mathematical sciences news 2018

Carnegie Mellon University

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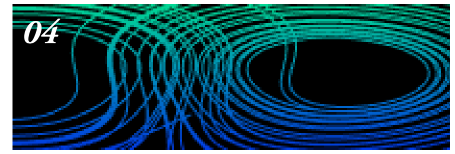
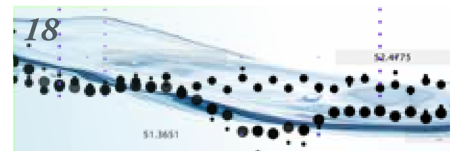
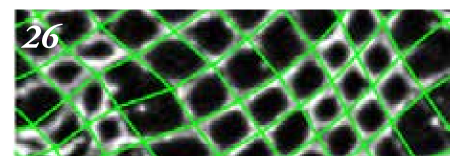






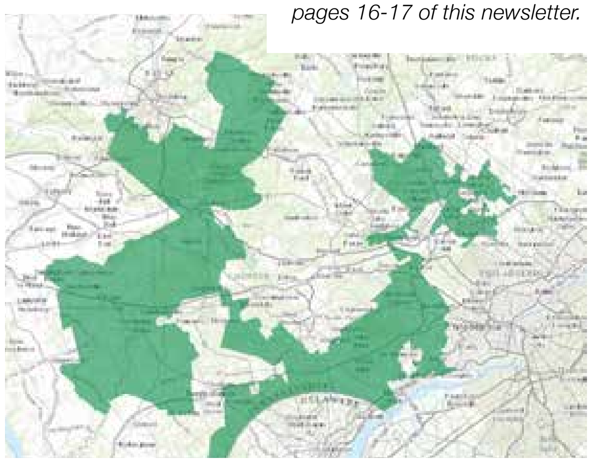
Math Helps Make Congressional Districts in PA More Fair

Until recently, the lines drawn on the congressional map of Pennsylvania looked irregular. So irregular, in fact, that the outline of the seventh district looked like a drawing of cartoon characters and was often referred to as “Goofy kicking Donald Duck.”

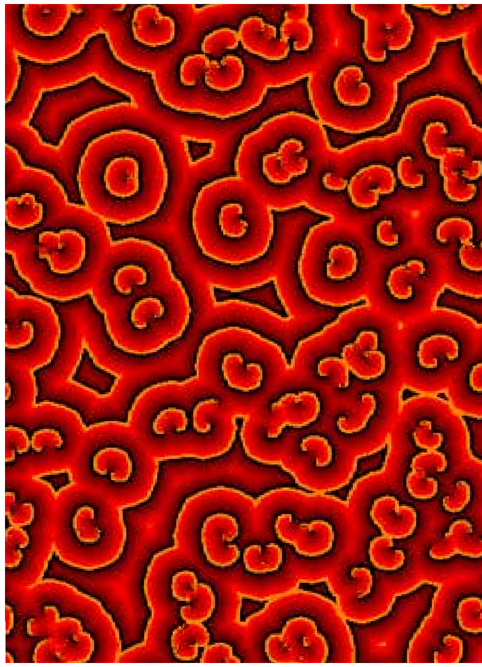
These wildly drawn maps are likely the result of gerrymandering, the more than 200-year-old practice of redrawing congressional and legislative lines to benefit a particular political party. Mathematicians, including Mathematical Sciences Associate Professor Wesley Pegden, have been enlisted to the forefront of the fight against gerrymandering.

In early 2017, Pegden, with University Professor of Mathematical Sciences Alan Frieze and the University of Pittsburgh’s Maria Chikina, published a paper in the Proceedings of the National Academy of Sciences that used Markov Chains to redraw Pennsylvania’s congressional maps step by step and show that there was little chance that the existing districts had been drawn at random or without bias. The paper caught the eye of lawyers who were challenging the Pennsylvania congressional map in front of the state Supreme Court. Pegden testified in the case. The court found the maps to be unconstitutional and called for the maps to be redrawn before the state’s May primary elections.

The newly drawn map appears to be more fair. In November’s midterm elections, Pennsylvania’s congressional delegation went from primarily Republican to evenly split, reflecting the popular vote in the state.



“Goofy kicking Donald Duck.” Pennsylvania's 7th district before the newly drawn map. United States Department of Interior.



