperfect source to "extract" a much better one—appears in all of the above examples as a powerful tool to deal with imperfect randomness. Yevgeniy first utilized such extractors for his doctoral dissertation at M.I.T. in 2000. With randomness extractors as one important component, Yevgeniy developed solutions for "Exposure-Resilient Cryptography"—i.e. maintaining the viability of a key even when that key has been partially exposed. For example, hardware may be physically stolen and halfway hacked, or malware may extract bits of secret information. Yevgeniy's dissertation shows that an attacker can uncover quite a bit about the actual secret without the application being compromised, by carefully extracting a shorter, "virtual secret" inside the actual secret. This virtual secret will be perfectly secure, even if the actual secret is partially compromised.

"A lot of things you can do in cryptography are seemingly impossible," says Yevgeniy. "I can prove to you that a statement is true without telling you anything else about the statement, beyond its validity. You're convinced, have no doubts, but you don't know why. This is zero-knowledge. I can do electronic currency—I can give you a string of bits which is money. You can see that it is money and, somehow, can spend it only once. These things are counterintuitive—they are like puzzles."

"Cryptography is really all about puzzles, and I love puzzles," he says.

Yevgeniy's first experience with cryptography was as a graduate student at M.I.T., in a class with Shafi Goldwasser.

"It really intimidated me," he says. "She went full speed into research, and I was used to just taking classes and doing homework." At the time, Yevgeniy's primary research area was in lower bounds. He did well in cryptography, but didn't think it was for him. The following year another cryptographer, Silvio Micali, was the head of his qualifying committee for candidacy into the doctoral program.

"Instead of just saying, 'You passed,' he said, 'You know, why don't I take you for lunch? Let's talk.' It was luck—he was looking for students because he had been on sabbatical. He said, 'You seem to be a talented guy, here is a cool problem.'" Micali had just picked up the problem while visiting another professor at the University of Montreal. It was about lower bounds in cryptography and didn't require much knowledge in the field.

"It was just complete serendipity," says Yevgeniy. Not only was the problem related to lower bounds, then his primary area of study, but it was also solvable using techniques he had learned while taking an elective outside of the computer science department, in electrical engineering.

"That very evening I solved the problem," he says. "Silvio was excited. Because I didn't have any experience in cryptography, he sat with me, and we wrote the entire paper together. He had to translate my technique to the proper notation because I had never written cryptography papers." Previously, Yevgeniy had been struggling to get papers on lower bounds accepted to conferences, but this new paper was accepted to Eurocrypt, the most prestigious conference in cryptography.

"I can summarize what I learned from [Goldwasser and Micali, now Turing Award winners] in one word: aesthetics," he says. "This is something I try to teach to my students. There are proofs which are beautiful; there are proofs which are ugly. I'm a deep believer that aesthetics governs the world, at least in science. There are counterexamples—complex papers which require lengthy and tedious calculations. Some of my papers are like that as well, they require you to just roll up your sleeves and dive in. But my favorite work is elegant: clever work that can be explained to an expert in five minutes. I don't write it on my grant applications, but for me, one of the main values in a paper is what is beautiful."

Computer Science announces Computing, Entrepreneurship and Innovation Masters Program

Last May, Courant's Computer Science department and the Stern School of Business welcomed an inaugural class of students into a new, joint M.S. in Computing, Entrepreneurship and Innovation program. Under the leadership of program Director Evan Korth and Co-Organizer Lakshmi Subramanian, the MS-CEI trains students to become entrepreneurs and leaders in high-tech organizations, filling roles such as CEOs, CTOs, VPs of engineering, and heads of innovation labs. The one-year, four-semester program has an incoming class of 8, and the program plans to steadily increase in size over the coming years, capping at 40.

The MS-CEI gives students a solid foundation in entrepreneurship, computer science applications, and systems engineering by integrating them into graduate-level coursework offered through Stern's MBA and Computer Science's Masters programs. In a slate of tech-centric entrepreneurship classes designed and developed specifically for the program, students gain expertise through experiential courses that lead them through conceptualization, incubation, development, deployment, and evaluation. An entrepreneurship capstone culminates the program, facilitating students' engagement with the startup and investment communities in New York City. ■

GSTEM students rank in top 25 percent in nation-wide competition

Under the leadership of GSTEM Faculty Director and Clinical Professor Matthew Leingang, the Courant Institute's Girls' Science, Technology, Engineering, and Mathematics (GSTEM) program welcomes 40 talented high school girls into its 6-week research program each summer, pairing them with a mentor from academia or industry.

In summer 2017, high schoolers Beiting Chen (from Corona Del Mar High School in Newport Beach, CA) and Tiffany Chen (from Stuyvesant High School in NY) were paired with mentor Dr. Rob Barton of Amazon and tasked with entering a million-dollar prize competition hosted by Kaggle, a predictive modeling and data analytics site. The goal of the competition: to improve an algorithm used by top real estate website Zillow.com.

At the time, the program was celebrating 5 years, and the duo brought the program another reason to celebrate by placing in the top 25 percent of all 1,650 competitors in Kaggle's challenge—despite having no previous experience in data science or coding prior to GSTEM.

