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How to build a heart:
Dave McQueen retires

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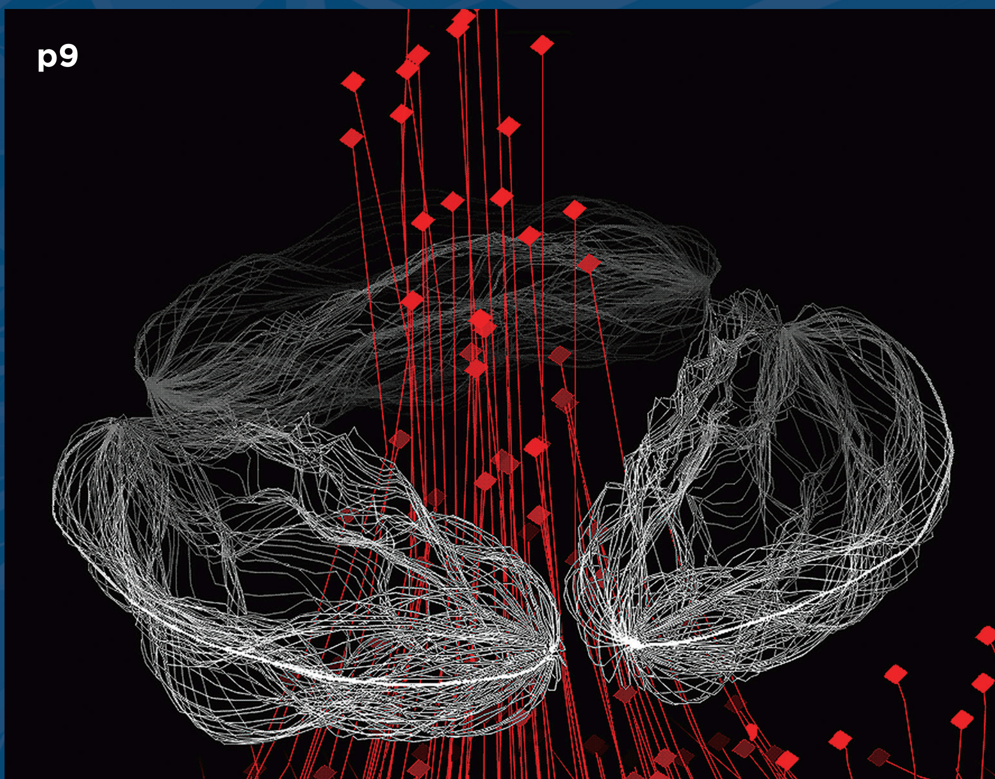

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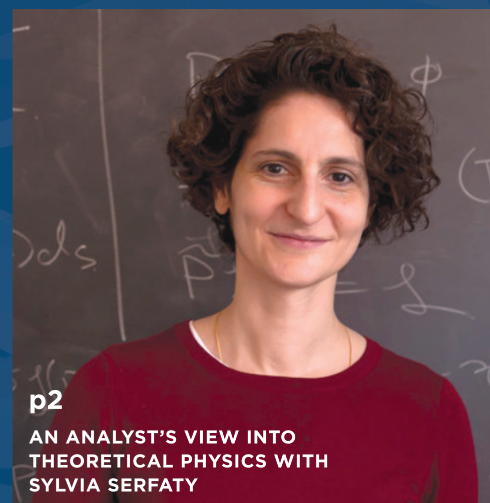

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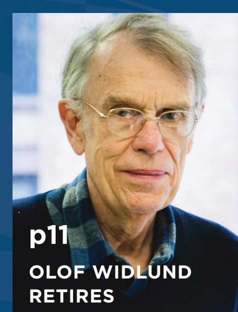

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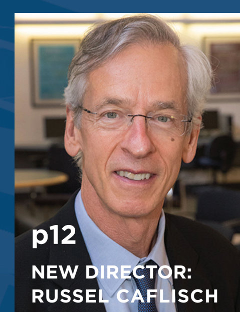

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An analyst's view into theoretical physics

With Sylvia Serfaty

by April Bacon

Sylvia Serfaty teaches Advanced Topics in Analysis. Photo on cover: Stefan Falke

Mathematicians can have different kinds of intuition, says Professor Sylvia Serfaty, and finding the area for which one is suited may take time. By both trial and chance, during her doctoral studies, Sylvia found what came most natural to her: analysis. Originally attracted to pure math, at a certain point in her studies of algebra, she found that "it was starting to be too abstract," she says. In formal analysis courses, however, the problems at hand felt easy again. "By a series of coincidences, I took a PDE course with Fabrice Béthuel and I liked it. It seemed natural. In the end, I did my Ph.D. with him and he is the one who proposed to me that subject of research [on the Ginzburg-Landau equation of superconductivity]."

Just two years after attaining her doctorate, in 2001, Sylvia joined the Courant Institute faculty. Starting in 2008, she spent 8 years as a Professor at the University of Paris 6. During that time she held a Global Distinguished Professorship at Courant, so although she returned full time to the Institute in 2016, in another way she never completely left.

"Yes, I was never fully out!" she says. "But it's a pleasure being back in New York and at the Institute."

Sylvia's work has deepened and refined our theoretical understanding of certain classic problems derived from physics. A significant body of her research has focused on models related to superconductors—those materials used to take medical scans of the body, investigate the properties of molecules, accelerate particles in the Large Hadron Collider, confine plasma in magnetic confinement fusion reactors, and levitate high-speed trains.

First discovered by Dutch physicist Heike Kamerlingh Onnes in 1911, superconductivity occurs when certain materials — certain metals, alloys, and ceramics — are cooled to extreme low temperatures, at which point resistance to an electrical current abruptly vanishes. In a popular experiment demonstrating what is known as the Meissner effect, a superconductor will float above a magnet once it completely repels the magnet's magnetic field. In Type II superconductors (which can be made from certain alloys), a magnetic field will penetrate the body of the superconductor in the form of magnetic flux vortices. As the applied magnetic field is increased, so are the number of vortices, until a critical point is reached and superconductivity is lost. Type II superconductors can withstand much more powerful magnetic fields than Type I, and are the kind used in technological applications such as those listed above.

In the late 1950s, building on the Ginzburg-Landau model of superconductivity, Alexei Abrikosov formulated the theory of Type II superconductors, demonstrating that when vortices form, they will arrange themselves in triangular arrays that are now known as Abrikosov lattices. What he predicted was observed in experiments a decade later. The triangular lattice is thought to be the most energetically efficient arrangement. "The vortices repel each other," Sylvia explains. "But on the other hand, the magnetic field confines them. It's sort of like people who don't like to be close but are confined together. The best arrangement they find is to put themselves in these triangular lattices."

In a series of works, Sylvia and collaborator Etienne Sandier (University of Paris XII) showed that a simplified model can be extracted from a physics model of superconductivity by reducing the vortices in size to points. "We derived this reduced problem which is a discrete problem on infinite configurations of points in the plane," she says. Deriving a reduced model is essentially reducing the original minimization problem to a simpler one. Looking for a minimum is like, by analogy, looking at all the temperatures of a given day and searching for the lowest point, says Sylvia. "We believe the minimum is achieved at the triangular lattice, but proving something like that is hard," and related to some important conjectures in number theory.

From their derived model, "What you see is that the point vortices behave […] like electrostatic charges. That is, their interaction is logarithmic," just as are the interactions between, say, electrons confined to a conducting surface.

Via a systematic analysis of the Ginzburg-Landau model, Sylvia and Etienne were able to provide a rigorous mathematical foundation for this tendency of magnetic vortices to form Abrikosov lattices, as well as the intensity of a magnetic field required for the vortices to form, and the number that will appear.

Sylvia's work related to these theories has earned her awards such as the prestigious Henri Poincaré prize (2012), "for her outstanding work on the theory of Ginzburg-Landau equations, including remarkable progress towards the rigorous proof of the onset of the Abrikosov lattice in the theory of superconductivity."

In a second line of work, Sylvia has described the dynamics of the vortices—how they move when allowed to relax over time until they reach a state of equilibrium. "Instead of describing all the points you just want to understand the force that the vortices collectively create," she says. "It turns out that the equations that govern the motion are very much like fluid equations." In 2016, Sylvia proved that in some instances, "the Euler equation—the standard equation for incompressible fluids in a 2-dimensional domain—can be derived as a limit of the time-dependent Schrödinger version of the Ginzburg-Landau equation."

