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Courant Newsletter

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Image: Neurons of the cerebral cortex.

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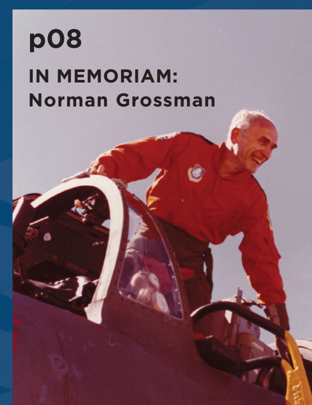

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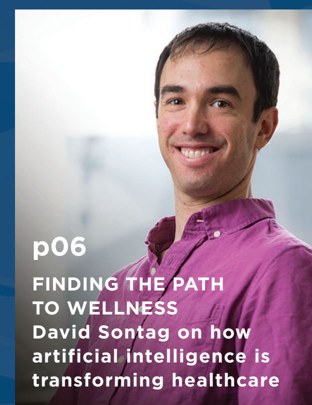

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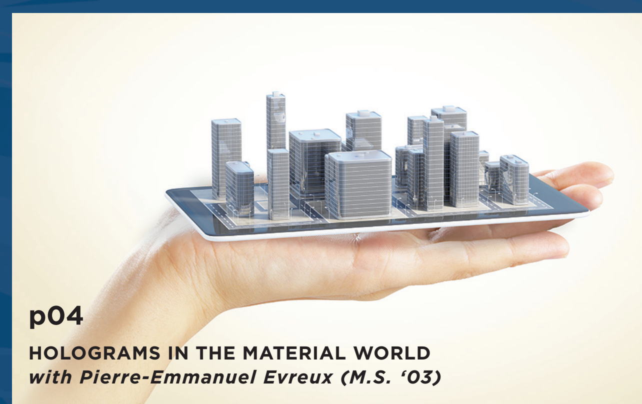

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Lai-Sang Young on
the mathematics of chaos and modeling the dynamical brain

by April Bacon

Signatures of chaos

"Everybody thinks they know chaotic behavior when they see it, but there's no definition people agree on, and I doubt that there can be a single definition that captures everything we want it to be," says Lai-Sang Young, world-renowned expert in dynamical systems, Henry & Lucy Moses Professor of Science, and Professor of Mathematics and Neuroscience at NYU.

Disorder (known colloquially as "chaos") and order (such as the predictable swing of a pendulum) make up the two ends of the spectrum of dynamical systems, a research field that seeks to understand how a system evolves over time. Dynamical systems can be found everywhere in nature, in neural networks, ecosystems, weather, financial markets, manmade structures, and in the mathematical equations and algorithms developed to model these processes. "You can see that it's kind of connected to everything," says Lai-Sang. While Lai-Sang doesn't believe there is a precise definition for the term, she says "there are *signatures* of chaos."

A framework she has laid out identifies three such signatures: *hyperbolicity*, a geometric measure of instability; *entropy*, from information theory; and *decay of time correlations*, from probability theory. These three signatures can roughly be equated to asking: Just how sensitively does a system depend on its initial conditions (hyperbolicity)? Does knowledge of a system's past offer enough information to predict its future (entropy)? And, how quickly is the system losing its memory (correlation decay)? The more sensitive, the less predictable, and the quicker the memory loss, the more chaotic. These ideas are not just intuitively but also formally related, and Lai-Sang has helped put some of that on firm mathematical footing.

Strange attractors of the simplest kind

The well-known example of Edward Lorenz's butterfly (see image on back cover) comes from a model of atmospheric convection abstracted down to just three variables that depend on each other in a non-linear way. Think of the three variables as the coordinates of a gnat as it flies around — the path, or trajectory the gnat takes is the solution to the equations. In Lorenz's model, the path always traces out a compact pattern, called an "attractor" (which in this case looks like a butterfly). Even with just three variables, there is no analytical solution, so a computer must be used to solve the equations. If you start your program with two different initial states, the computed solutions will take completely different paths on the attractor, even if their starting conditions differ by only a miniscule amount. This is what "sensitive dependence on initial conditions" means — every solution lies on the attractor, but the path taken along it is never the same.

As Lai-Sang explains, attractors are "stabilizing" because they draw a large number of initial conditions toward a relatively small region of the solution space. Yet the dynamics of models that have attractor solutions are chaotic in the sense that the trajectories of two nearly identical points on the attractor will widely and quickly diverge. One of the biggest realizations in the theory of chaotic systems over the past fifty years, says Lai-Sang, is that even when everything is determined by equations and nothing is left to chance, chaotic systems can produce data that are virtually indistinguishable from those of random processes (such as flipping a coin).

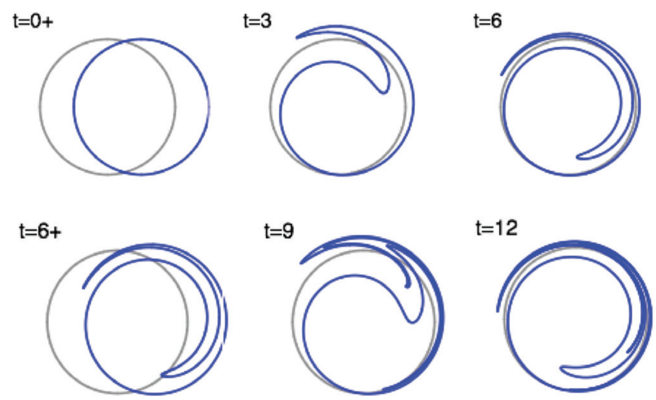


Image 1

Strange attractors are really messy objects, and it helps to have simple examples. Shear-induced chaos, a particularly simple instance of which is shown above (Image 1), is one of the very few paradigms of chaos theory where there is a well-developed mathematical theory with rigorous proofs, thanks to the work of Lai-Sang and collaborator Q.D. Wang (University of Arizona). They built on the seminal work of Michael Benedicks and Lennart Carleson, who analyzed a special system called the Hénon map. Using the techniques offered in this one instance, Lai-Sang and Wang built a general theory of what they call "strange attractors of the sim plest kind," or, more formally, "rank-one attractors." All attractors are very complex, but this kind is the simplest of strange attractors, as it has only one direction of instability, and has been shown to appear right after a system loses stability.

"Though I didn't know about it, an example similar to the one shown was studied numerically by the late George Zaslavsky, an NYU physicist, many years earlier. The idea is very simple," says Lai-Sang. At t=0, a periodic attractor (grey circle) attracts everything around it into its orbit; orbits outside of the circle move slightly faster than those inside, creating some shear. The system is then "kicked" to the right (blue circle), and allowed to settle back toward its original state. During this time, the shear acts on different parts of the blue circle differently, resulting

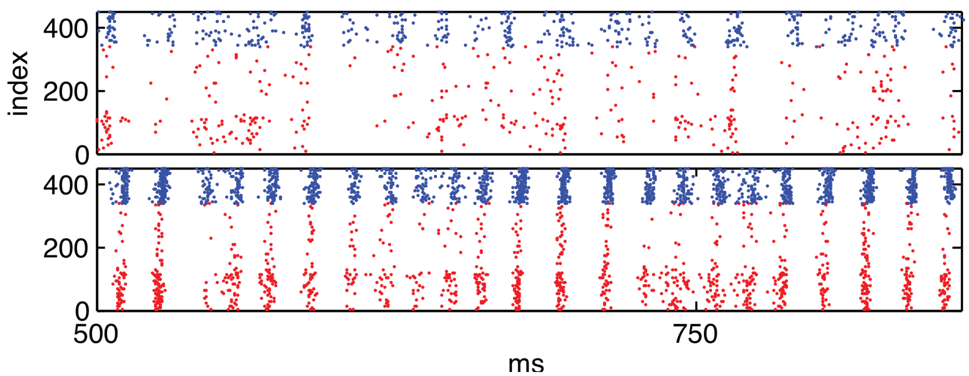


Image 2 These "raster-plots" show the spiking activity of more than 400 neurons in a local population, taken from the model of the primary visual cortex in Lai-Sang's current project with Professor Robert Shapley and Ph.D. student Logan Chariker. The vertical axis is neuron number, and the horizontal axis is time. The top panel shows background activity, and the bottom panel shows what happens when the model cortex is stimulated.

in the development of the 'tail' clearly visible at time t=3. The fold solidifies between t=3 and t=6 as the entire structure is attracted back to the grey circle. This process is repeated once every 6 units of time. The stretch-and-fold leads to the formation of a strange attractor, displaying the three above-mentioned signatures of chaos.