As explained by Catherine Tissot, GSTEM's Program Administrator, "Those at the top of the leaderboard are some of the industries' leading programmers, which makes Beiting and Tiffany's accomplishment all the more impressive...The girls analyzed and manipulated various housing data sets and reworked the Zillow algorithm used for home value predictions."

Chen and Chen were 2 of 6 Winston Data Scholars in 2017, receiving a merit-based, full-tuition scholarship to attend GSTEM. Beiting Chen has since enrolled at Santa Clara University. For her further developments on the GSTEM project, Tiffany Chen—now enrolled at M.I.T—was also selected as a Scholar in the 2018 Regeneron Science Talent Search competition, one of 300 out of 1800 applicants. ■

To volunteer, donate, or find out more about GSTEM, visit cims.nyu.edu/gstem/ or contact gstem@courant.nyu.edu.

Mathematics in Finance Program Celebrates 20 Years

At the Mathematics in Finance alumni event on October 12, 2018, well-known market practitioners and portfolio managers discuss topics such as machine learning, mathematical modeling of the markets, and portfolio and risk management techniques.

The Courant Institute's Mathematics in Finance program turns twenty in 2019. Throughout the year, we will be celebrating the program's anniversary with a number of events, including:

- **20th Anniversary Gala at the NYU's Rosenthal Pavilion on May 17**
- **Mathematics in Finance multi-day conference in the fall of 2019**
- **A special Mathematical Finance Seminar anniversary series with invited speakers throughout the year**

Event descriptions and schedules are available at: **http://MathFinance20Years.org.**

I hope you can join us in the celebrations!

Petter Kolm
Director Mathematics in Finance program, NYU Courant

Henry McKean retires

Henry McKean's mathematical career has been "rich and magnificent" (Steele Prize citation) and uniquely his own. Dan Stroock (M.I.T.) has said it like this: "Whether it is his early collaboration with Itô, his excursion into Gaussian prediction theory, or his interest in completely integrable equations and spectral invariance, Henry has chosen his problems because they interest him and please his sense of aesthetics. As a result, his mathematics possesses an originality, which is all his, and a beauty, which the rest of us can appreciate."

Henry's interest in mathematics originated in high school, though "at the beginning," he says, "I didn't really like mathematics at all. I remember my poor father trying to teach me the multiplication tables one summer when I was quite little." In high school, trigonometry and algebra were "dull and/or mysterious." But in another class, a great teacher introduced him to calculus, and something clicked. Then, as an undergraduate at Dartmouth College, he took a class with Professor Tom Doyle, studying a book by Francis Hildebrand (*Advanced Calculus for Engineers*).

"I began to understand a little bit about the heat equation, a little bit about the wave equation, and how the heat equation had something to do with diffusion, the wave equation had something to do with a violin string. Things like that. It was very exciting. I was hooked."

Henry earned his A.B. from Dartmouth in 1952, studied on fellowship at Cambridge (U.K.) for a year from 1952-53, and earned his doctorate from Princeton in 1955. He first encountered probability during his undergraduate studies, in a summer class at M.I.T. taught by Mark Kac (1951), and further delved into the subject at Princeton, completing his thesis on a related topic under Will Feller. It was during his final year at Princeton that he met a mathematician who was visiting from Japan: Kiyoshi Itô, who had extended Newton's calculus to handle Brownian paths.

"We became friends and we started to work together," says Henry. The next year, he went to Japan on a Fulbright. Together, the two wrote *Diffusion Processes and Their Sample Paths* (1965), one of two books that laid the foundation of stochastic analysis at the genesis of the field. Four years later, the second book—Henry's *Stochastic Integrals*—was published.

Of these two books, Terry Lyons (Oxford) says, "This was part of the beginnings of modern probability."

Stochastic Integrals is a hallmark of Henry's unique style. The book "taught a whole generation how to do analysis with sample paths," says Terry.

Terry was a doctoral student when he first met Henry. "It was a wonderful experience," he says. "I knew some of his stuff inside out, so it was easy to engage. Henry was the first person I met who could intuit formally. His formulas would leap across the board. He'd say, 'That formula should lead to that formula…I've never seen anything like that before."

After Japan, Henry spent 8 years at M.I.T. and then 4 years at Rockefeller University. While at Rockefeller, he would frequently visit Courant to hear some mathematics. "I used to come back on the subway and think, wouldn't it be nice to work at Courant? One day, I made up my mind to propose the idea to Monroe Donsker, a friend and professor at the Institute. Just as I was about to pick up the receiver, the phone rang, and there was Mony. He said, 'Will you come?' I didn't miss a beat. I said yes, and that was that."

Henry spent the next 47 years as a faculty member at the Institute, serving as its director from 1988-92, and retiring as a Professor Emeritus in 2018. He wrote several notable books, including two with Harry Dym, one on Fourier series and integrals in '72 and one on Gaussian probabilities in '76; one with Victor Moll on elliptic curves in '97; and another big solo book on probability in '14. Per the Mathematics Genealogy Project, he has advised 50 doctoral students and so far has 530 descendants. Henry is a Member of the National Academy of Sciences and the American Mathematical Society. In 2001, he was awarded an honorary degree from Paris 7 Denis Diderot. In 2007, he won the Leroy P. Steele Prize for Lifetime Achievement.