Systems of points with logarithmic—or, more generally, Coulomb—interactions, turn out to also be important in other problems within theoretical physics, such as the fractional quantum Hall effect and random matrices. "They arise as particular ensembles of statistical mechanics called log gases or Coulomb gases," says Sylvia. "You take a very large matrix and draw the entries to be random, complex iid [independent, identically distributed] Gaussians, you compute the eigenvalues, and you find that the eigenvalues are points in the complex plane which repel each other exactly like the vortices." One of the main questions to be answered about these systems is, does a critical temperature exist below which the system crystallizes, i.e. below which it gets ordered, or even forms lattices?

Sylvia and Courant Instructor Thomas Leblé looked at these systems of interacting points in which temperature is added to create some disorder. "When you zoom down, these points are very close together," says Sylvia, "but if you zoom out, what are the patterns that you see? What we believe is that if temperature is very small, then indeed you will see something very ordered, like a crystal. We prove that when temperature is very small, the system is more ordered, and when temperature increases, it is more and more disordered."

"With the language of large deviations, we have a way of measuring the fact that there is more disorder. What we essentially prove is that when the temperature tends to infinity in some suitable units, then the particles don't seem to remember that they repel each other. They're just living their own lives."

The relationship between increased temperature and disorder is well-known within one-dimensional systems, and Sylvia and Thomas have proven a formal relation between the two in a more general setting. "It's one of the first hints of that relationship—a clear indication," says Sylvia.

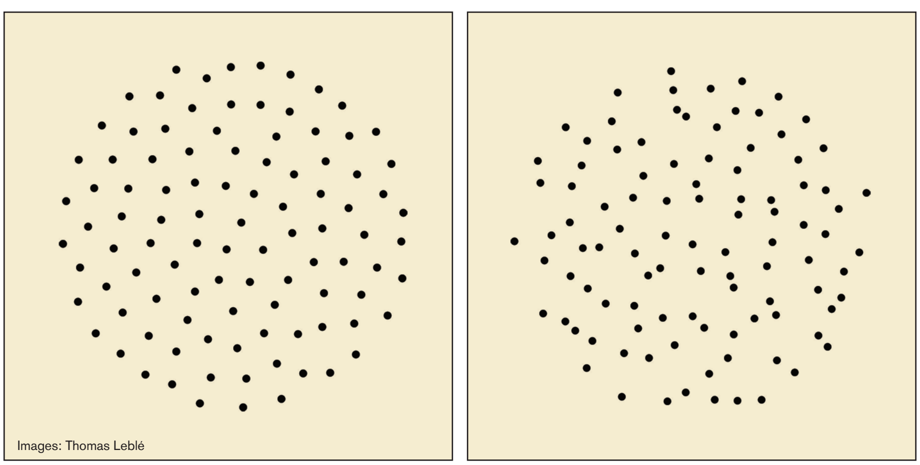
She first began working in this area of statistical mechanics in 2009. "I wasn't in my comfort zone. I had to pick up a whole new literature, meet new people, learn new things, new techniques. And I enjoyed that sense of renewal," she says. "And now I'm quite occupied with these problems of statistical mechanics. I approach them with the point of view of a mathematician with the tools of partial differential equations, functional analysis, calculus of variations, and more recently probabilistic tools. I'm sort of an analyst at heart with an interest in physics. And with expanding my toolbox into neighboring disciplines, I'm particularly interested now in the interface between analysis and probability." Sylvia also notes that there are several other faculty members—Gérard Ben Arous, Paul Bourgade, Percy Deift, and Ofer Zeitouni—at Courant working on random matrices. "They are all experts with different points of view. It's very interesting for me to be here in that sense."

"It's a great place to be," she says of the Institute. "A place with so much history in math and a particular spirit of collegial work. I think people put the interests of the Institute ahead of their personal interests. We see there's a collective endeavor. I also like the fact that compared to many departments, there are no formal boundaries between different types of math. You always have someone to talk to on any topic."

This approach to mathematics goes back to Richard Courant and the earliest faculty members he brought to NYU. "This was completely novel at the time," says Sylvia. "I really admire the pioneers of Courant, the older generation," she continues, gesturing to the wall that adjoins her office with the office of professor emeritus Peter Lax.

"The fact that this was created by refugees from the second world war—if you teach about the history of the Courant Institute, it was about that. It was people fleeing from Europe, who restarted from scratch. They had to build something new. I think that this really creates a soul for the place," she says.

"When you hear the old guys talk about it—it was like one big family supporting each other. I think that this history is in the DNA of the place. I feel it intuitively."



Images: Thomas Leblé

Points form triangular lattices. As temperature lowers (left), the points become more rigidly arranged and at higher tempratures (right) the lattice patterns begins to relax. When an external magnetic field is applied to a Type II superconductor, vortices also form a triangular lattice.

Courant at the Center for Data Science

by April Bacon

Four additions to the faculty prepare to welcome the CDS's first class of Ph.D. students. In research, they are making theoretical gains with application to diverse areas such as high energy particle physics, machine translation, and medical imaging.

Joan Bruna, Carlos Fernandez-Granda, Afonso Bandeira, and Kyunghyun Cho outside of 60 5th Avenue.

Assistant Professor Joan Bruna was doing Data Science before he knew it. That is, the still evolving field is so new that when he was an undergraduate student working at a startup company in the early 2000s, the name of the field hadn't yet taken hold. At that company, he explains, "we were doing signal processing applied to, for example, medical imaging and consumer television. Signal processing is a branch of applied mathematics that deals with noisy data and complicated high dimensional data; for me, these are already a form of data science but at the time we didn't know."

A similar story can be told across many fields of academic inquiry, as so many disciplines have been pursuing research directions in response to massive datasets. When NYU established the Center for Data Science (CDS) in February 2013, it was therefore already well-poised to create an interdisciplinary environment involving not only the departments of mathematics and computer science, but also, for instance, biology, business, education, law, medicine, physics, politics, and public health. Now, within the newly renovated Forbes building on 5th Avenue, theory and application meet, feed off one another, and innovate data science *in situ*. Four new Assistant Professors at Courant in affiliation with the CDS—Joan, Afonso Bandeira, Kyunghyun Cho, and Carlos Fernandez-Granda—were all in part drawn to Courant and the CDS for this reason.

"It's really rewarding when you see that a method you came up with can be applied to real data, and then that actually changes the world," says Kyunghyun.

From a theory standpoint, "It's crucial to be involved in projects that involve real data and applied scientists," says Carlos. "The environment for that is spectacular here."

This spring, Afonso, Carlos, and Joan initiated the Math and Data Group (MaD), which is designed "exactly for this purpose of cross-fertilization," says Afonso. MaD welcomes faculty, students, and other members of the NYU community interested in the marriage between data science theory and application for reading groups and a weekly seminar series that kicked off in January with a guest lecture by Dave Donoho (Stanford).

The CDS launched its Master of Science and Data Science program—the first of its kind—in September 2013 and this upcoming September, it will welcome its inaugural group of Ph.D. students. The four faculty members are unanimously excited for the arrival of the Center's first doctoral class of students, who will provide a kind of connective tissue for a wide range of research endeavors. Their presence will be "fundamental to the Center for Data Science," says Carlos. "Not only because they will channel a lot of the research and the collaborations between different faculty, but because they'll bring more life to the CDS."

As the Center heads into its fifth calendar year, we take a look at some of the research projects of these four recent additions to Courant and the CDS.

Optimizing medical imaging

with Carlos Fernandez-Granda

In collaboration with the NYU Radiology department, Carlos is working on techniques for determining what type of tissue is present in each pixel of an MRI image. Using techniques from optimization, algorithms can determine whether a scan of the brain, for example, contains gray matter or white matter, which is useful for diagnostics.

"If there is just one tissue in the pixel, you can get away with comparing your data with the elements of a precomputed dictionary and then choosing the element that is closer to your data. This is called MR fingerprinting," says Carlos. "If you have two tissues, you have to determine which two or more elements in the dictionary can be combined linearly to produce your data, and that is significantly more complicated. It is essentially a sparse estimation problem where the objective is to fit the data with a small number of predefined functions." Carlos and collaborators have been able to leverage an optimization technique to solve the problem and fit models with several tissues per pixel.

The model has had success on some preliminary data, and Carlos and collaborators are working to make it more robust. "In particular, we need to do more experiments with *in vivo* data, which means data taken out of actual subjects," he says.