The Dynamical Brain

"The brain is one big dynamical system, maybe the most fascinating one of all," says Lai-Sang. "In addition to being a very large and complex dynamical system," she elaborates, "[it] does not operate in isolation: It is constantly receiving input from the external world and from the rest of the body. As a dynamical system, it is 'out of equilibrium.'"

In collaboration with Robert Shapley of NYU's Center for Neural Science, she is studying the dynamics of the primary visual cortex (V1). Central to our ability to comprehend visual information, V1 is one of the few areas of the brain for which a large amount of experimental data already exists, due in part to its accessible location in the occipital lobe. A primary goal of this research is to build a model that behaves like the real brain, meaning it produces outputs that resemble experimental data, so that it can be used to answer questions about the real brain — it is far easier to run simulations on a model than to run tests on the actual brain! Another goal is to develop further paradigms for understanding dynamical systems.

Although still very much in the purview of dynamical systems, this work is different from the attractors mentioned above in some notable ways, including the constant input and the size. The scale of the object of study is vastly larger: "We have 10^{11} neurons in the brain," says Lai-Sang. "You don't study all of them — you study just a tiny piece of the brain, but even that tiny piece can have a million or more neurons." Also, the rules of operation of the system are unknown for the brain, and a major part of the research is to deduce these rules from the brain's outputs.

In terms of the above signatures of chaos, the questions need reframing. For example, it makes sense to ask how quickly cortical response diverges for small changes in the initial cortical state or stimuli, but this question itself immediately raises another question: "How do we measure the distance between cortical states? In a system that describes the interaction of hundreds of thousands of neurons, not every detail will carry weight," explains Lai-Sang, "and some amount of coarse-graining, or lumping, is necessary.... The challenge is to devise a meaningful metric that captures system attributes relevant to the investigation."

"For large systems, characterizations of chaos that work for systems with few degrees of freedom may not be so relevant — often it is not even clear exactly what chaos means. A much more important goal in studying large systems is to identify and understand *emergent phenomena*," Lai-Sang explains. In the brain, the organization of grouped neurons together cause behaviors to 'emerge' that are different from and beyond those exhibited by individual neurons. Emergent behaviors are characteristic of complex dynamical systems.

One such collective behavior (as seen in Image 2) is the tendency of excitatory and inhibitory neurons to fire in clusters. In the image, a dot represents a neuron spike — red for excitatory neurons and blue for inhibitory ones. The bottom panel shows that when the model cortex is stimulated, seemingly random subgroups of neurons fire near-synchronously in a semi-regular rhythm within the gamma range (40-70 Hz). "Individual neurons spike irregularly, and if you watch one neuron there's no reason to predict that together they will produce this rhythm," says Lai-Sang. "What happens is that when a few excitatory neurons start to fire, this tends to cause more of them to become excited; it's called 'recurrent excitation.' And then at the same time the inhibitory ones get excited, until at some point the inhibitory neurons step in and push everything back. …The rhythm comes from this push-and-pull kind of phenomenon. Any group of neurons hooked together will automatically start to form these patterns—and no matter what you do, you can't get rid of it, even if you try!" In some earlier modeling work, Lai-Sang and her collaborator Adi Rangan, also of Courant, first discovered these push and pull patterns. It turns out to match very well what people have observed in experiments.

"The diversity of behaviors in neuronal models is also an emergent phenomenon," says Lai-Sang. "You program the neurons to be more or less the same, but through their interactions they start to take on completely different properties."

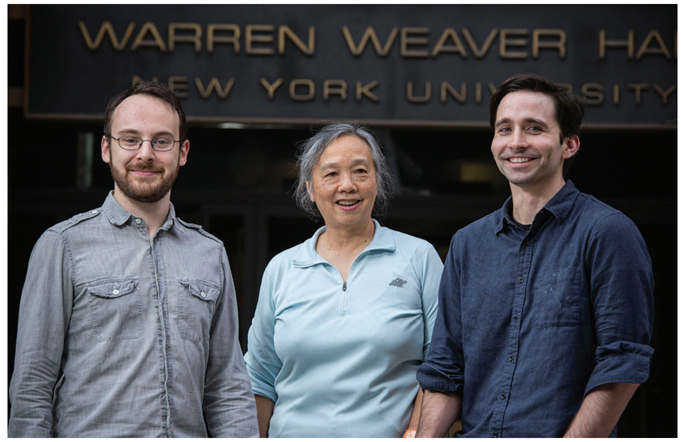
Lai-Sang and collaborators have mostly finished modeling the input layer of V1. "I'm pretty sure we can go further in the visual cortex," she says. "The deeper into cortex we get, the more ambiguous the situation will become, as there will not be enough data to tie the model down. The visual cortex is part of the cerebral cortex, a very thin sheet only about two millimeters thick that wraps all the way around the brain. It's mostly the thinking part of the brain. We hope to generalize some of our work on V1 to other areas of the cortex and that's where I would eventually like to go."

Dynamical systems is evolving

Lai-Sang sees the task of dynamical systems research for the 21st century as making these kinds of connections to other disciplines, and to other fields of mathematics. "The field itself is evolving—it's not just that it's about evolving things," she says. But the movement of some dynamical systems research from the theoretical to the applied — such as Lai-Sang's work on the brain — is not a one-way street.

"There are many questions that I want to take back to dynamical systems theory," says Lai-Sang, from broad questions such as "How do you analyze large dynamical systems made up of lots of small constituent subsystems (such as individual neurons) coupled together?" to "How do you develop a dynamical theory of systems in which two competing groups of agents play against each other, like excitatory and inhibitory neurons?"

Pure and applied mathematics "feed off of each other," she says, "and Courant is the best place in the whole world for fostering the entire spectrum. That's very special about Courant. That's the reason I came. You know that, right? Courant is really special." ■



Lai-Sang Young (center) stands outside of Warren Weaver Hall with finishing Ph.D. students Alex Blumenthal (left) and Logan Chariker. Alex has been awarded an NSF Postdoctoral Fellowship, and Logan a Swartz Foundation Fellowship.

Holograms in the Material World

Pierre-Emmanuel Evreux and LEIA 3D's mission for consumer holographics

by April Bacon

In 2013, Courant alumnus Pierre-Emmanuel Evreux (M.S., Mathematics in Finance, '03) travelled from his home in New York to Palo Alto, California to visit longtime friend David Fattal. There, Fattal revealed to Evreux a prototype for a new technology: a flat, transparent panel, about 2 inches in diameter, above which floated a holographic 'x' and 'o,' smoothly appearing in three dimensions to the naked eye. By December of that same year, Evreux, Fattal, and third co-founder Zhen Peng had formed LEIA 3D, with the goal of making holographic technology a mass-market reality.

From trading desk to start-up

The genesis of that partnership began over a decade before, when Evreux met Fattal while enrolled at Ecole Polytechnique. Evreux was studying finance and applied math, and Fattal physics. When they graduated in 2001, both were eager for a new experience and to come to the U.S., says Evreux. Fattal chose Stanford on the West coast, while Evreux chose Courant on the East.

"The reason I chose NYU was for the quality of its professors and the intersection with Wall Street," says Evreux. "When you study applied math dedicated to a certain field, you always want a balance between those two worlds. And Courant is doing a great job at this. So that's why I went to NYU. And obviously New York always played a part in it!"

While enrolled at Courant, Evreux was also working part time at JWM Partners, a hedge fund in Greenwich, Connecticut. "I wanted to gain as much experience and practical knowledge as I could," he says, and after graduating from Courant he continued in that role before taking a position at Morgan Stanley as a portfolio manager in '04. He worked seven years with the same group as they served Morgan Stanley, then left that company to form their own hedge fund—Old Lane Partners, later bought by Citigroup.