Cover Image
Greenberg-Hastings model

The cover image is generated by the cellular automaton known as the Greenberg-Hastings model. This cover image is based on work of David Griffeath of the University of Wisconsin. Griffeath has conducted extensive studies of cellular automata.

For more on the cover image and Greenberg-Hastings itself see pages 16-17 of this newsletter.

Letter from Mathematics Department Head, Tom Bohman

The Department of Mathematical Sciences pursues a strategy of developing and maintaining research groups in vibrant areas of mathematics that are enriched by natural connections with other research domains within mathematics and beyond. Our department has a tradition of being outward looking. We have research groups in applied analysis, combinatorics, logic and mathematical finance and probability, with a particular interest in research that has connections with other areas of strength at Carnegie Mellon. All of these research groups have been quite successful in recent years and the stories in this newsletter are reflections of that success.

The quality of our groups was affirmed by the 2018 *U.S. News & World Report* ranking of graduate programs in mathematics. Carnegie Mellon placed 16th in applied mathematics, 7th in discrete mathematics and combinatorics and 6th in logic, all improvements from the previous edition of these rankings. While rankings of academic programs have their flaws, I feel that these results reflect genuine improvements in the quality of the research the department has produced over the last few years. Our rise in the rankings also means that our peers are taking notice; the survey results are based only on input from mathematics departments that grant Ph.D.s in the area in question.

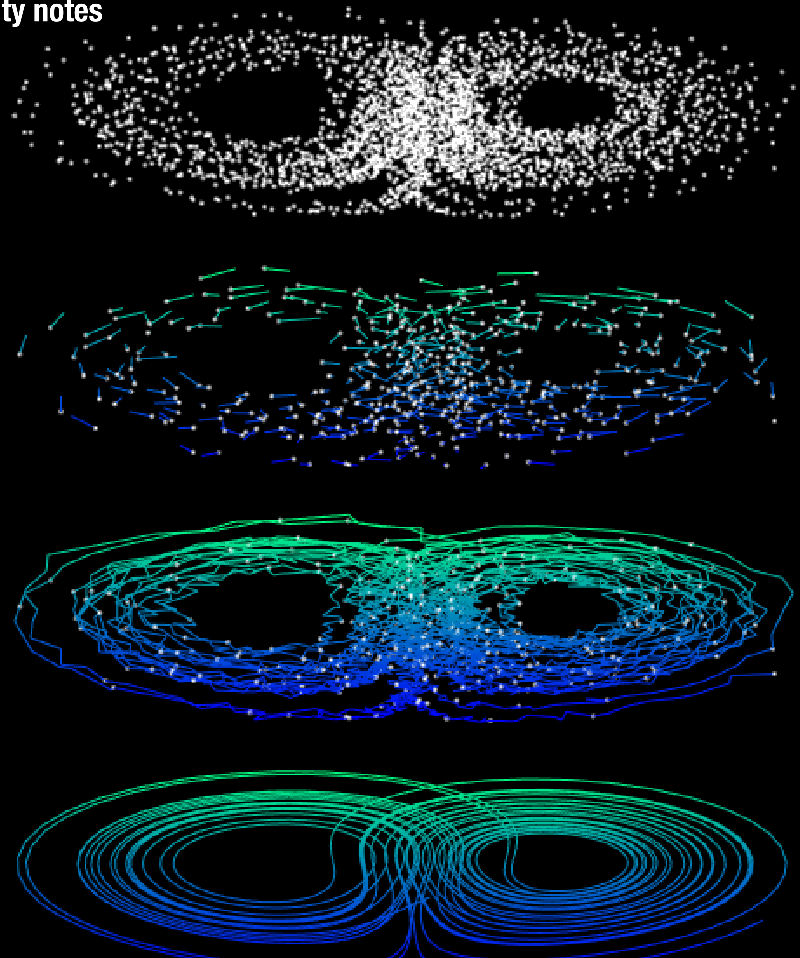
In this issue of the newsletter, we will introduce you to three tenure-track faculty members who joined the department in 2018. These new faculty represent our continued investment in research (see page 8).

The cover image for this newsletter was produced by the cellular automata known as the Greenberg-Hastings model (see page 16 for some mathematical details regarding this model). Jim Greenberg, who introduced this model in joint work with Stuart Hastings, passed away earlier this year. Greenberg was head of the Mathematical Sciences Department from 1995 to 2002. For more on Greenberg, see the story on page 14.