The Steele prize citation notes a selection of Henry's influential contributions: After his work with Itô "he delved into a variety of topics with probabilistic origins." These included "both Gaussian and Markov processes and including the first mathematically sound treatment of 'American options' [with P. Samuelson], I.M. Singer deflected McKean's attention from probability and persuaded him to turn his computational powers on a problem coming from Riemannian geometry. The resulting paper remains a milestone in the development of index theory.

"After moving to the Courant Institute, McKean played a central role in the creation of the analytic ideas which underpin our understanding of the KdV and related non-linear evolution equations, and here again his computational prowess came to the fore."

"His contribution was pretty holistic," says Terry. "And on top of that he is just a wonderful person. Our community has been very lucky."

An *Emergency* Mathematics Education

During the Second World War, the founders of the Courant Institute conducted research and offered consultations on war-related projects for industry and the military. These projects included the theory of shock waves, leading to the postwar publication of the famous *Supersonic Flow and Shock Waves* textbook, authored by Courant and Friedrichs and edited by Cathleen Morawetz. Perhaps less known is the teaching that founding faculty members Richard Courant, Kurt O. Friedrichs, and James J. Stoker did for the Department of Education during the war.

While military research occupied many mathematicians during the Second World War, including those at New York University, some also found themselves in the classroom in the name of national defense. Under the auspices of the United States Office of Education's Engineering, Science, and Management War Training Program, over 200 colleges and universities across the nation offered emergency courses to train engineers. The mathematics courses that were part of this program were meant to offer "methods of solving concrete problems."

When the national training program was first announced in the fall of 1940, Courant and his colleagues developed coursework to be funded by the Office of Education. In coordination with NYU's College of Engineering, the Mathematics Department began offering these federally funded courses during the summer 1941 term. During the first summer of the program, about 75 researchers and engineers enrolled in an assortment of classes at NYU. The courses continued until the war's end and reached a total enrollment of 86,000 nationwide.

In developing the courses, Courant, Friedrichs, and Stoker gathered input from members of industrial laboratories and governmental organizations in the greater New York and New Jersey region. The courses offered instruction in advanced methods of applied mathematics, fluid dynamics, elastic plates, electrical networks, and vibrations. They covered the most applicable elements of the topics, as they were "designed to meet particular needs of research workers in defense activities." They were meant for researchers working full-time in war-related industries, meeting in the evening hours and expecting sufficient backgrounds in mathematics and engineering for a higher level of study. Many students were from industries such as aircraft, rubber, acoustics, and communications. In some semesters, Courant had close to 60 students in a single course.

NYU's mathematics students in the emergency education program also included career academics, such as Charles De Prima, Claude Shannon, and Grace Hopper. De Prima went on to complete his Ph.D. in mathematics at NYU and to join its faculty. Shannon spent his career at Bell Labs and the Massachusetts Institute of Technology and is celebrated as a founder of information theory. Grace Hopper went on to a very distinguished career in the Navy and was a pioneer in computer science. When she took the courses at NYU, she was a faculty member at Vassar College and spent half-time studying at NYU over two semesters. Hopper credited the courses she took with Courant, including calculus of variations and differential geometry, as part of the reason she was assigned to the Harvard Computation Laboratory, propelling her career in computing.

As recorded in the Smithsonian's Computer Oral History Collection, Hopper later reflected, "Other than being a researcher and everything else [Courant] was a teacher. He was a terrific teacher... The sheer delight and inspiration of a teacher like that was fascinating."

In addition to contributing to efforts for the war, these emergency courses provided a venue for Courant and his colleagues to instill their particular vision of interdisciplinary connections between mathematics and engineering in a concrete way. They had significant impact on individual careers – and thus, perhaps the evolution of postwar disciplines. ■

***Brit Shields, Ph.D.**, is a historian of science currently writing a book about the Courant Institute. She can be reached at* **bshields@seas.upenn.edu**.

In Memoriam: Shenou David Cai (1963–2017)

Shenou David Cai, Professor of Mathematics and Neural Science, died on October 21, 2017 at the age of 54. A physicist by training, he attained his B.S. from Peking University in 1984 and his M.S. and Ph.D. from Northwestern University in ’89 and ’94, respectively. He first arrived to the Courant Institute as a postdoc in the mid-90s and was recruited onto the faculty later that decade. In 2009, the Chinese Ministry of Education appointed him as a Chang Jiang Scholar and, in 2010, a Chair Professor of Shanghai Jiao Tong University (SJTU) through the Thousand Talents Program in China. He then split his time between NYU and SJTU.

David was a founder of SJTU’s Institute of Natural Sciences (INS), playing “a pivotal role in making SJTU an active player in modern applied mathematics at the international stage,” as written by that university. His intent, as Mike Shelley explains, “was to start a Courant-style research institute in China” dedicated to mathematics, experimentation, and areas of physics—a vision that he succeeded in bringing to life.