With this group, Evreux invested the firm's money directly into the market. His focus was on understanding all of a company's securities (corporate bonds, equity, etc.) in isolation as well as in relation to one another—in order to judge how they might perform within the current macroeconomic environment. The experience gave the future start-up co-founder a clear picture of what fundamental ingredients make up a strong and scalable company, how a company raises funds, as well as the many ways a company can shape itself in regard to its core operations and what it will accomplish by partnerships. "One of the main things I got from finance," Evreux adds, "is thinking in terms of risk and optionality. Risk taking is an essential ingredient in building a company and you don't really learn it in any other industry. I really thank investing for that."

In 2011, Evreux left Citigroup and spent a few years as Managing Director of Corporate Credit at Hutchin Hill Capital before he went on his fateful visit to see Fattal, who was then a Research Scientist at Hewlett-Packard

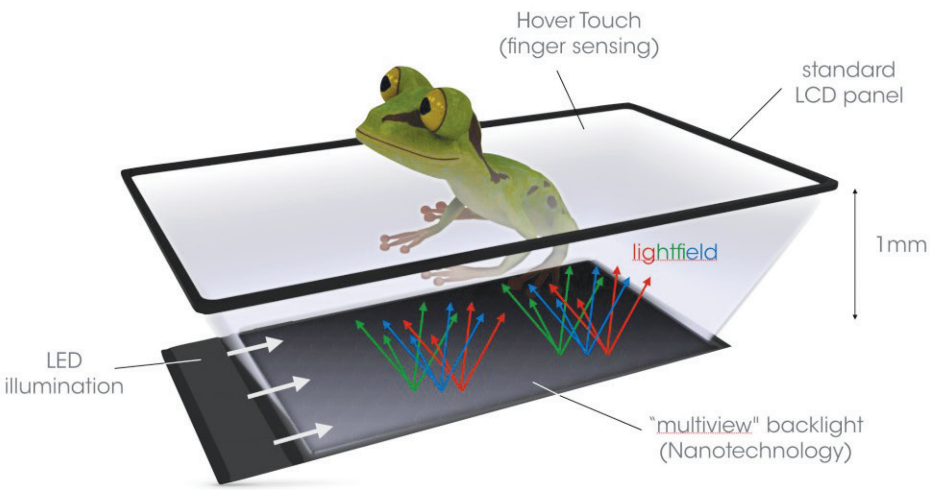


Image 1

Laboratories in Palo Alto. After the big reveal, "I was very much interested in the start-up adventure," says Evreux. "I had looked at companies for close to fifteen years. That experience gave me the opportunity to create my own company based on what I think are the soundest principles.

"And I always like to work with friends — it makes the adventure more fun."

Holograms you can touch

In just over two years, LEIA 3D has deployed development kit versions of its display to corporate and individual developers, and is scheduled for the first market release of its holographic display in consumer smart phones and automotive navigation systems by the end of 2017. The technology is as striking as the vision LEIA 3D has laid out for it. In a classic hologram, the 360-degree form of an object is reconstructed by a complex pattern of light projected and interfering with itself at many points, an arrangement too complex to allow for projection of an object at video speeds. LEIA simplifies the holographic rendering process and achieves a video-rate holographic effect by using a layer of nanotechnology (the size of a single hair divided by a thousand) underneath an LCD panel (see Image 1). Light from the backlighting unit interacts with a nano-grating system that "diffracts" light in many directions, creating a "lightfield" with 64 different images observable simultaneously from different positions in space. Upon looking at a LEIA display, the observer's right and left eye will naturally perceive different images and experience a 3D stereoscopic sense of depth (akin to the glasses-based 3D effect experienced at the movie theater). Moreover, when the observer moves around the display, different pairs of views will be presented to his or her eyes to achieve a full "motion parallax" effect — or the ability to see around objects.

With the goal to integrate the technology into everyday life as seamlessly as possible, LEIA is taking their displays two steps further. In partnership with other technology developers, the company has already developed a demonstration of their display to include hover touch — a way to interact with the digital object by directly "touching" the hologram, rather than the screen. And in other partnerships they are working to integrate *haptic* feedback, an ultrasound-based technology that will simulate for users not only the ability to touch, but to *feel* the hologram. They are hoping to have a demonstration which includes haptic feedback by the end of the year. These three things packaged together — the hologram, hover touch, and haptic feedback — constitute what LEIA describes as "holographic reality."

"We have this catchy phrase which basically says we are materializing the digital world," says Evreux, "and we think this is the new way people will interact with content in the future." The approach is in contrast to virtual reality, which requires the user to wear a headset. "With the VR approach, you sit in your living room with a large headset on and you get a very immersive experience which is centered around you. What LEIA is saying is, that's great when you're at home and you want that immersive experience, but how can you access these virtual worlds when you're in the street, in your car, or with friends?" By bringing the digital world into the material — rather than the individual into the virtual — "holographic reality" doesn't impair mobility or social interactions, explains Evreux.

The vision for the technology includes applications across a number of industries. Imagine, in medicine, viewing an ultrasound of an unborn baby in three dimensions, projected above a device held in the palm of a hand; in cell phones, the holographic presence of a loved-one states or countries away in "holochat" or 3D selfies; and in e-commerce, viewing a product for sale from every angle. Evreux says after the the company was launched, the first inquiries they received were from doctors interested in the technology's ability to give surgeons a sense of depth. And there has naturally been a big response from game developers as well. "You can imagine angry birds with the birds popping out of your display," says Evreux. "Most games today are being programmed in 3D but they're being shown in 2D. So we can actually show on our display all these games already."

"Building a company from scratch is a lot of work," he says, "but it's a fascinating experience because it's the combination many things. It's technology, it's nanofabrication, it's business development, it's software, it's content, it's supply chain, it's marketing, it's intellectual property." And, of course, "it's finance." At present, LEIA has assembled a team of 25, each with varying expertise in these areas. "It's a very exciting period," says Evreux. "And that's why I decided to move to the West Coast. I miss New York a lot. But it's worth it."

Finding the path to wellness

David Sontag on how artificial intelligence is transforming healthcare

by April Bacon

David Sontag and his group in front of the Washington Square Park arch. **Top:** Yacine Jernite, Rahul Krishnan, Uri Shalit, Carlos Guzman, Ankit Vani. **Bottom:** Justin Mao-Jones, Maya Rotmensch, David Sontag, Narges Razavian, Rachel Hodos, Aarti Bagul.

In the near future, algorithms running autonomously behind the scenes will inform healthcare practitioners by preparing an intelligent summary of each patient admitted to the hospital, says David Sontag, Assistant Professor of Computer Science at Courant, whose focus of research is on machine learning problems for healthcare. The algorithms will reason about the patient's health, presenting a summary of what is currently going on with the patient along with what it believes to be relevant from the patient's past medical history. David says the historical information "could provide essential context which could change treatment decisions."

Algorithms will always be thinking behind the scenes to keep track of patients by, for example, detecting if a patient is "on a trajectory toward clinical deterioration early on and alerting the clinical team." The algorithms will be able to prompt physicians if a prescribed drug doesn't match up with what has been prescribed to similar patients, or if a symptom is added to a patient's medical record which "looks like an anomaly." In the latter example, the quality of the data is improved with minimal effort by practitioners; and in the former, Artificial Intelligence (AI) is employed for "preventing simple mistakes, which happen every single day and lead to a lot of the heartbreak in healthcare," says David.

"There's nothing magical about this," he explains. "It's really just about doing things the way they should be done…But the problem is that the clinical team doesn't have time, and especially in the United States, clinicians are managing way too many things."

In the longer term, David envisions that machine learning will make healthcare more proactive than reactive, with patients participating more in their own care through apps and websites. "If one can extremely cheaply and easily get a blood test that can measure hundreds of different biomarkers for a few cents, and that data is made readily available to algorithms, then we don't necessarily need to wait until we see a patient exhibiting signs of diabetes in order to recognize that they're on a trajectory to becoming diabetic. We don't have to wait until someone develops a large tumor to recognize that they have a cancer."

A unique moment

"The set of questions that people are hoping to solve with healthcare and AI are not new," says David. "And there were very smart people that were tackling them 40 years ago."

Before David gave a talk in November at Stanford, he received an email from a former AI researcher who saw the talk announcement. The email said: "'Hi, David. I got a kick out of looking at your work just now. Here's a project that I ran in the 1970s and 80s. It should look very familiar'!

"The goals and the approaches taken back in the 70s were quite similar," says David. "There are new technologic improvements, but what's largely changed is the timing. Now we, number one, have electronic health data that is widely available for research and operations purposes and two, we have computers that are by the bedside."