The department’s outward-looking research orientation also has benefited our students. We have constructed a curriculum that gives excellent support to educational activities across the university while preparing mathematics majors for success in a wide range of careers both in academia and beyond. You can read about the success of our students in the stories on pages 22-31 of this newsletter to learn more about our current and recent students.

I hope that the many alumni of the Department of Mathematical Sciences have a chance to reconnect with the department by visiting cmu.edu/math

Let us know what's new with you!



Hayden Schaeffer Receives NSF CAREER Award

Assistant Professor of Mathematical Sciences Hayden Schaeffer received a Faculty Early Career Development (CAREER) award from the National Science Foundation. The award supports his work on optimization and machine learning for understanding features and structures in time-series data.

Schaeffer, whose research is also supported by an Air Force Young Investigator Program (YIP) grant, develops mathematical tools for extracting information from data, a task that is important to machine learning, data mining, image processing and automated analysis. Under the grant, Schaeffer plans to construct methods for learning the underlying process that generates some observed data, in a sense, reverse engineering models from data. These extracted models can be used to gain insights on the data and make data-enabled decisions.

CAREER Awards are among the most prestigious awards for young faculty. They recognize and support those who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research.

Image: Given a set of data (top image), Schaeffer computes the velocities (second image), uses an approximation to the trajectory to initialize the learning process (third image) and learns the best fit trajectory via an optimization problem (bottom image) to attempt to find the generating equations that govern the dynamics.

Mathematics Alumnus Sebastien Vasey Receives Prestigious Sacks Prize in Logic

Sebastien Vasey, who earned his doctorate from Carnegie Mellon University's Department of Mathematical Sciences in May 2017, has been awarded the Sacks Prize by the Association for Symbolic Logic for his dissertation. The annual international prize recognizes "the most outstanding doctoral dissertation in mathematical logic."

Vasey conducts research in model theory, one of the main branches of mathematical logic. He won the award for his dissertation titled "Superstability and Categoricity in Abstract Elementary Classes," which he completed under the direction of Professor of Mathematical Sciences Rami Grossberg.

In his thesis, the prize committee noted, "Vasey undertook a deep and sustained study of classification theory for abstract elementary classes."

"Among the many theorems he proved, his eventual categoricity theorem for universal classes is recognized as a landmark achievement toward Shelah's conjecture generalizing Morley's theorem on uncountable categoricity to abstract elementary classes," the committee continued. "A second remarkable result is his classification of the stability spectrum for tame AECs, which may well pave the way for connections with, and applications to, other areas of mathematics."

The Sacks Prize was founded in 1994 to honor noted logic researcher Gerald Sacks of Harvard and MIT. Sacks was known for serving as an advisor to many Ph.D. students. Vasey shared this year's prize with Matthew Harrison-Trainor, a postdoctoral fellow in mathematics at Victoria University of Wellington. Last year, Vasey was a recipient of the Guy C. Berry Graduate Student Research Award. He is currently a Benjamin Peirce Fellow in the Harvard University Department of Mathematics.

Kavčić-Moura University Professor of Mathematical Sciences **Irene Fonseca was featured in a special Women's History Month issue of the *Notices of the American Mathematical Society***. In the profile of Fonseca, it notes her contributions to the variational study of ferro-electric and magnetic materials, composites, thin structures, phase transitions and in the mathematical analysis of image segmentation, denoising, detexturizing, registration and recolorization in computer vision. In the article, Fonseca offers advice to young women, encouraging them to network, be confident in their skills and have fun.

Associate Professor of Mathematical Sciences **Po-Shen Loh** was named one of ***Pittsburgh Magazine's* "40 Under 40"** honorees for 2017. The program honors people who are making Pittsburgh a better place. Loh was recognized for his work that challenges people to learn math and reach their potential, specifically through his social enterprise startup, Expii. The success of Loh's teaching methods is evident in his students' triumphs. As the coach of the U.S. Mathematical Olympiad Team, he led the the U.S. team to a first place finish in the 2018 International Mathematical Olympiad — the United States' third win since Loh took over as coach four years ago. Under his direction, Carnegie Mellon had the second most students finishing in the top 500 of all students taking the Putnam exam for the past five years.

Irene Fonseca Named Kavčić-Moura University Professor of Mathematics

Professor of Mathematical Sciences Irene Fonseca was one of four Carnegie Mellon University faculty members appointed to new Kavčić-Moura Professorships, designed to provide sustained, long-term support for scholars across the university whose breakthroughs and discoveries have the potential to impact the world where human life and technology meet.