In each place he directed his energies, David dedicated himself fully to science, and held great devotion to his institutions, students and postdocs, and community. He made many important research contributions in theoretical and computational biology and neuroscience, network dynamics, applied dynamical systems, applied stochastic processes, and wave turbulence.

“David was an outstanding scientist and scholar, who attacked diverse conceptual problems,” as Gregor Kovacic (Rensselaer Polytechnic Institute) said at the May 2018 memorial conference held for David in Warren Weaver Hall. “He had great talent and deep intuition, which was also based on long experience.”

David made fundamental contributions to nonlinear and dispersive waves—an area he studied across his career, and the one which first brought him to the Courant Institute as a postdoc working with Dave McLaughlin and Jalal Shatah. During the 90s, through a set of computational experiments studying chaotic behavior for near integrable nonlinear dispersive waves, he revealed many properties of interactions between coherent waves, including the most violent waves that occur in the focusing nonlinear Schrödinger equation.

Dispersive waves become turbulent through a physical process called weak turbulence. Using an idealized model for this behavior, David was the first to uncover basic principles for these weakly turbulent systems and to identify how the model must be adjusted to maintain the validity of weak turbulence theory across differing conditions. As Dave McLaughlin says, “there was really no understanding of when weak turbulence worked and when it failed until David’s robust and insightful work on the model.”

David’s theoretical neural science work was significant and wide-ranging: for example, he applied information theory to coding schemes for cortical processing, investigated the importance of nonlinearity in the interaction of multiple synaptic inputs along dendrites, and played a significant role in developing comprehensive large-scale computational neuronal networks.

In visual neural science, he studied the role of sparsity and stochasticity in the performance of large-scale neuronal networks. He deepened our understanding of a common dynamical operating state of the visual cortex, brought to light the consequences of the cortex operating in this stochastic and heterogeneous state, and revealed how sparse connectivity set up conditions for the state to develop and be stable.

As Robert Shapley (NYU Center for Neural Science) says, “[David] appreciated that the degree of connectivity [between neurons] in these models makes a big difference into how the model works. That was really a very nice insight that had a lot of implications and a lot of influence.”

In another body of work that is becoming very influential, David and collaborators studied biological transport networks. These systems comprise many nodes connected by branching passages, as in blood circulation structures. In their model, David and Dan Hu (SJTU) further developed our understanding of those structures—for example, the amount of capillaries that will feed tissues with enough oxygen but also not be wasteful—and then adapted that knowledge to study veinage in tree leaves.

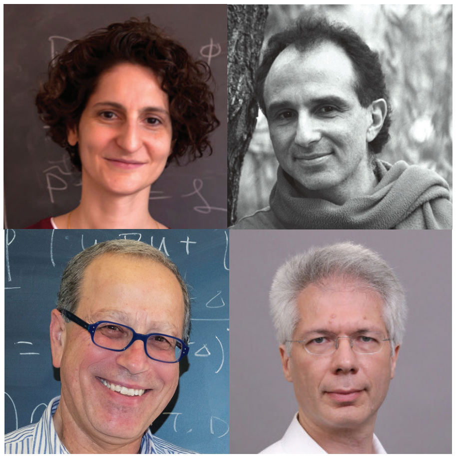
“David Cai was a truly brilliant applied mathematician, a great friend and a wonderful scientific collaborator,” says Andy Majda. “[He] had a very sophisticated scientific and cultural perspective on the world and he shared his ideas, insights and knowledge generously with his friends and students.”

As a dedicated mentor, David gave his students “excellent projects, […] guided them until they finished successfully, helped them secure good jobs afterwards, followed their careers, and gave them invaluable advice,” says Gregor.

As an individual, he was a “kind, engaging person,” says Mike. He was an independent thinker and inviting conversationalist. Whenever David was seen the hallways of Warren Weaver Hall, he was seen smiling.

“Despite his success, David was very humble and down-to-earth,” Gregor says. “He had half of this huge building [at SJTU] and soon would hire 30 top scientists, and yet when Pete [Kramer] and I showed up at his institute, he rode to meet us on a standard, one gear, Chinese bike.”

“David Cai was a truly unique person—a great person,” says Dave, who expresses a commonly echoed sentiment among David’s colleagues and friends: David will be missed. “It was a real honor and privilege to be his friend. He left us far too soon.” ■



Congratulations to Sylvia Serfaty, Dennis Shasha, Jalal Shatah, and Denis Zorin, who have been named Silver Professors!

Three faculty members have been named 2018 Sloan Fellows. As stated by the Alfred P. Sloan Foundation, the early-career scholars selected as fellows "represent the most promising scientific researchers working today." **Afonso Bandeira** builds methods for extracting information from large and noisy datasets, such as in recent work in reconstructing images of molecules from up to millions of messy images taken via cryo-electron microscopy. In recent work, **Joan Bruna** applies insights from his work with harmonic analysis and convolutional neural nets to fields such as particle physics and quantum chemistry, with an ultimate aim of advancing the mathematical foundations of deep learning. And **Miranda Holmes-Cerfon** develops computational and theoretical tools for studying the unique properties of materials at the nano and microscale, with a longterm goal of revealing how systems can be designed to assemble themselves spontaneously into a desired form.