The feedback loop for those doing medical diagnosis algorithms in the 70s was much longer, explains David: After questioning the patient, the researcher would have to run to the mainframe computer in another area of the hospital — such as the basement — type in patient responses, wait for the computer's output, return to bedside and repeat. In the fast-paced hospital environment, this made AI impractical to implement. Now that loop is significantly faster.

"Having the data and having computers gets us a large chunk of the way there," says David. "It opens the door but it doesn't solve all the problems. There are still some major challenges."

The data: noisy, incomplete, mismatched, and biased

Data for each patient is housed inside of his or her Electronic Health Record (EHR). The data in EHRs, however, is unstructured and noisy, and this is one of the biggest challenges in machine learning today: how to build algorithms that can structure, circumvent, or otherwise work on top of noisy data.

There are many ways in which the data is messy. For example, it is heterogeneous: Lab results, medical diagnostic codes, and clinical notes can all be a part of a patient's EHR. The data is imperfect: text may refer to a single condition with many different descriptive terms. There may be bias in the data, such as which specific diagnosis code is assigned (often the one that pays the most); and the data may have entry errors or be otherwise incomplete. Machine learning algorithms can work with this data, learning and improving a model over time — but it creates one of the challenges David and his team have been working to

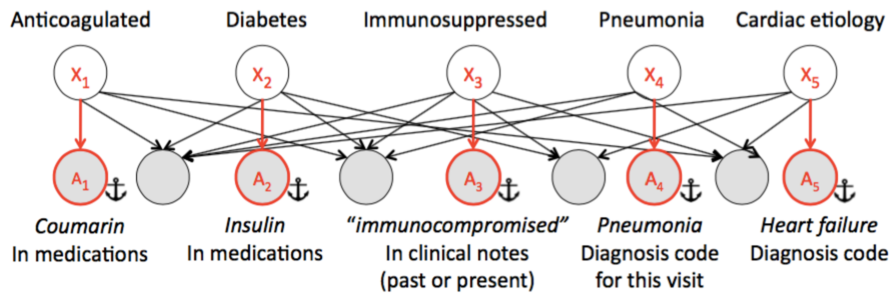


Image 1: Probabilistic model used to infer clinical state variables (top) from observed clinical data (bottom). Semi-supervised learning is able to recover the model from data in which the top variables' values are hidden so long as a domain expert specifies one or more "anchors" for each hidden variable.

overcome: transferability. There is a "cold start" problem of transferring the algorithms from one population to another. Applied to a different hospital's population, algorithms which are not transferable will have to learn the structure of the new hospital's data from scratch.

Building algorithms that can work on top of noisy data is "one of the last few things that need to be solved in order for AI to have a big impact in healthcare," says David.

Finding the path to wellness

The team already has implementations of their algorithms in place in several clinical environments. At Beth Israel Deaconess Medical Center's Emergency Room (in Boston), systems that inform clinical decisions, save time, and reduce the chance of error are already running for all 60,000 patients who use ER services there each year.

In one implementation, the team has improved the quality of chief complaints in the ER. Chief complaints — such as chest pain, cough, or pain in left arm — are taken when a patient is admitted and displayed along with name, age, and bed number on a big screen for the clinical team to see. "The better the quality of that information, the more useful it is for keeping track of patients and understanding who might be critical," David says. That data is also used for enrolling patients in clinical trials, and for retrospective clinical research such as assessing effectiveness of certain interventions and building risk stratification algorithms to help identify patients who are most at risk for certain diseases.

Utilizing a new ontology for the complaints — which was developed by Beth Israel's Steven Horng, MD, with help from David and his team, and which they hope will eventually be implemented nationwide — the team "changed the workflow in the ER and used machine learning to help automate the documentation process."

It works like this: Instead of immediately assigning a chief complaint to a patient who walks into the ER, the nurse first talks to the patient and writes a twenty- to fifty-word assessment including vital signs, symptoms, and reasons for the visit. That data — plus historical data if available — is processed by the algorithm to predict the top five possible chief complaints, one of which is then selected by the nurse. A text box is also available for manually entering a different complaint, which has a contextual autocomplete similar to those used by many internet search engines.

He and his team rolled out the system slowly, further optimizing and automating it based on how it was being used and was performing in the real environment. "We created a plot where you could see, over the course of one year, how the quality of the chief complaints got better and better," he says, "until, by one metric, it reached 100 percent. That's likely our biggest success case because it's being used for every single patient that comes into the ER today at that hospital — for about two years now."

In another implementation used for all of the hospital's ER patients, electronic health records are being used "to continuously predict in real time about 40 or 50 different clinical state variables," says David. "These include abdominal pain, alcoholism, allergic reaction, ankle fracture, diabetes, deep vein thrombosis, kidney stone, HIV, geriatric fall," etc.

If the algorithm predicts cellulitis, for instance, it will ask if the practitioner wants to enroll the patient in a clinical pathway for that infection. This system helps to ensure that care is standardized and that clinical pathways are not forgotten.

The algorithm is able to identify and trigger clinical pathways — and is also transferable to other institutions — because it has organized EHR data using *anchors*, which are observed variables that are linked to a hidden "parent" variable. For example, two anchors for the parent variable *diabetes* include diagnosis code 250.*xx* and a medication history of *diabetic therapy*. Barring possible entry error, either of these appearing in a patient's EHR make it pretty likely the patient has diabetes. However, no assumptions are made about what the absence of the anchors implies about the parent variable. David refers to these anchors as "noisy labels" as they do not label the data directly, but link data together in a predictive way.

The algorithms are "semi-supervised" because they require some manual input in order to add structure to the data — the clinical team "supervises" the system by suggesting anchors, and the algorithms learn the rest of the model autonomously. "As long as we can catch at least one of the ways that a condition is often mentioned, that's good enough," says David. "The other ways that it could be mentioned are automatically learned by the algorithm."

David and his team have been developing many other algorithms and systems that also integrate machine learning into healthcare by, for example, making AI better at checking symptoms and diagnosing conditions, pinpointing which tests are most likely to lead to a diagnosis, and identifying which patients are most at risk for developing certain diseases — all outcomes which improve patient care and maximize prevention in a cost-effective manner by targeting the right patients.

"The last five years that I've been at NYU, I've been digging deep into healthcare, understanding the fundamental problems, and then generalizing back to computer science," summarizes David. "I've been figuring out what are the theoretical questions that, if we solve them, will directly affect healthcare, and also so many other fields.

"But it's the healthcare part which is really guiding my work. There are many interesting theoretical questions to study in machine learning and which ones I tackle are guided by the ones that I think are most urgent in healthcare," he says. "My hope is that, if I succeed with my research, I'm going to ultimately save or improve people's lives. That's what drives my work."

Fedor Bogomolov and Subhash Khot named 2015 Silver Professors

Congratulations to Fedor and Subhash for being named Silver Professors! A bit about the work of each, as included in the announcement by Gérard Benarous, Director of the Courant Institute of Mathematical Sciences and Thomas Carew, Dean for the Faculty of Arts & Science:

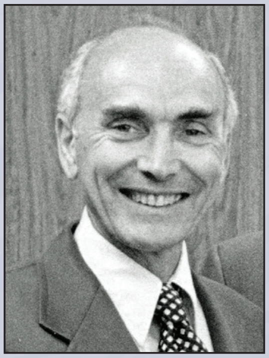
Fedor Bogomolov has contributed fundamental insights to a wide range of fields, from his early papers in topology, differential and algebraic geometry, to number theory, group theory, invariant theory and many others. His decomposition theorem is the basis of classification of varieties and forms the foundation of modern string theory and mirror symmetry, some of the most important concepts in modern mathematical physics. It is also the basis of the theory of holomorphic symplectic varieties, which have been intensely studied in recent years, as they encode highly nontrivial algebraic integrable systems. Bogomolov stability, Bogomolov-Miyaoka-Yau inequality, Beauville-Bogomolov form, Bogomolov conjecture about Galois orbits of points on abelian varieties — these are just a few of his deep ideas, which continue to inspire researchers worldwide. Fedor's most recent work, on almost abelian anabelian geometry, unraveled hidden structures in function fields of algebraic varieties, allowing the reconstruction of these fields from their Galois symmetries. This is a tremendously significant development, creating a whole new philosophy in higher-dimensional birational geometry.