Fonseca has been a faculty member in the Mellon College of Science since 1987 and is the director of the university's Center for Nonlinear Analysis. One of the world's leading researchers in the field of applied mathematics, Fonseca's research lies at the interface of applied analysis with materials and imaging sciences. In 2017, she was appointed to the Abel Prize Committee, which is responsible for selecting the winner of the top prize recognizing lifetime contributions to mathematics by the Norwegian Academy of Science and Letters. In 2012, she became the second woman to be elected president of the Society for Industrial and Applied Mathematics (SIAM). She is a fellow of the American Mathematical Society and SIAM. She is a Grand Officer of the Military Order of Saint James of the Sword (Grande Oficial da Ordem Militar de Santiago da Espada, Portuguese Decoration). In 2014, she was named a University Professor, the highest distinction that can be bestowed on a professor at CMU.

The Kavčić-Moura professorships honor inventors José M.F. Moura and Aleksandar Kavčić, whose scientific research and technological innovations have had a transformative impact on the computing industry for more than a decade and a half.

"We are delighted to honor José and Alek for their groundbreaking work and passionate commitment to advancing research and education at Carnegie Mellon," said President Farnam Jahanian. "The Kavčić-Moura Professorships will allow us to attract and retain outstanding scholars across a broad spectrum of disciplines, providing the funds for brilliant minds to make innovative advances in their research."

Moura, the Philip L. and Marsha Dowd University Professor of Electrical and Computer Engineering, and Kavčić, a former doctoral student of Moura who is an adjunct faculty member at CMU, developed and patented systems and methods that fundamentally increased the accuracy with which hard disk drive circuits read data from high speed magnetic disks.

The Kavčić-Moura Professorships are funded by the university's proceeds from the 2016 settlement of the patent infringement lawsuit against Marvell Technology Group Ltd. and Marvell Semiconductor Inc. As outlined in 2016, the majority of those proceeds were put into endowment, for the perpetual support of undergraduate financial aid, graduate student fellowships, endowed faculty chairs and cross-campus research initiatives.

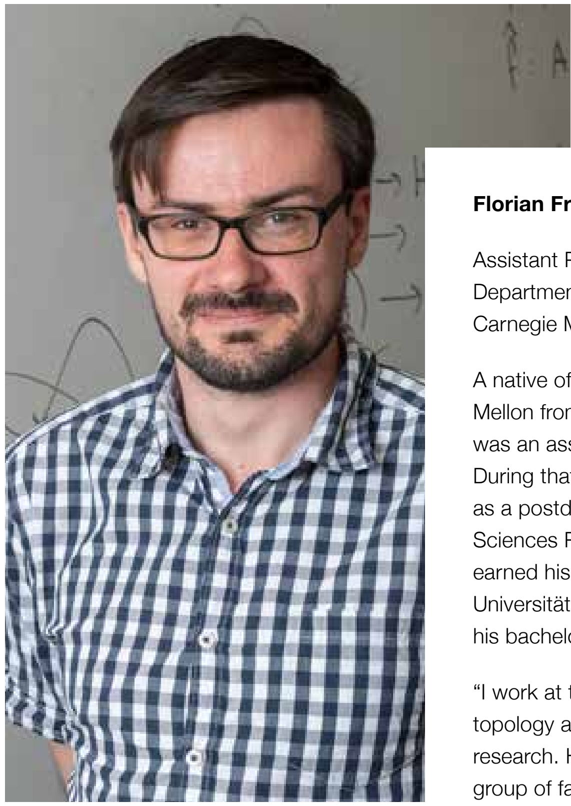
Fonseca Brings Abel to Pittsburgh

The Department of Mathematical Sciences will host some of the world's preeminent mathematicians for the Abel in Pittsburgh conference. The one-day conference, held on **January 11, 2019**, is the ninth edition of the "Abel in …" series that aims to increase public awareness of mathematics and the Abel Prize.

The Abel Prize, awarded by the Norwegian Academy of Science and Letters for a researcher's contributions to mathematics over the course of a career, is considered to be the most important prize in the field for a lifetime achievement.