Marsha Berger has won the American Mathematical Society's 2019 Norbert Wiener Prize in Applied Mathematics for "fundamental contributions to adaptive mesh refinement (AMR) and to Cartesian mesh techniques for automating the simulation of compressible flows in complex geometry." As the citation says, Marsha "provided the mathematical foundations, algorithms, and software that made it possible to solve many otherwise intractable simulation problems, including those related to blood flow, climate modeling, and galaxy simulation." Additionally, Marsha will be a 2019 invited speaker at the International Congress on Industrial and Applied Mathematics.

Paul Bourgade has been named a Poincaré Chair laureate for the 2018-2019 academic year. Established by the Institut Henri Poincaré and the Clay Mathematics Institute, the Chair supports "research of mathematicians of great promise during the early stages of their careers." Paul's research focuses on random matrix theory and its interactions with statistical physics. At the Institut Henri Poincaré, he will study the transition between localized and delocalized eigenstates, and the occurrence of random matrix statistics in deterministic contexts.

Sylvain Cappell was awarded the 2018 Award for Distinguished Public Service from the American Mathematical Society (AMS). He was selected "for his remarkable mentoring of talented young mathematicians, his dedication to protecting human rights, and his extraordinary involvement in outreach." As the AMS citation continues, Sylvain "has displayed an exceptional ability to recognize and nurture mathematical talent. He has also served as advisor to organizations ranging from the Rothschild Foundation and Caltech to New York Math Circles, the National Museum of Mathematics, and Math for America." Additionally, Sylvain was elected to the American Academy of Arts and Sciences.

Jeff Cheeger has been awarded the American Mathematical Society's 2019 Leroy P. Steele Prize for Lifetime Achievement for "fundamental contributions to geometric analysis and their far-reaching influence on related areas of mathematics." As the citation continues, "For more than half a century, Jeff Cheeger has been a central figure in differential geometry and, more broadly, geometric analysis. His work on the profound and subtle effects of curvature on the topology and geometry of manifolds has laid and continues to lay foundations for much of the progress in these areas ever since his 1967 dissertation."

Patrick Cousot received the 2018 John von Neumann Medal "for introducing abstract interpretation, a powerful framework for automatically calculating program properties with broad application to verification and optimization." Abstract interpretation, which Cousot invented with Radhia Cousot in the 70s, is a fundamental theory that has had far-reaching theoretical and practical impact in the area of formal methods. The Institute of Electrical and Electronics Engineers awards the medal "for outstanding achievements in computer-related science and technology."

Percy Deift has received the 2018 Henri Poincaré Prize for "for his seminal contributions to Schroedinger operators, inverse scattering theory, nonlinear waves, asymptotic analysis of Fredholm and Toeplitz determinants, universality in random matrix theory, and his deep analysis of integrable models." As written in Peter Sarnak's Laudatio for the prize, "Deift has built fundamental theories and developed novel tools that he and his collaborators, as well as others, have used to resolve many long standing conjectures."

Julia Kempe has been elected to the Academia Europaea in a 2018 cohort of just over 250. The Academy's approximately 4000 invited members "are scientists and scholars who collectively aim to promote learning, education and research."

Bob Kohn was elected to the American Academy of Arts and Sciences in its 2017 cohort. Per the citation, "Kohn has developed important new techniques in the calculus of variations and partial differential equations, motivated by challenges from a broad range of application areas." AAAS members are "world leaders" in their disciplines recognized for "excellence in the field and a record of continued accomplishment."

Nader Masmoudi has been awarded a 2017 Fermat Prize by the Institut de Mathématiques de Toulouse "for his very deep and creative work in the field of nonlinear partial differential equations and particularly for his recent contributions to the complete and rigorous resolution of hydrodynamic stability problems that were raised at the end of the nineteenth century by the founding fathers of modern fluid mechanics." The bi-annual prize aims to reward mathematicians whose research results in the fields of Pierre de Fermat are "accessible to the greatest number of professional mathematicians."

Mike O'Neil won a 2017 Office of Naval Research Young Investigator Award to pursue his research project "Toward Real-Time Electromagnetics Design: Fast, Accurate, and Robust Integral Equation-Based Solvers." He will be developing tools for modeling electromagnetic interactions using integral equation formulations of Maxwell's equation and fast, high-order, analysis-based algorithms. The main goal of the research is to make large inroads in electromagnetic design by simulation; the work will ultimately enable engineers to accurately model, simulate, design, and validate electromagnetic devices (such as radar and satellite communication systems) via computation in nearly real-time, instead of through costly physical prototyping.

Oded Regev has received the 2018 Gödel Prize for his seminal paper, "On lattices, learning with errors, random linear codes, and cryptography." The paper introduced the Learning With Errors (LWE) problem and led to the development of the most advanced cryptographic schemes likely to be secure against quantum computers. As stated in the European Association for Theoretical Computer Science's citation, Oded's work "has ushered in a revolution in cryptography, in both theory and practice. On the theoretical side, LWE has served as a simple and yet amazingly versatile foundation for nearly every kind of cryptographic object imaginable.[…] Toward the practical end, LWE and its direct descendants are at the heart of several efficient real-world cryptosystems."