Fedor has published more than 110 papers, given plenary talks at major international meetings, and served on editorial boards of leading mathematical journals. He is one of the giants of modern algebraic geometry.

Subhash Khot's most celebrated work, and the one that led to his recent Nevanlinna Prize, is on the "Unique Games conjecture." […] The conjecture addresses the main question in computational complexity: how hard are problems to solve or approximate? For over three decades, the main approach to this question was through NP-hardness: namely, we provide strong evidence for the hardness of a problem by showing that it is as hard as any other problem in the class NP. Assuming that NP contains hard problems, as most experts strongly believe, we deduce that our problem is hard. This paradigm has been extremely fruitful and has led to a complete understanding of some important combinatorial optimization problems. Yet, a large number of problems did not succumb to this approach, and their hardness remained a mystery for many years.

Subhash's Unique Games conjecture (UGC), introduced in his ingenious 2002 paper, turned out to be the missing key. His conjecture says that the so-called Unique Games problem, a mild variant of the standard NP-complete constraint satisfaction problem, is hard. So in order to show that a problem is hard based on UGC, one needs to show that it is as hard as the Unique Games

In Memoriam: Norman Grossman *(November 3, 1922-May 29, 2015)*



Dr. Norman Grossman (Ph.D. '58), a distinguished alumnus of the Courant Institute, spent his entire career at the Fairchild Republic Company in Farmingdale, Long Island. Beginning as a junior engineer (at what was then Republic Aviation) and retiring as chairman and CEO, Grossman had only a single, two-year absence in the 40s to serve in the Merchant Marine during World War II. After returning from the war, Grossman began attending the Courant Institute at night while working full time at Republic. It took him 10 years to earn his Ph.D., which he completed in 1958 with the dissertation "Nonlinear Problems in Elastic Stability," advised by Fritz John.

At Fairchild Republic, Grossman was responsible for design, production and testing of high-performance military aircraft. During his tenure there, the company secured many military contracts. One of the most well-known and long-lived was the A-10 jet, which was conceived in the early 1970s as a strategic response to combat challenges in Vietnam, where the Air Force's sleek, fast planes were not well suited to assisting and providing cover to troops on the ground. First deployed for combat in the Gulf War, a 1991 Forbes article describes the A-10 as "Squat, heavily armored, with bulging jet engines perched high and to the rear of its boxy fuselage" and with a "peak speed of just 420 mph." The relatively inexpensive Warthog, as it is known, was and remains a single-seat plane that can fly for extended periods of time, at low altitudes, and with excellent maneuverability. It is extremely durable, accurate in weapons deployment, and capable of destroying armored vehicles such as tanks. Grossman was paraphrased by Forbes as saying, "the plane is so resilient that it can lose an engine, 16 feet of a wing, and part of its tail, and still return to base." Some 700 A-10s have been made. Though much beloved by its pilots and arguably the most successful close air support aircraft in Air Force history, it has been threatened with mothballing over the years. It's currently still scheduled to fly at least through 2022.

Despite knowing every nook and corner of the plane, Grossman didn't ride problem. Using the UGC, one can show that many natural optimization questions are hard. Moreover, one can often nail down precisely the best approximation factor achievable. In a series of remarkable papers by Subhash and others, it was then realized that for a large family of problems, the UGC gives the precise approximability factors.

Subhash Khot's research has received extraordinary levels of recognition and honor. In 2014 he won the Rolf Nevanlinna Prize, the highest scientific award in theoretical computer science, awarded once every 4 years at the International Congress of Mathematicians, for outstanding contributions in Mathematical Aspects of Information Sciences. In 2010 he was awarded the NSF Alan T. Waterman award, given annually to a single scientist in the U.S. aged 35 or younger. He was named a Simons Foundation Investigator in 2015. In 2010 he was an invited speaker at the International Congress of Mathematicians. He has received an NSF CAREER award, a Sloan Foundation Fellowship, and a Microsoft New Faculty Fellowship. ■

STUDENT HONORS

Henning Biermann Prize
Shravas Rao
Rahul Gopalkrishnan

Sandra Bleistein Prize
Irena Vankova

Thomas Tyler Bringley Fellowship
Alexander Kaiser

Hollis Cooley Prize
Taher Dahleh

Janet Fabri Prize
Jonathan Tompson
Sunandan Chakraborty

Kurt O. Friedrichs Prize
Nan Chen
Ian Tobasco

Paul Garabedian Fellowship
Emily Denton

Max Goldstein Prize
Abhinay Ashutosh

Harold Grad Memorial Prize
Vitaly Kuznetsov
Moumanti Podder
Thien Nguyen

Moses A. Greenfield Research Prize
Nadejda Drenska

Martin and Sarah Leibowitz Graduate Prize for Quantitative Biology
Benjamin Fogelson

Wilhelm Magnus Memorial Prize
Travis Askham
Insuk Seo

Math Master's Thesis Prize
Chanyang Ryoo

Master's Innovation Prize
OnYou Hwang
Kavitha Vishwanathan
Nishant Kumar

Matthew Smosna Prize
Yi Wan
Prashant Singh Tewatia

Congratulations to our 2016 Student Award Recipients!
Find out more about these awards at http://cims.nyu.edu/academics/student_recognition.html

inside of one until sometime in the 80s, when he got a call that an experimental two-seat Warthog at Edwards Air Force Base in southern California was waiting to take him up in the air. The pilot flew the plane blind, at night, and in between mountains. At the end of the flight, Grossman emerged (see photo) with watery eyes — happy to be back on the ground!

"As quick with a smile as he was with the answer to a complex theoretical problem, Grossman was a rare bird in today's world, a gentleman, a true scholar," says the obituary printed in the New York Times. He was "one who lived his life with integrity and joy." Grossman is survived by his wife Thelma, with whom he hosted several NYU alumni gatherings in their home in Greenwich Village, and by nieces Susan Scribner and Meryl Fiedelman. He passed away peacefully last spring at the age of 92. ■

FACULTY HONORS

Courant Director **Gérard Benarous** was elected a member of the American Academy of Arts & Sciences, one of the nation's oldest and most prestigious honorary societies. "Each new member is a leader in his or her field and has made a distinct contribution to the nation and the world," said Don Randel, chair of the Academy's Board of Directors.

Richard Bonneau received the 2015 Iakobachvili Faculty Science Award from the NYU School of Arts and Science. The award recognizes "science faculty who've most clearly demonstrated evidence of past excellence and future prospects of growth."

Subhash Khot has been named a Simons Investigator in Theoretical Computer Science by the Simons Foundation. As stated in their announcement, Subhash "initiated a new direction in computational complexity theory and approximation algorithms, based on his Unique Games conjecture, which is currently one of the most important conjectures in theoretical computer science."

Peter Lax received an Honorary Doctor of Science degree from NYU for his contributions to Mathematics and the university. An alumnus and Professor Emeritus at the Courant Institute, Peter is also the recipient of the Abel prize in 2005, and recently went to Washington to receive the Lomonosov Gold Medal, the highest award given by the Russian Academy of Sciences, which he was awarded in 2013.

Yann LeCun was awarded the IEEE PAMI (Pattern Analysis and Machine Intelligence) Distinguished Researcher award at the 2015 International Conference on Computer Vision. The award recognizes candidates "whose research contributions have significantly contributed to the progress of Computer Vision."

Andrew Majda has received the American Mathematical Society's 2016 Leroy P. Steele Prize for seminal contributions to research. The award honors two 1983 papers which, "To date, [remain] the only available complete and general result about multidimensional systems" of conservation laws, "which are fundamental in fluid mechanics," writes the AMS. The papers — *The existence of multidimensional shock fronts* and *The stability of multidimensional shock fronts* — "pioneered the expansion" of research in this area from the one-dimensional to the multi-dimensional case.

Theodore Rappaport is the recipient of the 2015 IEEE Communications Society Edwin Howard Armstrong Achievement Award, "for broad contribution and outstanding leadership in channel measurement and technology research fundamental to mobile communication." The Armstrong Achievement Award recognizes "outstanding contributions over a period of years in the field of interest of the Society."