Sparse estimation is a common theme in another project he is working on with Brett Bernstein, a current Ph.D. student. The work concerns estimation of a sparse signal from samples of its convolution with a smoothing kernel, a problem that arises in many signal-processing applications. The pair are analyzing a popular method to tackle this problem: l1-norm regularization. Despite having been introduced in the 70s and 80s by geophysicists working on reflection seismology, the performance of this technique is not well understood theoretically. Carlos hopes to apply the insights to spike sorting, a major challenge in neuroscience. "Spike sorting is necessary when electrodes pick up signals from different neurons," he says. "We can model such data as a convolution of different waveforms with the spikes corresponding to each neuron, so teasing them apart is equivalent to a deconvolution problem. We hope to leverage insights from our theoretical work to this application."

Detailing microscopic structures

with Afonso Bandeira

In electron microscopy, a beam of electrons is shot through a biological sample, both illuminating microscopic structures and damaging or destroying them in the process. An innovation to this technique known as cryo-electro microscopy (cryo-EM) fortifies the samples against the beam's radiation by first freezing them to cryogenic temperatures. Cryo-EM, chosen by *Nature* as their 2015 Method of the Year for enabling "impressive leaps in achievable resolution," has led to detailed structures of molecules, viruses, and the machinery of cells to a degree not possible before.

Images captured by cryo-EM, though, are extremely low quality, and data across images is mismatched as there is no way to control the position of the sample before the image is taken. "We have tons and tons of pictures taken from different angles, all very poor quality, and we have to estimate the tridimensional molecule density from these," says Afonso. "It is like building a million-piece three dimensional puzzle without the image on the box, where each piece is so noisy that one can barely tell, at naked eye, whether there is actually anything in the image or it is just random noise."

Traditional approaches use what Afonso calls a "rinse and repeat" process of aligning an image to a former estimate, updating the estimate, then repeating—but this iterative process is biased to the original model and so risks falsely confirming it. Afonso and collaborators have developed algorithms for aligning the images without using prior models. Their approach uses synchronization methods that align the angles of the images.

With different collaborators, Afonso has also applied similar tools to a synchronization problem in robotics: If a robot is self-navigating roads and taking pictures, for example, it has to simultaneously know the map of its location and know where it is in that map. As the robot moves in-between taking pictures, the images need to be properly aligned to accurately construct a map.

Afonso is also interested in understanding why and when these hard synchronization problems turn out to be not as difficult as imagined. "We have a certain understanding of which problems are easy, which ones are hard. But this understanding is being challenged. Often, problems are not as hard as one might believe," he says. He provides a loose analogy to approximately illustrate how this could be possible: Imagine you're trying to make your way to the lowest point of an immensely complex mountain range. "Because there are so many dimensions, when you're looking around to walk, the chances that every single direction will point up is very slim. You expect that at least one direction will point down and you can make progress there." He and collaborators have proven that in some instances of the problem, there won't be any obstructions to progress, and they are continuing to work on determining when and why these seemingly intractable problems turn out to be solvable.

Training a multi-lingual machine

with Kyunghyun Cho

An ultimate goal of Natural Language Processing is to develop artificial intelligence agents that can consume and understand all the knowledge contained within digital texts. It's a grand challenge, but Kyunghyun Cho and collaborators have made a natural first step by building a multi-lingual machine translation system. The researchers built their system on recurrent neural networks, one of the latest advances in deep learning. Their method was quickly picked up for major translation services by Google and Microsoft, and has become the standard in machine translation.

The previous dominant framework, phrase-based translation, worked by using a parallel corpus—a very large assemblage of texts with paired phrases from one language to another. Every language pairing requires its own parallel corpus, and the system translates a given sentence by considering phrases rather than a whole sentence.

The layered approach of neural networks allows the new system to read the source text one character at a time, remembering each part of a sentence as it advances to the end. "The translation of each word depends on the full sentence," says Kyunghyun. "And it makes this model much better at deciding or disambiguating among multiple possible dictions."

Another benefit of using a neural network is that "we can ask our neural net to map all those sentences in different languages to some shared, hidden representation space," says Kyunghyun. "We can think of that internal state as a kind of shared space across multiple languages." The neural network projects all words from every language it learns into this shared space, linking words or phrases with similar meanings in proximity, regardless of the language to which they belong. This means that if, for example, the system has only been taught English to French translation and French to Spanish translation, then it can also translate English to Spanish without extra steps because of the way all languages are networked together in the shared multi-lingual space. This final translation is not as accurate as the ones for which the machine has direct data, so Kyunghyun and collaborators are continuing to fine tune this work.

Additionally, the content of the data the system receives matters, but the form of that data does not, meaning that it can handle multi-modal translation involving images and videos. "The data we start with is, let's say, images and captions from Flickr," says Kyunghyun. "So we downloaded all the images and captions and then try to train the neural net to go from an image to the corresponding caption." This kind of technology has now been rolled out in practice by companies such as Facebook.

"I think we have made a small step toward the ultimate language-understanding machine," says Kyunghyun. ■

Isolating particles through the noise

with Joan Bruna

Neutrinos are created in nuclear reactions, such as in stars, supernovae, and nuclear bomb explosions, and by the decay of radioactive elements. These nearly massless particles with zero charge are difficult to detect, but a powerful telescope at the Lawrence Berkeley National Laboratory's IceCube Observatory in Antarctica is set to track them. Every day it picks up about 275 atmospheric neutrinos in a sea of 275 million cosmic rays.

The Large Hadron Collider (LHC) accelerator in Switzerland, which in 2012 famously created what is largely believed to be a Higgs boson particle, provides a similar mass of data. When the accelerator "crashes" particles together, it creates a "fireworks of particles," says Joan. Every second, 40 million packets of protons collide at the center of the ATLAS detector. "When there's the proper configuration, these explosions create a new particle," he says. No human could sift through the massive amounts of data generated by the IceCube and the LHC to isolate the small number of events significant for study.

"You need to have a machine that is able to take these events and classify whether they are interesting or not," says Joan, who is associated with both high-energy physics experiments. "Physicists have these very sophisticated simulators that solve all the PDEs [partial differential equations] that are very involved in particle dynamics to construct these events." Once constructed, Joan's contribution is building the neural network that will be able to make sense of the experimental data.

A class of algorithms at the forefront of research in deep machine learning, the structure of a neural network is inspired by neurons in the visual cortex. The main feature of these networks is that they are organized in layers: Each layer is computed in turn, going deeper with each operation. One of Joan's tasks is to work out how to build prior information—in this case, the relevant laws of physics—into the architecture of the neural network. Prior information is "fundamentally important" to machine learning, says Joan. It introduces into the model what is referred to as inductive bias—if done correctly, inductive bias can lead to significant gains in optimizing the model; that is, it can allow the neural network to learn the data and produce answers more efficiently. "You will do much better with far less amount of data," he says.

Joan is also interested in understanding one of the big, open theoretical questions in deep learning: the theory of optimization. "You can think of learning as a dynamical process," says Joan. "You need to understand not just the architecture but also the learning process [itself]." Cracking the question of optimization in these models would enable researchers to identify cases in which deep learning is expected to succeed, where it might get stuck, and at which point the learning process cannot be pushed any further.

Computer Science department moves into former Forbes building

The new home of computer science at 60 5th Avenue.

Photos: © NYU Photo Bureau: Gallo

This past January, the Computer Science (CS) department moved into the former Forbes building on 5th Avenue, a ten-minute walk from Warren Weaver Hall. For over thirty years, the department occupied space at Warren Weaver and at 715-719 Broadway. With both spaces already at capacity and the latter needing extensive renovations, the new space has solved many challenges. Additionally, it's offered many new benefits, such as close proximity to the Center for Data Science (CDS). The CDS is collocated with Computer Science at 60 5th Ave., which greatly enhances opportunities for collaboration across departments and schools, in particular the Stern School of Business and Tandon School of Engineering.

The new space allowed the department to bring together systems and formal methods and verification groups (previously split between Warren Weaver and the Broadway building), strengthening already developing research connections.

The space is newly renovated and configured in a way that will facilitate future expansion. With accessible, open common areas, and many glass-walled offices, the space has been designed to let light in. "We aimed to design a space where people will just naturally run into each other," says Denis Zorin, chair of the department, who explains how beneficial the new space has been in fortifying the department's research activities and recruiting efforts. 60 Fifth Avenue also creates a second location, in addition to Warren Weaver, with a large number of classrooms for which CS has priority access.