Sylvia Serfaty has been named a 2018 Simons Investigator from the Simons Foundation. Per the citation, "Sylvia Serfaty works on understanding the behavior of physical systems via the tools of mathematical analysis, partial differential equations and probability. … She has recently turned her attention to the statistical mechanics and dynamics of Coulomb-type systems and other many-particle systems with long-range interactions." Additionally, Sylvia will be a 2019 invited speaker at the International Congress on Industrial and Applied Mathematics.

Joel H. Spencer has been named a 2018 Fellow of the Society for Industrial and Applied Mathematics (SIAM) in a class of 28 scholars chosen for their "exemplary research" and "outstanding service to the community." As stated in the citation, Joel was selected for his "contributions to discrete mathematics and theory of computing, particularly random graphs and networks, Ramsey theory, logic, and randomized algorithms" as well as for his service, including terms as "Vice-Chair and then Chair of the SIAM Activity Group for Discrete Mathematics in the group's early years" and involvement in organizing two SIAM Discrete Math conferences.

Olof Widlund was named a 2019 Fellow of the American Mathematical Society for his "contributions to numerical analysis of domain decompositions within computational mathematics and for incubation through his writing and mentorship of a broad international, creative community of practice applied to highly resolved systems simulations."

ALUMNI NEWS

In a cohort of 7, Ming-Chih Lai has been named a National Chair Professor by the Ministry of Education in Taiwan. Lai, Chair Professor and Founding Director of the Center of Mathematical Modeling and Scientific Computing (CMMSC) at National Chiao Tung University, received his Ph.D. in Mathematics from Courant in 1998, advised by Charlie Peskin. The National Chair Professorship is the highest honor bestowed by the Ministry of Education in Taiwan and is extended to "exemplary role model[s]" in the academic community.

Congratulations to our 2018 Courant Prize and Fellowship recipients!

Henning Biermann Award
Zvonimir Pavlinovic

Sandra Bleistein
Emily Denton

Thomas Tyler Bringley Fellowship
Jinzi Huang

Hollis Cooley Prize
Dominic Louis Wynter

Janet Fabri Prize
Noah Stephens-Davidowitz

Kurt O. Friedrichs Prize
Oliver Conway
Alexander Kaiser

Max Goldstein Prize
Parker Hollingsworth
Cole Smith
Rayat Mubassir Rahman

Harold Grad Memorial Prize
Brett Bernstein

Moses A. Greenfield Research Prize
Kevin DallaSanta

Martin and Sarah Leibowitz Graduate Prize for Quantitative Biology
Karen Ong

Wilhelm Magnus Memorial Prize
Federico Buonerba
Reza Gheissari

Matthew Smosna Prize
Ankit Vani
Srivas Venkatesh

Master's Innovation Prize
Saniya Lalani
Sohil Sunil Shah
Neeraj Patil

Computer Science Master's Thesis Prize
James Bannon

Math Master's Thesis Prize
Kaiqi Yang

Math Master's Thesis Prize
Kaiqi Yang

Math

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Blaise Delmotte

Cathleen Synge Morawetz Postdoctoral Fellowship
Thomas Leblé

Isaac Barkey and Ernesto Yhap Fellowship
Brett Bernstein

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Jeffrey and Denise Rosenbluth Fellowship
Montacer Essid

Computer Science

Jacob T. Schwartz Fellowship
Abhinav Tamaksar

NYU Courant Institute Hedwig Kurzbart Master's Fellowship
Puneet Kaur

NYU Courant Institute Joann and Stanley Benson Master's Fellowship
Jonathan J. Rodriguez

NYU Courant Institute M. Michael Waller Master's Fellowship
Jiadong Zhu

Congratulations to our 2016-2017 Ph.D. Graduates!

COMPUTER SCIENCE

Huxley Bennett
On quadtrees, Voronoi diagrams, and lattices: Results in geometric algorithms
ADVISOR: Chee Yap and Daniel Dadush
PLACEMENT: Postdoc, Northwestern University

Kai Cao
Improving event extraction: Casting a wider net
ADVISOR: Ralph Grishman
PLACEMENT: Deep Learning Scientist, Cambria Health Solutions

Chaya Ganesh
Zero-knowledge proofs: Efficient techniques for combination statements and their applications
ADVISOR: Yevgeniy Dodis
PLACEMENT: Postdoc Researcher, Aarhus University Denmark

Aleksandr Golovnev
Circuit complexity: New techniques and their limitations

ADVISORS: Yevgeniy Dodis and Oded Regev
PLACEMENT: Research Scientist, Columbia University and Yahoo Research

Michaël Mathieu
Unsupervised learning under uncertainty
ADVISOR: Yann LeCun
PLACEMENT: Research Scientist, DeepMind

Julian Panetta
Fine-scale structure design for 3D printing
ADVISOR: Denis Zorin
PLACEMENT: Postdoc, École Polytechnique Fédérale de Lausanne.

Noah Stephens-Davidowitz
On the Gaussian measure over lattices
ADVISORS: Yevgeniy Dodis and Oded Regev
PLACEMENT: Postdoc, Princeton University

Laura Zaremba (Florescu)
Random growth models
ADVISOR: Joel Spencer
PLACEMENT: Engineer, Groq Inc.