Dennis Shasha has been named an INRIA international chair, a research award given to approximately five international researchers per year. He is hosted by the ZENITH project team in Montpellier, France, which focuses on designing algorithms for large scale scientific data problems.

Victor Shoup has been named a Fellow of the International Association for Cryptological Resesearch, "for fundamental contributions to public-key cryptography and cryptographic security proofs, and for educational leadership." He has also been awarded the 2015 Richard D. Jenks Memorial Prize by ACM's SIGSAM (Special Interest Group in Symbolic and Algebraic Manipulation) for Excellence in Software Engineering Applied to Computer Algebra for his work on NTL: A Library for Doing Number Theory.

Georg Stadler and colleagues won the Association for Computing Machinery's 2015 Gordon Bell Prize in recognition of outstanding achievement in high-performance computing. The team received the prize for the development of algorithms for solving large nonlinear systems arising in geodynamics. The work is detailed in the paper *An Extreme-Scale Implicit Solver for Complex PDEs: Highly Heterogeneous Flow in Earth's Mantle,* and will "[allow] researchers to gain new insights into the geological evolution of the planet,'' says the ACM.

Duke University has awarded **Raghu Varadhan** an honorary degree, a Doctor of Science, *honoris causa*, citing his distinctions including the Abel Prize, awarded for "his contributions to probability theory and for creating a unified theory of large deviations," and his National Medal of Science. Duke President Richard H. Brodhead said: "These degrees honor individuals who have made outstanding contributions in diverse fields. We lift them up as inspiring examples of how today's graduates might use their talent and education to make their own contributions to the world."

Fedor Bogomolov and **Subhash Khot** were also named Silver Professors (see page 8).

Math outreach champion: Fred Greenleaf retires, but doesn't slow down

by April Bacon

Professor Fred Greenleaf retired in January after 48 years at Courant. For the past 25 plus years at the Institute, he has been dedicated to mathematics outreach and education. The number of students Fred, winner of two NYU Golden Dozen Awards for Distinguished teaching, has reached, extends well beyond those who took his classes.

In 1955, as a high school student, Fred was the Westinghouse Science Talent Search Grand Prize winner across all of the sciences for a project in his original area of interest—chemistry. As an undergraduate at Pennsylvania State University, he studied chemistry, physics and math in an Engineering Physics program and his master's NSF fellowship at Yale was in biophysics. In the middle of his first semester of graduate studies he transferred to the Ph.D. program in Mathematics, as an NSF Fellow. He completed his Ph.D. (Mathematics) at Yale in 1964. After a year as an instructor at UC Berkeley, he became an Assistant Professor there. Three years later, in 1968, he came to NYU.

Fred's research in the 70s and early 80s focused on geometry of groups, says Martin Moskowitz (CUNY), a longtime collaborator of Fred's. "We studied the set B(G) of bounded conjugacy classes in a Lie group G and proved it is closed (quite unexpected), and is precisely the union of supports of the finite G-invariant measures," says Moskowitz. Later Fred began investigations applying Kirillov's "method of coadjoint orbits" to break new ground in representations of nilpotent Lie groups, noncommutative harmonic analysis on their homogeneous spaces, and structure and solutions of invariant differential operators that live on those spaces. This work with Larry Corwin began when Larry was a postdoc at Courant and extended over 20 years until 1992, when Larry died unexpectedly.

An Anchor for Math Outreach and Education

Fred's focus on math education began in 1990, when, as chairman of NYU's Science Education Policy Committee, he led development of the math and science curriculum required of all non-science majors. In 1993 he continued to steer reform of large-scale core education through NSF-funded NYU initiatives, leading a team of faculty that included the Chairs of all Science Departments. Together they created the Math and Science components of the Morse Academic Plan (MAP). "I got to work with a lot of people in many different fields," says Fred, whose multi-disciplined background made him well-suited for the role. MAP provides a solid foundation for students in answering questions like: How do we know what we know about the universe? How can we use mathematical tools to find out how it works?

Fred's many contributions to math education are difficult to summarize because they are so numerous: He has written textbooks and course notes, designed curricula, and mentored high school and undergraduate students. He's played a part in cSplash, NYC Math Circles, and Courant's Center for Mathematical Talent (CMT). He served as chief advisor for the Math for America Fellows at NYU, a joint program with Steinhardt that trained highly gifted high school math teachers. "He was invaluable for the students going through that program," says Courant Professor Sylvain Cappell, "as a mentor, as a teacher, and as a person who helped shape the program." Additionally, says Sylvain, "Fred supported high quality high school teachers when they were facing people that wanted a watered-down math curriculum."

Parents also concerned about K-12 math education have called the Institute for decades. Fred has been a central part in initiatives designed to provide those students with opportunities they need yet are not necessarily getting in their schools. Through the CMT, for example, talented high school students attend Courant courses. One student, who graduated this year, "has ten graduate math courses under his belt," says Fred. "He's ready to start dissertation work. After one more semester, he'll work with an advisor, pick a topic and start reading the literature."

Fred has also had successes in some mathematics policy reform. Fred and David Garbasz met around 2000 through New York Hold, an organization of concerned parents and educators. Garbasz, an entrepreneur and philanthropist who gave seed money for the CMT, says that, as two examples, Fred was "instrumental" in getting a more rigorous math curriculum adopted in Israel and in convincing the selective New York City NEST school to adopt Singapore math, which emphasizes mastery of math content.

Later, Garbasz's mathematically talented daughters took coursework with Fred when they were in high school. "He was always very welcoming," Garbasz says. "When one of my daughters was studying algebra with him, he gave her a dozen textbooks off his walls. He's a very generous guy, a very good mathematician, and a great teacher," he says, lamenting that Fred is retiring. The silver lining: "Fred's still very active. I doubt he'll slow down."

In retirement, Fred will continue to advise and participate in the CMT. They plan to expand the number of high school students attending Courant classes as well as develop programs for "NYC middle school students who would benefit from enrichment programs," says Fred. He has been collaborating with Fedor Bogomolov on lecture notes for graduate Algebra I and II. "Being retired, I actually have time to think about this stuff more!" he says. He also meets regularly with Moskowitz to work on questions about lattices and discrete subgroups.

"As my wife says, 'How will they know he's retired? He's still got an office and his computer account. He lives two blocks away. He's over there all of the time,'" says Fred. As Sylvain expresses, we hope for many years that Fred will "continue in his involvement, because of his wisdom, his deep concern, deep knowledge and understanding of the issues involved in mathematics education."

Like family: Larry Cohen, tireless staff member, retires

by April Bacon

Larry Cohen, Duplicating and Mail Services Coordinator, is retiring after just over four decades at the Courant Institute. Larry, a Vietnam veteran, was trained in software by CDI (Control Data Institute) and in 1975, after returning from the military, he was hired by Paul Garabedian to serve as the third shift operator for Courant's CDC 6600. After nearly a year keeping the computer in operating condition, Larry requested to move into a daytime role at the Institute so that he could preserve his evenings for his family—his wife, Sheri, and his daughter on the way. While on his first vacation for the birth of his daughter, Staci, Larry recalls receiving a call from his supervisor who said: "I have good news and I have bad news — the good news is you can have a day job if you want it. The bad news is you have to Start ASAP!"

With that phone call, Larry began his service to the Institute in the role in which so many faculty, students, and administrators have come to depend on him. There are few who have passed through the Institute who haven't heard Larry's five reassuring words: "I'll take care of it." While the days of typing, copying and shipping cartons of proposals for grant applications are, thankfully, long gone, Larry's contributions to daily operations continue to be essential to life at Courant. Mail correspondence arrives to its destinations on time, mail for Warren Weaver Hall occupants is delivered directly to mailboxes on the ground floor, the implements of daily Institute life are always in supply, and thousands upon thousands of exam copies get safely made, even if an out-of-service copier means Larry has to run the job across campus to get it done on time. "In recent weeks, I've overheard many faculty wondering what will happen after Larry retires and asking him to stay a little longer," says Irene Robling, Associate Director of Administration and Finance at Courant. "For most of us, we've never been at Courant without him and he will be missed by everyone, especially those who will no longer be able to find Larry before 7am to copy finals or midterms!"