The new home of computer science includes an improved hardware lab for faculty working in areas such as digital fabrication and robotics, and an improved and expanded space for Virtual Reality research. Additionally, a server room has been built that can accommodate the increasing computational capacity required for research activities in AI, distributed systems, and networks.

A Rare Event: *Celebrating Raghu Varadhan's 50 years on the faculty*

> "To me, beauty in mathematics comes from unification and simplicity. When a simple underlying idea can explain many complex things, it is almost like watching a magic show."
>
> — S.R.S. Varadhan,
> *Asia Pacific Mathematics Newsletter* (2012)

Raghu (center) and grandson Liam listen to remarks. Gérard Ben Arous (at left), Interim Director Richard Cole, Henry McKean, Charlie Peskin, Jalal Shatah, Marti Subrahmanyam, and Rangarajan "Raghu" Sundaram (NYU Stern) gave speeches at the celebration in November.

S.R. Srinivasa "Raghu" Varadhan, Frank J. Gould Professor of Science and professor of mathematics, joined the Courant Institute as a postdoc in 1963 and was hired onto the faculty three years later. Since then, his singular work and generous service have been paramount in building the Courant Institute and the field of probability theory into what they are today. This past November, the Institute had the opportunity to host a gathering at Warren Weaver Hall to celebrate Raghu, a rare mind who has given deeply of his time and wisdom for over half a century.

Born in Chennai (formerly Madras), India, Raghu received his Bachelor's and Master's degrees in Statistics from Presidency College of the University of Madras (1959 and 60, respectively). Recollections he recently offered reveal a collaborative, people-centered focus that has persisted across the decades: "When I started out in India, I was with a small group of graduate students and we taught each other whatever we could and worked on problems that we ourselves generated. This taught me that mathematics was 'fun' and it was particularly enjoyable when working with someone."

In 1963, Raghu received his Ph.D. from the Indian Statistical Institute in Kolkata (1963), advised by C.R. Rao. Rao timed Raghu's Ph.D. defense so that famous Russian probabilist Andrey Kolmogorov could sit on the committee. After returning to Moscow with Raghu's thesis in hand, Kolmogorov sent a report, saying: "This is not the work of a student, but of a mature master." That same year, Raghu joined the Institute, hired as a postdoc on the Alfred P. Sloan Foundation grant that, just a year before, brought Monroe Donsker to the Institute's as its first faculty member in probability theory.

"When I came in the sixties there was no Warren Weaver Hall," Raghu says. "We were split between 4 Washington Place and 25 Waverly Place. It was hard to run into people by chance. But it all changed when we moved to Warren Weaver [in 1965]."

In probability theory, "the big names are few," says Professor Gérard Ben Arous. "You have people like Paul Lévy in France, Kolmogorov in Russia, and [Kiyosi] Itô in Japan, and then Raghu. Raghu came later, but has completely changed the field. He is by far the most important probabilist today, and has been for a very long time."

In 1966, Raghu introduced a unified theory for large deviations, which analyzes rare events and which, since then, has become a cornerstone of probability theory. In the 1930s, Harald Cramér made the first precise estimates of large deviations to determine the probability of certain rare events in the insurance industry. Thirty years later, Raghu saw the underlying principles of large deviations and formulated a general theory. In the 60s, "Donsker had an idea of how some function space integrals can be estimated through what we would now call large deviation ideas," says Raghu in *Asia Pacific Mathematics Newsletter.* "But it was slowly dawning on me that entropy controlled all large deviations. Almost all large deviations are shadows of 'entropy,' and although the shadow may not immediately reveal what is behind it, we can now perceive it."

Raghu and Donsker wrote a series of important papers in the 70s on large deviations, deriving the level 3 large deviation principle and applying it to hard problems in statistical physics such as the Wiener sausage problem, named after Norbert Wiener. Concurrently, Raghu was working with Dan Stroock developing a new method for defining a diffusion process using a martingale solution. Three important papers culminated with the 1979 book *Multidimensional diffusion processe*s.

In the 1980s, Raghu made foundational contributions to the theory of hydrodynamic limits for systems of many interacting particles, collaborating first with George C. Papanicolaou (Stanford) and Mao-Zheng Guo, and then others. Raghu then began to apply methods from random processes to problems coming from physics—where randomness naturally occurs—helping to push the field in that direction. A focus of Raghu's current work is on seeking to prove that a random walk in a random environment behaves like a normal random walk.

"It's now a very favorable time for probability," says Gérard, "and the choice of topics on which we are working collectively is largely due to Raghu's influence."

Raghu has received numerous awards, including a 2007 Abel Prize and a 2010 National Medal of Science. Across the decades, he has advised 36 students, many becoming leaders in their fields. He has twice served as Director of the Institute, as well as in many other roles of scientific and administrative leadership. And he has offered his time generously to mathematicians at all levels in many fields who hold a common motto shared by Gérard: "You keep your hard problems for the discussions with Raghu."

Gérard recalls that when he was working as a postdoc with Dan Stroock in the early 80s, "at some point we were stuck, and [Dan] said, 'Then I have to ask the grand master.' [Dan] called Raghu and, as predicted, Raghu—in something like half an hour—unblocked us," he says. "He's like the wise man that you go to see when you're really lost. And that's the role he plays with a lot of grace."

There was much to celebrate when the Courant community and friends gathered at the event in November. "We at the Institute always throw nice parties!" says Raghu, who was accompanied by his wife Vasu Varadhan (NYU Gallatin), son Ashok, and grandson Liam. "It was indeed a nice occasion." ■

— A.B.

Bodies in fluid motion

With Lisa Fauci (Ph.D., Math, ’86)

ALUMNI PROFILE

by April Bacon

Over her career, alumna Lisa Fauci has laid bare the motility of a broad range of organisms in fluid, including the neuromechanic locomotion of fish in water and the movement of individual bacteria between soil particles.

Lisa Fauci

Lisa Fauci, Pendergraft Nola Lee Haynes Professor of Mathematics and Associate Director of the Center for Computational Science at Tulane University, is an applied mathematician and computational scientist who works on problems in biological fluid dynamics. Throughout her career, she has advanced our fundamental understanding of a wide variety of these problems, from the movement of microorganisms — such as sperm flagella in the female reproductive tract, phytoplankton in the ocean, and bacteria colonizing a surface — to the neuromechanic locomotion of fish.

“These things seem very different, right? The underlying theme is the interaction of elastic moving objects with a fluid,” Lisa explains, “so it’s no surprise that my mentor was Charles [“Charlie”] Peskin [Silver Professor at Courant].”

Earlier in her graduate studies, Lisa was attracted to numerical analysis and scientific computing, but wasn’t sure to which problems she hoped to apply these tools. That changed after she attended one of Charlie’s lectures. In the lecture, “he motivated what he was doing by illustrating how computational models of cardiac blood flow could be used to guide design of artificial heart valves, and his explanations were so clear,” she recalls. “I was excited that I understood the goal of his work. And he also was approachable and kind. He still is approachable and kind.”

After graduating, Lisa and her husband, Victor Moll (Ph.D. in Mathematics, Courant, 1984), were offered positions at Tulane University. “We thought it would be really cool to be in New Orleans for a couple of years — that was 1986,” says Lisa. “When I first got here, I thought it would be culture shock, but in fact, the two cities are very similar. They are vibrant, cultural centers.”

For three decades, Lisa has been making waves in biological fluid dynamics. Her work has earned her distinctions including being named a Fellow of the Society for Industrial and Applied Mathematics (SIAM), elected a member of the Council of the American Mathematical Society, and selected to present the AWM (Association for Women in Mathematics)-SIAM Sonia Kovalesky Lecture, “for her pioneering contributions to mathematical and computational modeling of aquatic locomotion, microorganism motility, and fluid dynamics of human reproduction.” As the AWM-SIAM citation continues, “Her career combines rigorous asymptotic analysis and biological data to validate computational models, a history of service to the mathematical community, and a lasting legacy of mentoring early career scientists.”

“I owe my success to a few very supportive faculty,” says Lisa, naming Charlie; Ricky Pollack (her first advisor) and Steve Childress, both now Professors Emeriti; and Research Professor David McQueen.

“It’s a lifetime relationship,” she says of mentorship in mathematics. This fact was on display last July when she attended special sessions in celebration of Charlie’s 70th birthday at the SIAM meeting in Boston. “It was wonderful,” she says. “[Charlie] had an entire family there — Ph.D. children and grandchildren and nieces and nephews and all that.” One presenter, Christina Hamlet, was a Postdoctoral Fellow working with Lisa at Tulane, and is now an Assistant Professor at Bucknell University.