MATHEMATICS

Onur Alper
Topological defects in nematic liquid crystals
ADVISOR: Fang-Hua Lin
PLACEMENT: Visiting Assistant Professor, Purdue University

Benjamin Blum-Smith
Two inquiries about finite groups and well-behaved quotients
ADVISORS: Yuri Tshinkel and Fedor Bogomolov
PLACEMENT: TED Resident

Noah Brenowitz
Data analysis and non-local parametrization strategies for organized atmospheric convection
ADVISOR: Andrew Majda
PLACEMENT: Postdoc, University of Washington

Weikun Chen
Data driven optimal transportation and its application
ADVISOR: Esteban Tabak
PLACEMENT: Associate, Credit Suisse

Thomas Conway
Asymptotics of polynomials orthogonal with respect to a logarithmic weight
ADVISOR: Percy Deift

Giulia DeSalvo
Theory and algorithms for learning with stratified decisions
ADVISOR: Mehryar Mohri
PLACEMENT: Google Software Engineer

Yilun Dong
A new VIX pricing model
ADVISOR: Marco Avellaneda
PLACEMENT: Strategist, Morgan Stanley

Nadejda Drenska
A PDE approach to a prediction problem involving randomized strategies
ADVISOR: Robert Kohn
PLACEMENT: Postdoc, University of Minnesota

Sylvester Eriksson-Bique
Quantitative embeddability and connectivity in metric spaces
ADVISOR: Bruce Kleiner
PLACEMENT: Assistant Adjunct Professor and NSF Postdoctoral fellow, UCLA

Robert Friel
Optimization closures for mixing shocks in stratified hydrostatic flows
ADVISOR: Esteban Tabak
PLACEMENT: Data Scientist, 98point6

Hang Fu
Division polynomials and intersection of projective torsion points
ADVISOR: Fedor Bogomolov
Postdoctoral Fellow, National Center for Theoretical Sciences

Jihun Han
Spontaneous oscillation and fluid-structure interaction of cilia
ADVISOR: Charles Peskin

Halyun Jeong
On fast phase retrieval, efficient quantization for phaseless measurements, and elimination of spectral tones in Sigma-Delta modulation
ADVISOR: Sinan Gunturk
PLACEMENT: Postdoctoral fellow, University of British Columbia

Alexander D. Kaiser
Modeling the mitral valve
ADVISOR: Charles Peskin
PLACEMENT: Postdoctoral Scholar, Department of Cardiothoracic Surgery, Stanford University School of Medicine

Simeng Kuang
Two topics in data analysis: Sample-based optimal transport and analysis of turbulent spectra from ship track data
ADVISOR: Esteban Tabak

Flavien Léger
On the mixing of incompressible flows and on the geometry of regularized optimal transport
ADVISOR: Nader Masmoudi and Alfred Galichon
PLACEMENT: Assistant Adjunct Professor, UCLA

Zhuoran Lu
Properties of soft maps on Riemannian manifolds
ADVISOR: Fang-Hua Lin
PLACEMENT: Associate, The Goldman Sachs Group, Inc.

Mihai Nica
Non-intersecting random processes and multi-layer random polymers
ADVISOR: Gérard Ben Arous
PLACEMENT: NSERC Postdoc, University of Toronto

Ethan O'Brien
Rods with misfit and twisted ribbons; two problems in the mechanics of thin elastic objects
ADVISOR: Robert Kohn
PLACEMENT: Postdoc, Carnegie Mellon University

Liming Pang
Some relations between genus 0 and genus 1 configuration spaces
ADVISOR: Sylvain Cappell
PLACEMENT: Visiting Instructor, New York University

Moumanti Podder
The strange logic of Galton-Watson trees
ADVISOR: Joel Spencer
PLACEMENT: Postdoc, Georgia Institute of Technology (2017-2018) and Acting Assistant Professor, University of Washington (2018-2020)

Di Qi
Strategies for reduced-order models in uncertainty quantification of complex turbulent dynamical systems
ADVISOR: Andrew Majda
PLACEMENT: Postdoc, New York University

Alex Rozinov
Statistics of random sorting networks
ADVISOR: Percy Deift

Levent Sagun
Explorations on high dimensional landscapes: Spin glasses and deep learning
ADVISORS: Gérard Ben Arous and Yann LeCun
PLACEMENT: Postdoc, French Atomic Energy Commission (CEA) in Saclay and École Polytechnique Fédérale de Lausanne

Jim Thomas
Wave-vortex interactions in rotating, stratified, and compressible flows
ADVISORS: Oliver Bühler and Shafer Smith
PLACEMENT: Postdoc, Woods Hole Oceanographic Institution and the Department of Oceanography, Dalhousie University

Jun Wang
Integral equation methods for the heat equation in moving geometry
ADVISORS: Leslie Greengard
PLACEMENT: Flatiron Research Fellow, Simons Foundation

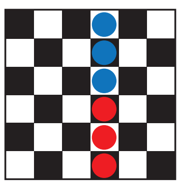
Qiu Yang
Multi-scale models for the scale interaction of organized tropical convection
ADVISOR: Andrew Majda