"Larry Cohen has been at the Courant Institute for 41 years," remarks Dave McLaughlin, NYU Provost and Professor of Mathematics and Neuroscience. "For the entire 41 years, Larry has been an integral part of the Courant community, always going above and beyond in the performance of his duties at the Institute." In 2000, Larry was recognized for that service with an NYU Violet Award. He also received an award for never being late on the job, a distinction he has maintained for the entirety his service — arriving not only on time, but an hour and a half early each day. "I've always had bosses tell me, you're starting too early! You're spoiling everybody!" says Larry, "And it does my heart well to do that. I'm here. I'm here for the people."

Larry has many happy memories from over the years. Peter Lax and Louis Nirenberg still visit Larry on occasion to reminisce about "the good old days" and to remember dear friends who have passed on, like Professors Paul Garabedian, Harold Grad, and longtime Instructor Samuel Marateck. Remembering those times "keeps us young," says Larry. One personal memory with Sam Marateck began in their youth: In the early '60s, Larry and Sam lived across the street from one another in Long Beach, and the two used to go surfing together. And in Larry's earlier years at Courant, when dancing was a common feature of the Institute's parties, Larry and his wife and children would join Professors Lax, Nirenberg, and Garabedian and their wives, as well as other faculty and administrators on the dance floor.

Over the years, both of Larry and Sheri's children, Staci and Matthew, earned degrees from NYU's Stern School of business. Larry also got to see the Courant Institute's students earn their degrees, graduate, and come back to visit the Institute years later as "deans and chairpersons" at other Universities.

"It was like family here," Larry says.

After retirement, Larry will be moving from his home in Forest Hills to Laguna Hills, California. He and his wife will live near their two children and grandsons Jake (13), Max (12), and Noah (5), and in May will be celebrating the arrival of their fourth grandson. Their children are naturally thrilled about the move—"and not just for the babysitting!" says Larry, "But for all of us to be together — that's important with a family. It's time, after 41 years, to make time for my children. To live out the rest of my life. And take up surfing again!"

With his parting message, Larry offers: "I'll always remember everybody here [at Courant]. Everybody has a place in my heart. Boy, let me tell you: The years go fast. They really do. But I'll tell you, they were beautiful years here. Good years."

"Larry will be missed by all," concludes Dave. "And while we all wish him the very best in retirement, it is hard to image the Courant Institute without him." ■

A lot of heart: Tamar Arnon, student advocate, retires

by April Bacon

Before a graduate student in mathematics arrives to the Courant Institute, one of the first names they come to know is Tamar Arnon, Assistant Director of Student Affairs. Tamar arrived at Courant in 1986, after about half a decade in the Office of the Dean of the Faculty of Arts and Science. She served one semester in computer science before moving to the mathematics department. Now retiring after 30 years of service to the Institute, Tamar has seen many generations of students come through Warren Weaver Hall, easing the path of each one from admittance to graduation.

Nadia Drenska, a fourth-year Ph.D. student studying optimal control theory and advised by Bob Kohn, recalls well her visit to the Institute after being admitted. Tamar had arranged meetings for her with seven faculty members in one day. "It was kind of overwhelming!" exclaims Nadia—"but it was exactly what I needed to get a feel for the department."

Originally from Bulgaria, Nadia sought out Tamar again on several occasions. Once, as president of the Student Association, she needed help implementing a student mentor program for the next incoming class of students. "We wouldn't have been able to implement this if she weren't so willing to help out," says Nadia. "You can see she really cares about you and she really wants to help… She's been a sort of mother figure to us."

Students go to Tamar with any number of questions, asking for guidance on and assistance with, for example, things like what courses to select, when to find a faculty mentor, how to organize an event, and for broader general advice such as on how to be an effective teacher. With some English as a second language students, Tamar has even put in extra hours coaching them through classics. As a lover of great literature, she has guided them through works like Harper Lee's *To Kill a Mockingbird*, John Steinbeck's *East of Eden* and, for young women, Louisa May Alcott's *Little Women.* Regardless how big or small the issue, Tamar is always there, eager to listen and help.

"Everybody knows her impact with students is enormous," says Melissa Kushner Vacca, Manager of Academic Affairs for the math department, who has been with the Institute for ten years. For Melissa, one moment in particular characterizes perfectly Tamar's commitment to students: the morning of one prospective Ph.D. student visit, when Tamar called Melissa into her office. "She's sitting in her office with a scarf wrapped around her arm, holding her *broken wrist* up. And she looks at me very seriously and says: 'I think I may need to go to the emergency room but I needed to come and meet these students today'!

"Her dedication is so evident," Melissa says. "She's come in through injury, through illness. She fights her way back in."

Nadia's experience and Melissa's story are emblematic of the dedication and heart that, in 2000, earned Tamar an NYU Distinguished Administrator Award.

"I know it must be very hard to finish a graduate degree," says Tamar, "and I want to be there. I always think of myself as holding a giant broomstick, running a little bit ahead of them and clearing the path as much as I can — all the little things. Every once in a blue moon a big thing. But all the little things that are going to make it difficult for them. Sometimes they don't quite feel secure, the pressure gets to them, the difficulty of doing a graduate degree, being away from home — and there I am. And I can bring them up and out. And this is one of the things that I treasure."

"It's a collective memo of how we feel about her," says graduate student Nadia Drenska of this poster which Tamar displays in her office. Students made the gift for Tamar in spring 2014, when she was battling breast cancer for the second time. "I fought hard to come back as fast as my little legs would carry me," says Tamar, "because here is where all the good things happen to me."

Although her work prior to arriving at Courant was pleasant enough, something about the Institute was different for her. Before Courant, "I didn't have in my career anything that was central to my life, that gave me a real purpose," she says. At Courant, she was able to answer the questions, "'What do I do with my day?' And, 'What I do, how does it matter'? … I think that what we do here matters a great deal, to individual people and to the cause of education."

"Until I came to Courant," Tamar says, "I'd never really been able to use my brain on the job. When I came here, the faculty asked me for really the first time, the all important question: 'Tamar, what do you think?' And I almost died. I'd never been asked that before. And since then they've spoiled me into becoming a thinking person and now they hear what I think whether they want to hear it or not!"

What is immensely evident is that her advice *is* wanted, and sought out by students, faculty, and administrators alike. "There are so many times that we will run to her — her advice is so valuable. Her impact will be felt even after she's gone," says Melissa. "I can speak on behalf of all of the staff here that we will miss her enormously."

Tamar returns the affection. "We have a team here [in the math department] of several women [administrators]," she says. "We're 'all for one, one for all.' It's really neat when, as a team, we come up with something creative to solve [a student's] problem… it really makes your day when you see these students who ran into trouble persevere."

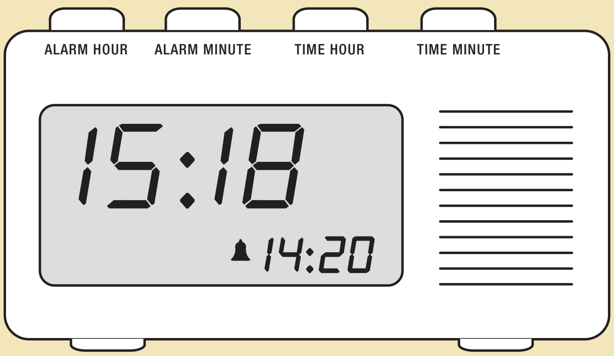
What will Tamar do when she leaves the Institute? "One thing I'll be doing is the day after I leave, I come right back!" she says. "I'll be working part time so that I have a softer landing." After that, "One [idea] is to be a lady of leisure in New York City. I can't think of a better thing. I love museums and theater and opera and ballet. But something will be missing just doing that, there's no question. So, working or volunteering with young people. Maybe with people who need help with English as a foreign language. There are a lot of possibilities and I hate to admit, but I haven't explored them yet because I've been Tamar from Courant for such a long time and loving it so much that the idea of any other Tamar is not easy for me. It'll happen.

"A lot of heart goes into this," says Tamar. "It's been good for *me*. Working here really gave me a focus about what is important and how all of us in our own way can be part of something much bigger." ■

PUZZLE SPRING 2016

Sleep No More

by Dennis Shasha
Professor of Computer Science



As with every alarm clock, this one can hardly wait to ring, and you must figure out how to set it to wake you up when your nap is over, making as few button pushes as possible.