Addressing Charlie, who sat in the audience during her talk, Hamlet said: “We’ve never actually directly worked together, but my graduate mentor was one of your students and my postdoctoral mentor was one of your students: So, thank you for my mentors!” Hamlet was presenting research she worked on with Lisa at Tulane from 2012-2016.

In this work, which has been under way for about a decade, Lisa and collaborators are studying the neuromechanics of fish. Specifically, they are uncovering how the neural signals of the primitive lamprey (see image 1) are connected to its swimming. The lamprey swims like an eel, by wavelike undulations of its body, with no flippers or fins on the side of the body to further complicate the movement. Because the animal and its movements are relatively simple, the collaborators — including a group of neuroscientists headed by Avis Cohen (University of Maryland) — can begin to address one of the essential questions in neuroscience today: How does neural signaling give rise to animal behavior?

As Lisa explains, neural signals sent from the lamprey’s brain and down the spinal cord are continuously stimulating the body’s muscles, which affects the shape of the body. There is also a coupled relationship between the body’s passive traits (form and degree of flexibility, for example) and the fluid mechanics of its environment. The actual motion of the lamprey emerges from these complex interactions. Several pieces of this puzzle — neural signaling, muscle behavior, fluid mechanics — have been studied separately before but this group has been studying them as a coupled system.

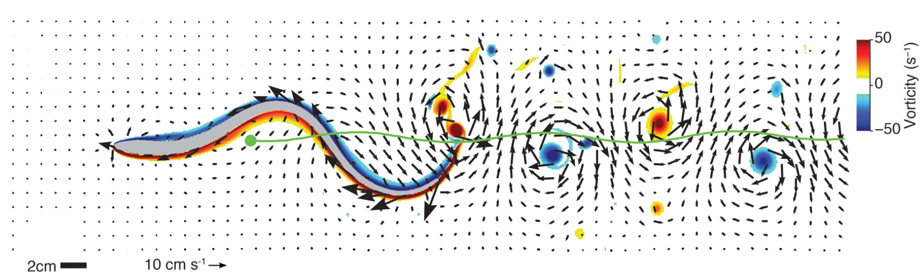
Their simulations suggest that fish with more flexible and weaker-muscled bodies are more energy efficient, but stiffer-bodied, stronger-muscled fish accelerate more quickly. By stiffening their bodies with muscle contractions, then, fish may be able to maximize acceleration when needed, then return to a more efficient state when swimming at constant speed.

“Our models are based on differential equations,” explains Lisa, who has brought her expertise as a computational fluid dynamicist to bear on the study. “We’re solving the full Navier-Stokes equations of fluid dynamics to describe the interaction of the organism with the surrounding fluid. But at the same time, we're using differential equations to model the neural signaling down the spinal cord."

In addition to neural signaling, unpacking the basic science of lamprey locomotion opens pathways to understanding other important questions, too – such as stability (which has applications to, for instance, robotics) and the regeneration of an injured spinal cord. Along with her collaborators, including Eric Tytell (a fish biologist at Tufts University), Lisa has constructed a computational lamprey model that sheds light on these questions. "We're trying to understand, in swimming, what are the internal sensory mechanisms that fish have to stabilize themselves," she says. Using a computer-modeled lamprey they built with data gathered by experimentalists, they can test how perturbations in the environment affect locomotion and how the swimming kinematics change with the modification of passive body traits. And in a second application, they hope that by computationally injuring the spinal cord of the model lamprey — by turning off certain parameters or changing its connectivity structure — they will be able to understand the effects of spinal cord injury on movement and describe neural wiring in the spinal cord.

Just this past year, Lisa began working on a project as a part of a group grant with the Gulf of Mexico Research Initiative. "I'm working with plant biologists and chemical engineers to understand the role of bacteria to clean up oil spills [in the marshy Gulf]," she says. The research centers on a type of bacteria known as endophytes, which live symbiotically with sea grasses, inside of their roots and leaf tissues. Some endophytes are capable of ingesting and metabolizing petroleum, and so offer the potential to naturally remediate polluted marsh ecosystems as an alternative to methods such as burning or raking up grasses. But there is still substantial lack of knowledge about the basic dynamics of the bacteria involved. The group is working on building a computational model for simulating how bacteria sense, move to, and ingest oil.

The juxtaposition of this work with the former on lampreys is a beautiful example of the diverse nature of research Lisa has pursued which all fit within the area of "the interaction of elastic moving objects with a fluid." Her former students and postdocs also display a great variety in their career paths. "I'm really pleased that some of them have gone on to academic jobs [as well as] to government and industry jobs," says Lisa. They are working in areas such as pharmaceuticals, plasma physics, and oncology research in universities and labs in every region across the U.S. ■



(Top) Image 1. Lampreys, the most primitive vertebrates, have been studied extensively by neuroscientists seeking to understand nerve signaling down the spinal cord.

(Bottom) Image 2. Example flow patterns around a computational lamprey. Arrows indicate flow velocity; background color shows vorticity. The green line indicates the path of the center of mass of the swimmer. (PNAS, Vol. 107, no. 46, 2010).

How to build a heart

Dave McQueen retires

RETIREMENT

After 39 years at the Institute building hearts with Charlie Peskin, Research Professor David McQueen retires.

Charlie Peskin and Dave McQueen have been building models of the heart and its valves for four decades. Dave, a Research Professor at Courant, retired in November, though the work he began doing by Charlie's side in 1977 continues. "It's been great working with him all this time," says Charlie. "It really has. And despite retirement so far, he's just continuing to do the work as diligently as before."

Dave received his Ph.D. in Mechanical Engineering from Stevens Institute of Technology in 1976. Charlie, already a faculty member at Courant, sat on his thesis committee. Dave then spent a postdoctoral year at the Albert Einstein College of Medicine with cardiac physiologist Ed Yellin, Charlie Peskin's former doctoral advisor. During that time, Dave took a course at Courant with Charlie, and when Charlie had a chance to hire someone on a National Institutes of Health grant shortly thereafter, the choice was clear.

Charlie Peskin and Dave McQueen with a model heart.

"His contributions have been everything," says Charlie. "What he's doing is really heart building." Dave constructs and validates models of the heart and its valves, including its coupled fluid, mechanical, and elastic systems; goes beyond his formal training to write computer programs for visualizing and running experiments on the models; and adapts the work to advances in computing. The models are computed with the immersed boundary method, a seminal numerical approach for simulating fluid-structure interactions that Charlie first developed in the early 70s.

"When this work began, the computer that was available to us—which was just about the fastest computer on earth—was right here in the building," says Dave. "This is a legendary computer—a CDC 6600, serial number 3!" Using the 2D model the pair built (Fig. 1), they, for example, simulated flow through an artificial butterfly bi-leaflet valve and studied a delay in the electrical signal of the heart. Cray then developed a computer with more memory, which opened the door to 3D modeling. "We made this donut-shaped fiber-wound heart [Fig. 2] and we even made the fibers active so it would pump fluid around the donut, so to speak," says Charlie.

"That was a high point for us, because it was the first time we used our method to generate three-dimensional flows," says Dave. "Then, an even larger computer became available, and we could contemplate doing a three-dimensional heart." They mathematically replicated the muscular structures of the heart as detailed in the late 1950s by Carolyn Eyster Thomas, who dissected hog and dog hearts. The model (Fig. 3) "worked like the real thing to a great extent, but it didn't look like a person's heart because it was made of cones! It turns out, you can put together a couple of simple cones that look a lot like surfaces that Thomas reported."

Their most recent model is based on CT (Computed Tomography) scans from an actual diseased heart. Although they thought they were getting healthy heart data, the size of the chambers and pressures looked off, and the Clinic that provided the scans confirmed their suspicions. Once the model was complete, "We ran a simulation—I think it was seven or eight beats long," says Dave. "Every beat looked different, and this points out the need for simulating many beats until the periodic steady state is reached. It was medically interesting to see the development of mitral regurgitation which the patient actually had" (see Fig. 4).