The conference comes to Pittsburgh through Irene Fonseca's position on the Abel Committee. Fonseca is co-organizing the conference with Professor of Mathematical Sciences Dejan Slepčev. Scheduled to speak are Abel Laureate Yakov Sinai and Abel Prize Committee member Sun-Yung Alice Chang from Princeton University, Abel Prize Committee member Gil Kalai from the Hebrew University of Jerusalem and Scott Sheffield from the Massachusetts Institute of Technology.

The meeting also will serve as an opportunity for the Abel Committee, which consists of Fonseca, Chang, Kalai, François Labourie from the Université de Nice and Hans Munthe-Kaas from the University of Bergen, to meet. The group will recommend a candidate for the 2019 Abel Prize on March 19, 2019, and the prize will be bestowed at an awards ceremony in Oslo on May 20.



Math at CMU Welcomes Three New Faculty Members

Florian Frick

Assistant Professor Florian Frick joined the Department of Mathematical Sciences at Carnegie Mellon in July.

A native of Germany, Frick came to Carnegie Mellon from Cornell University, where he was an assistant professor for three years. During that time, he also spent a semester as a postdoctoral fellow at the Mathematical Sciences Research Institute in California. He earned his Ph.D. in 2015 from Technische Universität Berlin, from which he also obtained his bachelor's and master's degrees.

“I work at the triple-point of combinatorics, topology and geometry,” Frick said of his research. He said Carnegie Mellon's strong group of faculty who work in combinatorics attracted him to come here.

An example of Frick's research is his work to calculate whether it's possible to find four points that form a square within a curved figure on a plane. Another area of mathematics he's interested in is one that is relatable to many people at some point in their lives: fair rent division.

“It's always possible,” he said.

In a paper that will appear in *American Math Monthly*, Frick and his collaborators found an algorithm that could divide roommates so they would be content with their different rents and rooms, even if one doesn't know the preferences of one of the people who will be living in the apartment.

“I am impressed by his work on the disproof of topological Tverberg conjecture,” said Boris Bukh, associate professor of mathematics.

Before joining the faculty, Frick previously presented at Carnegie Mellon in December 2017 on the intersections of finite sets as part of the Department of Mathematical Sciences' colloquia program.

Outside of his research, Frick said he enjoys attending music concerts, running and watching Netflix. “I don't know Pittsburgh yet, but I'm hoping it turns out to be exciting.”

Tomasz Tkocz

Assistant Professor Tomasz Tkocz joined the Department of Mathematical Sciences at Carnegie Mellon in January.

A native of Poland, Tkocz came to Carnegie Mellon after time spent working as a Berlekamp Postdoctoral Fellow at the Mathematical Sciences Research Institute in California and as a postdoctoral research associate at Princeton University. He obtained his Ph.D. from the Mathematics Institute at the University of Warwick in the United Kingdom after studying at the University of Warsaw.

“My research revolves around probability,” Tkocz said, and the number of Carnegie Mellon faculty working in this field incentivized him to come here.

“I'm interested in problems related to probabilistic questions that don't have too much structure,” Tkocz said. “I'm also interested in applying such theory to related fields like convex geometry.”

Tkocz said he is "particularly fond" of studying high-dimensional phenomena, the topic on which he based his Ph.D. thesis. An example Tkocz offered of his work in this field is studying what one could say about the typical volume in a high-dimensional setting. (For an introduction to this class of problems, see pages 12-13.)

“The mathematical areas he's worked in are all essential for theoretical computer science,” Professor of Computer Science Ryan O'Donnell said of Tkocz's research “His work is important to many fields. His work on mixtures of Gaussians is important for machine learning, his work on entropy inequalities is important to information theory, his work on random matrix theory is important to quantum computing and his work on chaining is important to coding theory and compressed sensing.”

Before joining the faculty, Tkocz previously presented at Carnegie Mellon in December 2016 on Gaussian mixtures as part of the Department of Mathematical Sciences' colloquia program.

Outside of his research, Tkocz describes himself as a nature lover, and he enjoys hiking and climbing in the various parks around the Pittsburgh area. He also enjoys experimenting with new dishes and styles in cooking.

Franziska Weber

Assistant Professor Franziska Weber joined the Department of Mathematical Sciences at Carnegie Mellon this fall.

Weber came to Carnegie Mellon from the University of Maryland, College Park, where she worked as a postdoctoral fellow. She obtained her Ph.D. from the University of Oslo in Norway after receiving bachelor's and master's degrees from the Swiss Federal Institute of Technology in Zürich, Switzerland, where she also held a postdoctoral research position.