We begin simply, with a 60-minute clock that counts only minutes, going from 0 to 59. The alarm can also be set from 0 to 59 and will go off when the clock reaches the same value. Say you want the alarm to go off in m ($m < 60$) minutes, the time value now is x, and the alarm value is y. You want to move the time value or alarm value forward as little as possible so the alarm goes off m minutes from now.

WARM-UP The time is at 20 minutes, and the alarm is at 5 minutes. You want the alarm to go off in 35 minutes. One possibility is to move the alarm forward (the only allowable direction) to 55. Another is to move the time value ahead to 30. The second solution is less expensive, requiring only 10 pushes, so you prefer that.

SECOND WARM-UP In general, for this 60-minute clock, if T is the time value and A is the alarm value and you want to wake up in m (< 60) minutes, which value do you move and at what cost in terms of number of minutes ahead you must push that value?

Solution to Second Warm-up

Recall $(y - x) \bmod 60 = y - x$ if $x < y$ or $(y+60) - x$, otherwise; for example, $(14 - 4) \bmod 60 = 10$, but $(4 - 14) \bmod 60 = 50$; $(y - x) \bmod 60$ is thus the number of minutes on the 60-minute clock that value y is ahead of x.

Let $L2$ be the minimum non-negative value having the property $m = (A - (T+L2)) \bmod 60$. $L2$ is the number of minutes we would have to advance the time to achieve our goal of waking up in m minutes. We call it timeadvance and solve for
it as follows: timeadvance(A, T, m) = $(A - (T+m)) \bmod 60$.

If timeadvance(A, T, m) <= 30, then advance the time by that amount, else advance the alarm by 60 — timeadvance (A, T, m). *End of solution.*

Now imagine you have a 24-hour clock for both alarm and time. You have the same problem. You want the alarm to go off in m minutes where m can now be any number up to (24 x 60) — 1 minutes.

You can move the hour value (between 0 and 23) for both time and alarm separately from the minute value (between 0 and 59). Each move forward by one of any hour or minute counter costs one unit of effort. (Moving the minute value past 59 to 0 does not affect the hour value.)

Is it ever an advantage to move both a time value and an alarm value, as opposed to just one?

Solution

Yes. Suppose the time is set at 15:18 and the alarm is 14:50. You want the alarm to go off in 30 minutes. The best thing is to move the alarm forward by one hour and the time to 15:20, costing a total of three units of effort.

Can you now find an elegant solution, that is, by minimizing the case analysis and figuring out a cost-minimizing algorithm for this problem? Your alarm clock will still have the pleasure of waking you up, but it will never know what time it really is.

Dennis Shasha is a professor of computer science in the Courant Institute at New York University, New York, as well as the chronicler of his good friend the omniheurist Dr. Ecco.

The Institute presented a discussion for alumni and friends on global sea level rise on February 24. Here, Center for Atmosphere and Ocean Science Professor David Holland (right) speaks with Jack Cogen (MS'82, MBA '87). Holland was joined by Professors Dale Jamieson, Chair of Environmental Studies, and Michael Oppenheimer of NYU's Law School and Princeton's Woodrow Wilson School.

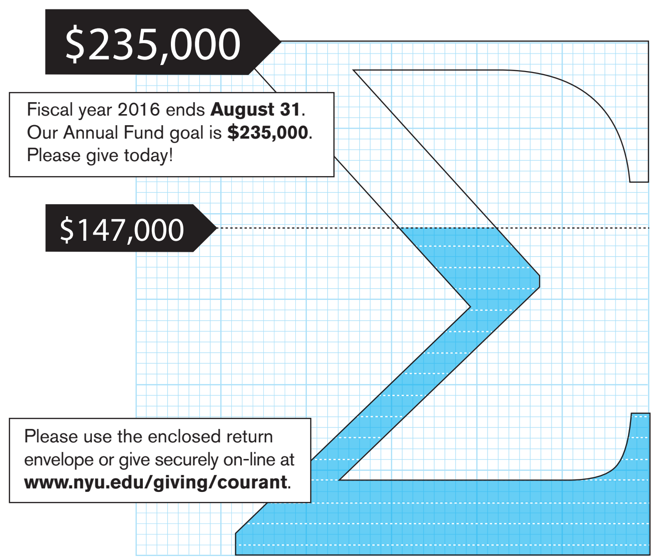
Jun Zhang, Courant Professor and Co-director of the Applied Math Lab (AML), presented this year's Holiday Lecture on "The Little Lab in the Lobby," discussing the history and complexities of fluid dynamics and experiments conducted in the AML. As Courant Director Gérard Benarous said in his opening remarks, "Jun's work is well known for its creativity, its flare, and its elegance, whether it's flags flapping, fish swimming, or cyclic motions of the earth's continents, his experimental work has inspired many people across the world." Watch this and other holiday lectures at http://video.cims.nyu.edu/media/HolidayLectures/.

THE GENEROSITY OF FRIENDS

Tuition and fees do not cover the true cost of education. Donations from alumni, friends and others who believe in the importance of education and research provide support for the Courant Institute's mission and are critical to its remaining competitive with its historically well-endowed peers. Private support makes possible scholarships and fellowships and adds resources for research facilities like the Applied Math Lab. They enable the Institute to invite distinguished speakers for both technical and public lectures, and assist in maintaining an up-to-date learning environment. They also support student clubs such as Women in Computing (WinC), alumni social and professional networking events and community outreach programs like The Center for Mathematical Talent which provides math enrichment to New York City elementary, middle and high school kids — many from underserved communities — and the GSTEM girls' summer STEM internship program.

We are deeply grateful to our all our donors, which is why we initiated the **Sigma Society** in the Fall of 2015 to recognize those who have given a gift of any size in each of the last five years. Giving is extremely personal but we hope that if you are in a position to give special support, that you will consider contributing at the **Director's Circle** level of $1,000 or more, or contact the Development Office to find out about the Institute's specific needs. Donors at the $2,500 level are also invited to join the **NYU Society** and at the $5,000 level the **President's Council**.

A Challenge to Double the Impact of Your First Gift to Courant!



Did you know that alumni participation in giving affects university rankings? To demonstrate their commitment to Courant and to encourage giving in any amount from all Courant alumni, several loyal and generous alumni are offering a special challenge. For the remainder of fiscal year 2016, they have pledged to match the gifts of all first time donors 1:1 up to a total of $30,000! So if you give for the first time between now and August 31, your gift will be worth twice its face value.

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DONOR ACKNOWLEDGEMENT

The annual list of donors to the Institute will appear in our Fall 2016 issue. Make your gift conveniently and securely online at **www.nyu.edu/giving/Courant** and visit **matchinggifts.com/nyu/** to see if your employer matches your gifts to education.

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To join our community of Courant donors, please visit the new NYU online giving page at giving.nyu.edu/courant or contact **Robin Roy** at **robin.roy@cims.nyu.edu** or call **212-998-6974**.

STAY CONNECTED

You can continue to make connections with fellow alumni, faculty and friends by attending lectures and other events in New York and all over the globe! See Institute news and activities on the Courant website (CIMS.nyu.edu) and Courant Alumni webpage (**CIMS.nyu.edu/alumni**).

Send us news of job changes, moves, and meet-ups with Courant alums at alumni.news@cims.nyu.edu. We also invite all Alumni to keep colleagues and friends up-to-date on life events such as career achievements and family milestones; submitted items will be considered for publication in the Newsletter or online.

Please make sure your contact information is up to date by visiting the NYU Alumni website at **www.nyu.edu/alumni** or send your email and postal address, phone or employment changes to **alumni.relations@cims.nyu.edu** and we'll take care of the rest.

There are benefits to being an NYU alumnus/a. Check out the NYU Alumni webpage for campus and library access, insurance, entertainment and dining, university club memberships in your area, and much more, including NYU alumni networking events wherever you go!

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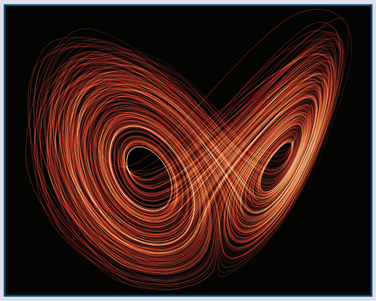

Dynamical systems studies have advanced considerably since Edward Lorenz's butterfly attractor (at left) first offered a point of entry for understanding them (see page 2).