To build a heart, Dave segments the data by hand. He traces cross sections of the walls and finds geometric shapes to approximate the contours. "We've developed a few techniques that let you construct relatively complicated surfaces that can pass through or nearly through the curves that you've segmented," he says. Next, he constructs valves of the heart from pre-existing

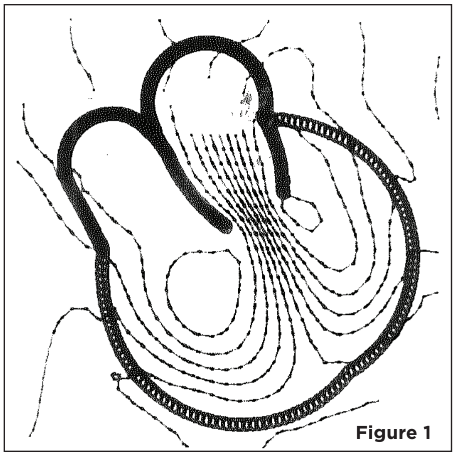


Figure 1

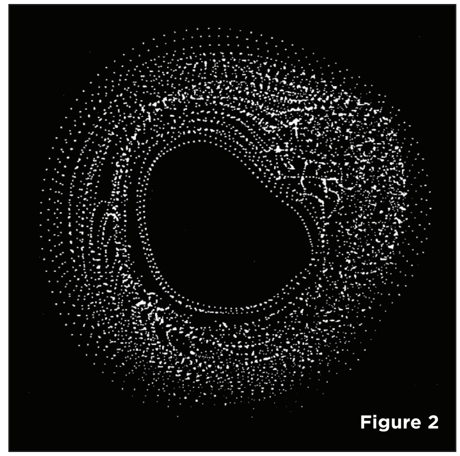


Figure 2

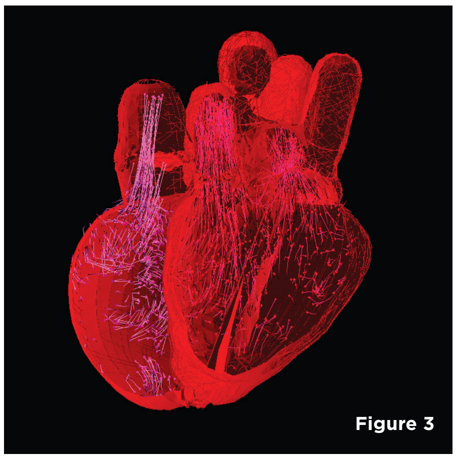


Figure 3

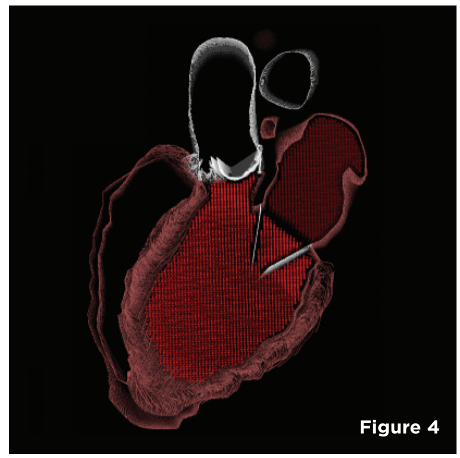


Figure 4

knowledge, sets properties such as muscle direction and stiffness, and validates the model by comparing its images or its data to the original. "If you get good agreement, that means you got a working model of the heart!" says Dave.

Boyce Griffith, a former Ph.D. student of Charlie's who is now an Assistant Professor at the University of North Carolina at Chapel Hill, joined the Institute in 2000. About three years into his studies, he began to develop simulation software called Immersed Boundary Adaptive Mesh Refinement, which is now used by the team as well as many other researchers modeling fluid-structure interactions. "Dave very patiently worked with me on getting [Charlie and Dave's 3D heart model] to work in the simulation framework that I developed," he says. "I spent a lot of time talking with Dave about model construction and getting a lot of feedback about what looks realistic, what looks artificial," he says. They also collaborated on some preliminary modeling efforts to add electrical propagation—an ongoing research interest of Boyce's—to the existing 3D model.

"Dave is an expert at all things related to simulating cardiac mechanics, and has provided a lot of help and guidance as I've learned the field," says Alex Kaiser, a fourth-year Ph.D. student advised by Charlie. Further, "Dave knows the details of what makes immersed boundary simulations function." In the 90s, Dave and Charlie modeled an aortic valve (See cover image). "I am working on an analogous project for the mitral valve," says Alex.

"The thing [Alex] is doing now is like magic," says Dave. "He's trying to replicate not just the fiber paths in the leaflets of the valve, but he's also trying to replicate the complicated structure of the cords that attach the leaflets to the muscle in the heart wall. I spend a lot of time talking with him about anatomy. In fact, I was talking to him only yesterday. And I expect to be talking to him again today."

"[Dave has] had a big influence on a lot of my students," says Charlie. "He's helped people a lot. I'm just in the habit, when something gets to the details, of saying, 'Well, talk to Dave.'" ■

— A.B.

Olof Widlund retires

Michael Overton (left) reads remarks as Olof Widlund (at center) and other audience members look on.

Olof Widlund, leading theoretician of Domain Decomposition, has retired after 50 years at the Institute.

In late February, scientists and friends gathered in Warren Weaver Hall for a workshop celebrating Professor Emeritus Olof Widlund. Olof—who was a Silver Professor of Mathematics and Computer Science at Courant until his retirement in January—has been foundationally influential in Domain Decomposition, both in his research as well as in training students, many of whom have gone on to become significant contributors to the field. At the workshop, speakers from around the world offered a celebratory survey of the vitality of the field to which Olof has been integral.

Olof received his Ph.D. from the Royal Institute of Technology in Stockholm (1964) and his habilitation degree from Uppsala University (1966). He was hired as a faculty member at Courant in 1968 by Jürgen Moser, after holding visiting positions at UC Berkeley, the French Institute for Research in Computer Science and Automation ("INRIA"), and at Courant.

About a decade after it was founded, he served as chair of the Computer Science department (1980-86). It was a challenging time for hiring in the fairly new discipline, but under Olof's care, the department nearly doubled in size. At the workshop, Professor Michael Overton said: "Remarkably, Olof hired 11 CS faculty who are still here today: Allan Gottlieb, Chee Yap, Richard Cole, Marsha Berger, Ernie Davis, Alan Siegel, Zvi Kedem, Ken Perlin, Dennis Shasha, Bud Mishra, and Ben Goldberg." Michael was also recruited by Olof, the year before Olof became chair. With the growth, the department made its first expansion into space on Broadway, and grants also increased significantly. Concurrently, the area of Domain Decomposition began to take off, and in the late 80s Olof had 5 doctoral students in the field.

Prior to then, Olof's work was focused on finite difference approximations of initial value problems for partial differential equations. Some of his early work was on capacitance matrix methods and developing a nonsymmetric conjugate gradient method. He also started working on iterative methods for elliptic problems. For the past thirty years, his work has been in Domain Decomposition, which is a subfield of those kinds of iterative methods. In Domain Decomposition, "his papers have been and continue to be extremely influential, giving the foundation of many advances in the field," says Professor Daniel Szyld of Temple University, a former student of Olof's (Ph.D., 1983) and co-organizer of the workshop along with Michael.

Domain Decomposition is a method that stipulates how to break up systems to be solved on massively parallel computers. "You have typically an underlying geometry," says Olof. "You divide it into many pieces, maybe tens of thousands. And these subdomains, as they're called, are then assigned to different processors in the large computer system.

"What we end up with is very large algebraic systems of equations of a special kind, because they originate with these partial differential equation-based models," says Olof. Computations can then occur mostly locally, with little interaction between the processors. Domain decomposition proceeds by iteration, with as few steps as possible, for efficiency, and the crucial design issue is always the design of the interaction between the local problems.

At the workshop, a dozen and a half experts presented work in the field, with applications to, for example, blood flow in the arteries, the gravitational potential of the asteroid-struck Chicxulub crater, and modeling the earth's mantle.

"Everybody was in good spirits," says Olof of the event. "And I'm pleased because I feel that my chosen research area is doing very well."

The first International Conference on Domain Decomposition Methods was held in 1987 in Paris and there have now been 24 in total. Olof has co-edited the proceedings of about half of these, and is a member of the international organizing committee. "At the conferences you can see his influence [on the field], with plenary speakers being his former students, former postdocs, or the students of those students and postdocs," says Szyld.

Olof advised 21 students in Domain Decomposition and 32 students in total. He ascribes his style of educating others to his mathematical lineage. His advisor, Heinz-Otto Kreiss, was advised by Carl-Gustaf Rossby at Stockholm University when Kreiss emigrated from Germany to Sweden. "Rossby stressed that you work for yourself. It's very important of course that you work hard," says Olof. "Then I became the first student of Heinz Kreiss in the middle of my graduate studies in Stockholm. I was extremely lucky to find him."