“There are a lot of really good people in my extended field here,” Weber said of why she came to Carnegie Mellon.

Weber’s research focuses on partial differential equations, which provide mathematical descriptions of physical phenomena. As these equations cannot be solved explicitly, instead, one must construct an algorithm that can then be used to solve the equation.

“My job is to construct algorithms for certain kinds of equations like those governing fluids and waves,” Weber said of her research. For example, Weber creates algorithms to study the Rosensweig instability, a sequence of peaks and valleys that form on the surface of a magnetic fluid in the presence of a strong magnetic field.

“Fluids, such as ferrofluids and liquid crystals, show up in daily applications and have special properties,” said Irene Fonseca, Kavčić-Moura University Professor. For example, Weber creates algorithms to study the Rosensweig instability, a sequence of peaks and valleys that form on the surface of a magnetic fluid in the presence of a strong magnetic field.

Before joining the faculty, Weber previously presented at Carnegie Mellon in December 2017 on the structure preserving numerical methods for nonlinear partial differential equations modeling complex fluids as part of the Department of Mathematical Sciences’ colloquia program, and in April at the Women and Mathematics at Carnegie Mellon University conference.

Outside of work, Weber enjoys outdoor activities such as running, hiking, skiing and snowboarding.

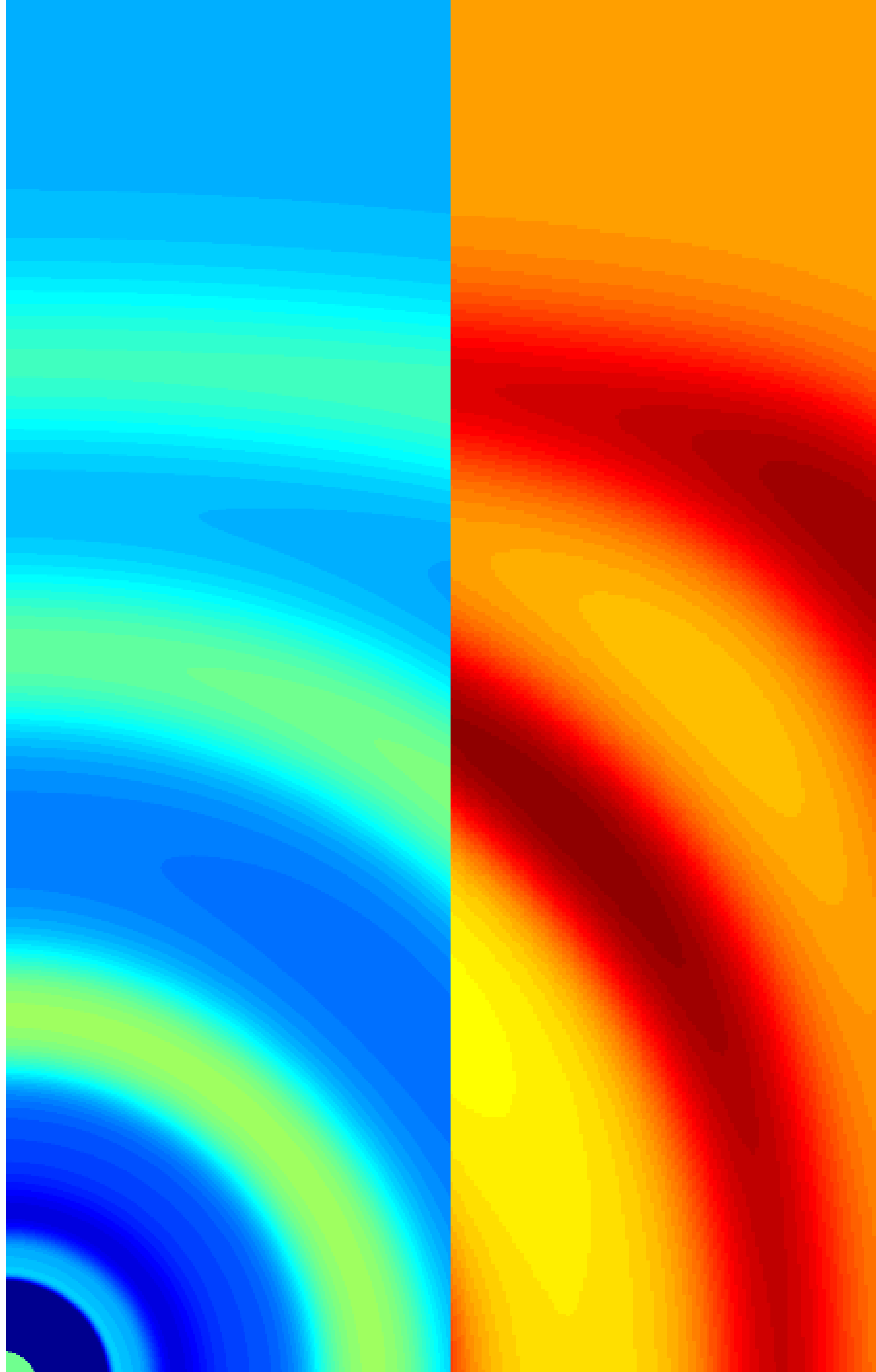


Image: A simulation of the “*quarter five-spot problem*” *that models water injected in an oil reservoir. This simulation was generated by a finite difference scheme for a model of two-phase flow in porous media and is the joint work of Weber, Nils Henrik Risebro, Sid Mishra and Giuseppe Coclite.*

Convex Sets in High Dimensions

by Tomasz Tkocz