Scott Yang
Theory and algorithms for dynamic and adaptive online learning
ADVISOR: Mehryar Mohri

Polychromatic Choreography

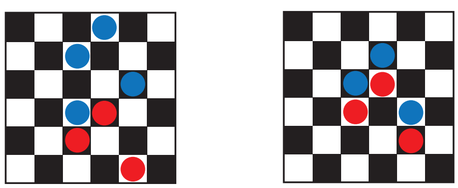
By Dennis Shasha, Professor of Computer Science

A certain modern dance choreographer has her dancers wear k different-colored leotards. For example, when k is 2, half the dancers wear red and the other half wear blue. In general, there are k colors with n dancers wearing each color. The basic algorithmic problem she has to solve is how to instruct her dancers to move in synchrony from some given configuration to a configuration in which the dancers form disjoint vertical or horizontal line segments, with each line segment consisting of one dancer from each of the k colors in any order—a "perfect lineup." A movement of one dancer consists of a horizontal or vertical step.

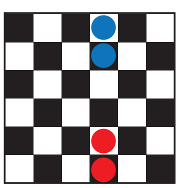


Warm-Up. Consider the following configuration of six dancers on a grid, where three wear blue leotards and three wear red leotards. Can you achieve a perfect lineup in just two synchronized moves?

Solution to Warm-Up

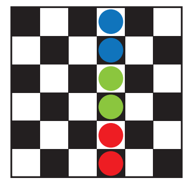


and then moving vertically

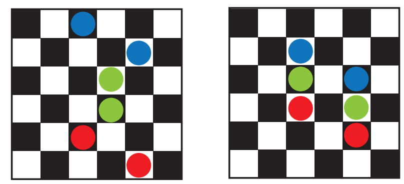


Challenge. Starting with two red and two blue dancers, now add two green dancers. We want to create two disjoint segments, each with a red, blue, and green dancer in any order, constituting the perfect lineup in this case. Note the blues and reds are two spaces apart. Where should the two greens start in order to create a perfect lineup in two steps? Show those two steps.

Solution



Here are the two steps



Upstart 1. Given an initial configurations of k colors, each with an equal number n of dancers of each color on a grid, design an algorithm that uses as few steps as possible to achieve a perfect lineup.

Upstart 2. Given k colors and n dancers of each color and a board of size BxB, find a maximally hard configuration of the dancers; a configuration c is maximally hard if c requires m parallel steps to achieve a perfect lineup and no other configuration requires more than m steps to achieve a perfect lineup.

Upstart 3. Given a maximally hard configuration with cost m, is there any way to add a k+1st color of n dancers to reduce the number of steps required to achieve a perfect lineup?

Upstart 4. How would these upstarts change if diagonal (and counter-diagonal) segments were allowed?

This puzzle also appeared in Vol. 61 No. 1 of Communications of the ACM.

THE GENEROSITY OF FRIENDS

Contributions to the Courant Institute support our academic mission

Your donations to the Courant Institute are very important and much appreciated. Unrestricted gifts to the Annual Fund support students and fellows and their conference travel, enhance extra-curricular activities such as cSplash and student clubs, and provide resources for outreach programs such as the Center for Mathematical Talent and the summer GSTEM internship program. They also enable the Institute to invite distinguished speakers for technical and public lectures, and assist in maintaining an up-to-date learning environment and comfortable public spaces in Warren Weaver Hall and other Institute spaces. Gifts to the Fellowship Fund directly underwrite the cost of education for our stellar doctoral students. And gifts to the Math Finance Fund help sustain that Masters of Science program with networking programming, guest speakers, and financial aid. Your investment in virtually any field of inquiry, area of study or activity of the Courant Institute is welcome.

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The Courant Institute recognizes with gratitude the following alumni, faculty, parents, and friends who made gifts during the 2018 fiscal year (September 1, 2017–August 31, 2018). Special thanks to members of our Sigma Society—indicated by a Σ—donors who have given in any amount in each of the last five years.

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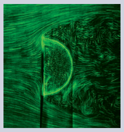

The Physics of Blowing Bubbles
A team of researchers with Courant's Applied Math Lab, including Professors Leif Ristroph and Michael Shelley, have uncovered the physics and mathematics of blowing bubbles. The experiments used a wand that suspends an oil film in flowing water (see photo) as a stand-in for soap films in air. "We can now say exactly what wind speed is needed to push out the film and cause it to form a bubble, and how this speed depends on parameters like the size of the wand," says Leif, as reported in an article in *Ars Technica*. And in another article in *Popular Science*, he says, "Films as materials behave strangely as you push on them with a flow [...] As you increase the flow speed, the film does not deform much at all until just before it's ready to bubble or pop, then it deforms all at once." The work was inspired by Richard Courant's famous 1950s "soap bubble experiments," and the new results could have implications for the industrial production of many consumer products. Read more about the work in NYU's news release at **https://bit.ly/2NorQUg**.

Correction
Our last issue incorrectly referred to Cathleen Morawetz as the first female recipient of the National Medal of Science. She was, in fact, the first female mathematician to receive the National Medal of Science.

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