"He's a truly great teacher," Professor Charlie Peskin says of Olof. "He had a huge influence on me." Charlie joined the Institute as a faculty member with a background in physiology. "I think Olof decided that he would fill the [mathematical] gaps…He never seemed like he was educating me, but he was."

Continued, bottom of page 12

Courant welcomes Director Russel Caflisch

Russel Caflisch returns to the Courant Institute as its 15th Director.

Professor Russel Caflisch received his graduate degrees at Courant in 1977 and 78, joined the faculty in 1984, and departed as a full professor to the West Coast in 1989. For the past three decades, he has been at the University of California, Los Angeles, and for the last nine years, director of its Institute for Pure and Applied Mathematics. In September, he is returning to sit at the historical desk of Richard Courant as the Institute's 15th director.

Russ, who is in the mathematical lineage of Courant himself, received his B.S. from Michigan State University (1975) and his M.S. and Ph.D. from the Courant Institute, all in mathematics. His Ph.D. advisor, George Papanicolaou (now at Stanford), was the student of Joe Keller, who was advised by Richard Courant. Before joining the faculty in '84, he spent a year at the Institute as a postdoc, and three years at Stanford as an assistant professor.

"I never envisioned I would be coming back as director," Russ says. "It's a real honor and a privilege." When asked about the future of Courant, Russ describes its long history: Its core strengths in combining analysis, applied math, and computer science and its now decades-long history in geometry and probability theory are met with the "tremendous promise and opportunity" of the university-wide Center for Data Science, the recent merger with the Tandon School of Engineering, and the international centers at NYU Abu Dhabi and NYU Shanghai.

As Professor Dave McLaughlin says, "Russ brings back to the Institute not only his analytical and applied mathematics skills, but also his administrative experience from leading IPAM." IPAM is a National Science Foundation-sponsored math institute at UCLA, which hosts extensive workshops and programs in pursuit of fostering interaction between math and other disciplines, such as engineering, medicine, physical sciences, and social sciences.

In research, "[Russ] fits very well with the applied math portfolio of Courant," says Professor Raghu Varadhan, who led the director search committee. "His line of research is very much in the tradition of Courant, kinetic theory, fluid dynamics, Monte Carlo simulations, and recently some mathematical finance."

Russ's doctoral thesis, "The Fluid Dynamic Limit and Shocks for a Model Boltzmann Equation," was a detailed analysis of a simplified model in kinetic theory. As Professor Jonathan Goodman explains, kinetic theory is about modeling, for example, the distribution of velocities of molecules in a "gas like air, but especially a very hot gas like a plasma in a Tokamak reactor." Kinetic theory's connection to magnetohydrodynamics has made it historically important at the Institute. Russ's thesis "had to do with [the] Broadwell model, a simple model of a Boltzmann type equation," says Raghu. "He was interested in obtaining a scaling limit and was successful." The Boltzmann equation has continued to be important in kinetic theory and has been a lasting area of interest in Russ's broad research portfolio.

Lately, Russ has been combining his expertise in PDEs, fluids, and materials with interesting methods coming from data science. "There are ideas around sparsity that have been really powerful in data science," he says, with application to areas such as imaging and machine learning. Sparsity-based ideas can improve both the efficiency and quality of numerical solutions. In some cases, one can derive new, modified PDE models which enforce a sparsity constraint, giving rise to new mathematical questions, novel algorithmic approaches and, in certain physical settings, simpler phenomenological descriptions.

In addition to serving as director of IPAM, Russ is a founding member of the California NanoSystems Institute. He is a fellow of the American Mathematical Society, the American Academy of Arts and Sciences, and the Society for Industrial and Applied Mathematics (SIAM). He has been an invited lecturer at the International Congress of Mathematics and the SIAM National Meeting. He was previously an Alfred P. Sloan Research Fellow and a Hertz Foundation Graduate Fellow.

As Dave concludes, "We're all very excited that he's returning to Courant as the director." ■

— A.B.

Olof Widlund Retires (Continued)

And before Charlie had his own office, Olof offered him a desk in his office, "which is a pretty extraordinary thing to do," says Charlie. Stories of Olof's warm generosity to others in their times of transition or in the face of small to large obstacles were echoed by many at the workshop, painting another portrait of his dedication to the well-being of his colleagues, friends, and community. "He was very supportive when I was a postdoc and was an important factor in my coming to Courant," says Professor Leslie Greengard. "He has been a great friend over the years."

In retirement, Olof is finding even more time for research. "I have a very nice office. A lot of projects. And I live a third of a mile away, so Courant is still very much a second home."

Some ongoing work is with a group of collaborators in Italy. "We're doing numerical methods for isogeometric analysis, which is a new way of doing simulations," he says. "When mechanical engineers and architects design structures, they use what's called computer-aided design (CAD). And isogeometric analysis is a successful attempt, which is by now about 10 years old, to design algorithms and models for these often geometrical objects which are much closer tied to what the CAD people do. So that cuts out an intermediate, often very frustrating and expensive step. We're working on solving those resulting algebraic systems. And I hope that'll continue because I love to go to Italy," says Olof. "And also, I mean, they are very great friends."

For the workshop, Barry Smith, a former student (Ph.D., 1990) of Olof's who is now at Argonne National Lab, prepared remarks which sum it up: "I hold Olof in the highest regard for both his mathematics and his humanity. His devotion to his students, his postdocs and his colleagues reflect the very best of the scientific community." ■

— A.B.

Richard Courant: Scientific Ambassador

By Brit Shields
bshields@seas.upenn.edu

The Institute's founder was among the first to participate in the US/Soviet Union inter-academy exchange program.

Perhaps best remembered for his administrative faculties, textbook writing, and academic research, the Courant Institute's founder, Richard Courant (1888-1972), also served as a scientific ambassador throughout the postwar and Cold War eras. Courant's exposure to the international mathematics community began in his student days, having completed his doctorate in 1910 under the tutelage of David Hilbert in Göttingen. Courant later succeeded Felix Klein as the Director of the Mathematics Institute at Göttingen, which continued to flourish as an international center of mathematics research and held faculty, students, and visitors such as Max Born, Harald and Niels Bohr, Emmy Noether, and Pavel Alexandrov.

Following Courant's dismissal by the Nazi government in April 1933, he spent a year at the University of Cambridge, then immigrated to the United States and joined the faculty of New York University. In New York, Courant, along with Donald Flanders, J.J. Stoker, and Kurt O. Friedrichs, grew a small graduate department into a flourishing institute of mathematical sciences through projects for the war department during the Second World War and, in the postwar years, large contracts and grants from the government, private foundations, and industry.

Throughout his time as Director of the NYU mathematics institute, Courant articulated the contributions mathematicians could make to the international peace effort. He visited postwar Germany on an annual basis with funding from the US Navy, to help the reconstruction efforts of their scientific institutions. He also regularly participated in international meetings, including those hosted by the International Congress of Mathematicians. Maintaining contact with his Russian peers, especially during times of tremendous political strain, was important to Courant. He invited these colleagues, including Olga Ladyzhenskaya, to publish in the institute's journal, *Communications on Pure and Applied Mathematics*.

When the National Academy of Sciences and US Department of State announced in July of 1959 that there would be a program with the Soviet Academy of Sciences to foster cultural exchange in the sciences, Courant became an active participant. The inter-academy exchange agreement fell under the umbrella of a larger diplomatic effort, the Lacy-Zarubin agreement, which promoted cultural, technical, and educational exchange between the two countries, leading to the visits of ballet companies, hockey teams, and musicians. Scientific exchanges within this program took the form of visits by distinguished scholars and larger research symposia. Courant was selected as one of the first to participate and was sent to the Soviet Union in 1960 to visit mathematics and computing centers in Moscow, Leningrad, and Tbilisi. He was accompanied by Peter Lax, who recalls that a US spy plane had been shot down shortly before the trip and was on display in Gorky Park in Moscow. While Courant and Lax attended the exhibit, Courant was approached by an admiring colleague, exclaiming that he had studied his textbook.

Courant members at the 1963 inter-academy exchange in Siberia include (Top) Peter Lax, at right of center, (Middle) CPAM technical editor Natasha Brunswick who walks just to the left of Richard Courant, and (Bottom) Louis Nirenberg, who sits front and center.

Following the success of his first visit, Courant began planning a larger inter-academy symposium on partial differential equations with his colleague Ilia Vekua. In August 1963, Courant chaired the delegation of two dozen American mathematicians who visited the growing "Academy Town" of Akademgorodok, just outside of Novosibirsk in Siberia. Natasha Brunswick, the technical editor of *Communications on Pure and Applied Mathematics*, participated as a translator. Other NYU mathematicians in attendance were Kurt O. Friedrichs, Harold Grad, Peter Lax, Jürgen Moser, Louis Nirenberg, Robert Richtmyer, and Martin Schechter. (Lipman Bers had planned to attend, but was called away with a family emergency.) The two-week event was deemed a tremendous success. The mathematicians enjoyed time listening to talks, with the aid of translators, as well as activities throughout the Academy Town, such as boat rides, hikes, and social gatherings. In recent interviews with Nirenberg and Lax, both reflected on the lifelong friendships they made on the trip.

Following the 1963 symposium, Courant returned to the Soviet Union several more times and hosted Russian visitors at the Courant Institute of Mathematical Sciences in New York. After each of the exchanges, he was required by the NAS to circulate reports among NAS officials, reflecting on the status of scientific life in the Soviet Union. Courant consistently reflected on the quality of mathematical education there and, also, on the important role mathematicians could play in fostering international peace as scientific ambassadors.

In February 1966, Courant was one of three American scientists to be elected as a member of the Soviet Academy of Sciences. Previously, only three other American scientists had ever been elected. Courant's final trip to the Soviet Union was in the fall of 1967, when he returned to Moscow, Leningrad, Tbilisi, and the Academy Town of Akademgorodok. ■

***Learn more in Shields' article, "Mathematics, Peace, and the Cold War: Scientific Diplomacy and Richard Courant's Scientific Identity," in the November 2016 issue of* Historical Studies in the Natural Sciences.**

FACULTY HONORS

Congratulations to Michael Overton, Bob Kohn, and Joel Spencer who have been named Silver Professors!

Deena Engel and **Craig Kapp** have received the NYU College of Arts and Science "Teach/Tech" award, which recognizes faculty members who have "developed innovative technological solutions to enhance student learning." The pair was selected for their efforts in redesigning the popular class "Introduction to Programming." They created self-paced, hands-on learning modules for the course. Now in the fourth semester of implementation across all sections of the course, students continue to achieve greater sophistication in their software development than in previous models.

Leslie Greengard has been elected to the American Academy of Arts & Sciences in a class of 212 distinguished scholars and practitioners. Leslie has made contributions to the fields of scientific computing, potential theory, and data analysis. Along with Vladimir Rhoklin, he invented the Fast Multipole Method (FMM), a seminal technique with transformative impact in the computational sciences that has found a wide range of applications from chip simulation to molecular modeling.

Subhash Khot has been named a 2016 MacArthur Fellow for, per the MacArthur Foundation, "tackling unresolved questions in optimization and approximation and contributing to significant advances in the field of computational complexity." In 2002, Subhash proposed the Unique Games Conjecture, which has turned out to precisely identify the dividing line between problems which are tractable or intractable. Even without being yet proven, the conjecture has motivated many new techniques and results and is a major driving force in theoretical computer science.

Yann LeCun has been elected to the National Academy of Engineering "for developing convolutional neural networks and their applications in computer vision and other areas of artificial intelligence." He also received a *Lovie Lifetime Achievement Award* from *The International Academy of Digital Arts and Sciences*. The award recognizes "the unique and resonant nature of the European Internet community." As the Academy writes in their citation, "LeCun's contributions to the science of machine learning, mobile robotics and computational neuroscience among other learned fields, is legendary." Yann has also been awarded a doctorate honoris causa from the Instituto Politécnico National and has been inducted into the New Jersey Inventors Hall of Fame.

Eyal Lubetzky has been elected a fellow of the Institute of Mathematical Statistics "for fundamental contributions to the cut-off phenomenon and the dynamics of the Ising model." Fellowships are awarded to IMS members who demonstrate exceptional research in statistics or probability or substantial leadership in those fields**.** Eyal has also received the *American Mathematical Society's Centennial Fellowship*. "The Centennial Fellowship plays a special role by supporting outstanding young mathematicians at a critical stage in their careers," says the AMS. "The primary selection criterion is excellence in research achievement."

Daniele Panozzo has been awarded an NSF CAREER award to support his project "Coupling Geometric Acquisition and Digital Fabrication." He is designing foundational algorithms for integrating 3D scanning and digital fabrication and is introducing an integrated process for scanning, simulating, and fabricating variants of existing 3D objects. The work will support the design of custom medical devices and prostheses and the development of a new microscopy technique fundamental for understanding cell migration in the development and genesis of cancer.

Victor Shoup has been named a Fellow of the International Association for Cryptologic Research for "fundamental contributions to public-key cryptography and cryptographic security proofs, and for educational leadership." The fellows program recognizes "outstanding IACR members for technical and professional contributions."

STUDENT AWARDS

Congratulations to our 2017 student prize recipients!

Henning Biermann Award
Bowen Yu

Sandra Bleistein Prize
Jun Wang

Hollis Cooley Prize
Sanchit Chaturvedi
Hari Rau-Murthy

Janet Fabri Prize
Yonatan Halpern

Kurt O. Friedrichs Prize
Di Qi
Sylvester Eriksson-Bique

Paul Garabedian Fellowship
Lamont Nelson

Max Goldstein Prize
Vidyadhar Thatte

Harold Grad Memorial Prize
Liying Li
Yixin Tao
Scott Yang

Moses A. Greenfield Research Prize
Jim Thomas

Wilhelm Magnus Memorial Prize
Simeng Kuang

Matthew Smosna Prize
Subhankari Mishra

Master's Innovation Prize
Aditya Kurup
Ramandeep Singh
Vidur Uthappa

Computer Science Master's Thesis Prize
David Kasofsky

Math Master's Thesis Prize
Alastair Doggett

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Open Field Tic-Tac-Toe

by Dennis Shasha
Professor of Computer Science

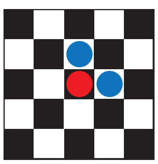
In the spirit of gomoku, two people play a version of the classic paper-and-pencil game tic-tac-toe but on an infinite checkerboard. In it, a player wins by getting four pieces in a row—vertically, horizontally, or diagonally.

Warm-up

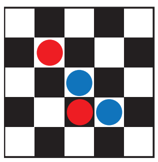
Can the first player—blue—force a win in seven turns or less, where a turn consists of both blue and red placing pieces?

Solution to warm-up

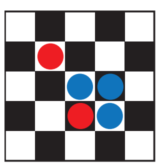
The first player can force a win in five turns. Blue moves. No matter where red moves, blue can, in the second move, have two in a row.



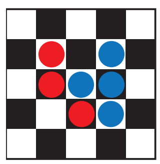
Red must now respond to prevent blue from having three in a row that is open on both ends. So red blocks, giving us something like:



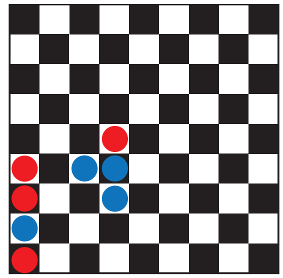
Blue can now force a two-by-two fork.



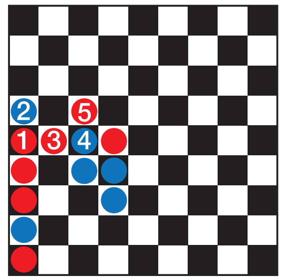
No matter where red goes, blue can force an open-ended vertical or horizontal line with three blues, as in:



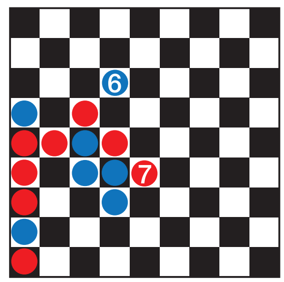
So... now that we know how it works, let us try it for some other problems.



Suppose we have a board with a nine-by-nine grid with the configuration, at left, and red is about to take the next turn. Can either side force a win?



Solution. Yes, red can force a win. Red threatens with (1). Blue (2) then red (3) then blue (4), and then red threatens again (5).



Blue responds (6), then red gets three in a row with open ends on either side (7).

UPSTART. Suppose the board is a six-by-six grid with a red exactly in every corner. Blue moves first. There is no limit on the number of turns. Can either side force a win?

This puzzle also appeared in Vol. 60 No. 1 of Communications of the ACM.

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