This note briefly surveys several results, classical by now, which shaped high-dimensional convex geometry and describes its major open problems. We start with a closer look at Euclidean balls and then try to make a point that "in high-dimensions, all convex sets, despite their rich structure, behave a bit like Euclidean balls."

A set of points A in $\mathbb{R}^n$ is called convex if along with every two points a_1, a_2 in A, the whole segment $[a_1, a_2]$ joining a_1 and a_2 is contained in the set A. For example, balls and ellipsoids, or cubes and parallelopipeds are convex, whereas annuli are not. How is volume distributed in a convex set? Say we have a convex set of volume 1. Where is *most* of its volume *concentrated*?

Consider the example of a centered Euclidean ball $B = \{ x \in \mathbb{R}^n,\ x_1^2 + \ldots + x_n^2 \leq r^2 \}$. Choose its radius r such that it has unit volume, $r = v_n^{-1/n}$, where v_n is the volume of the n-dimensional ball with radius 1. Thus, $r = \frac{1}{\sqrt{\pi}} \Gamma\left(1 + \frac{n}{2}\right)^{1/n}$, which is approximately $\frac{n}{\sqrt{2\pi e}}$ for large n. For $x \in \mathbb{R}$, let $f(x)$ be the $(n-1)$-dimensional volume of the cross-section of B with a hyperplane perpendicular to the 0_{x_1} axis passing through $(x, 0, \ldots, 0)$. Plainly,

$$\int_{-\infty}^{\infty} f(x)\mathrm{d}x = \mathrm{vol}(B) = 1.$$

The function f is the probability density of the volume distribution of the ball B in the direction of the vector $(1, 0, \ldots, 0)$. What is this distribution like? That cross-section is again a ball, whose radius is $\sqrt{r^2 - x^2}$ (Pythagoras' theorem). Therefore,

$$f(x) = \sqrt{r^2 - x^2}^{\,n-1} v_{n-1} = \left(1 - \frac{x^2}{r^2}\right)^{\frac{n-1}{2}} r^{n-1} v_{n-1}$$

We check that $r^{n-1} v_{n-1} \approx \sqrt{e}$ for large n and when x is much smaller than r, we can write $1 - (x/r)^2 \approx e^{-(x/r)^2}$ and thus conclude that, approximately,

$$f(x) \approx \sqrt{e} e^{-\pi e x^2}$$

This means that f, the volume distribution in the ball B is roughly Gaussian with variance σ of constant order ($\sigma = \frac{1}{\sqrt{2\pi e}}$)!

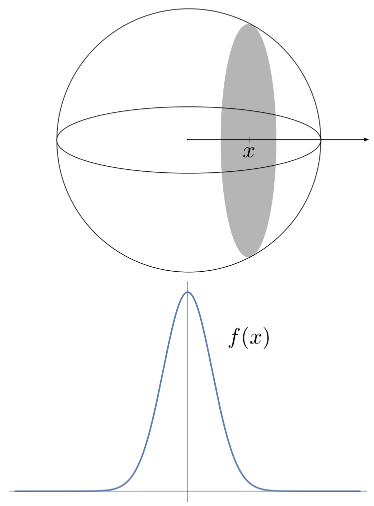


Figure 1: Volume distribution is Gaussian.

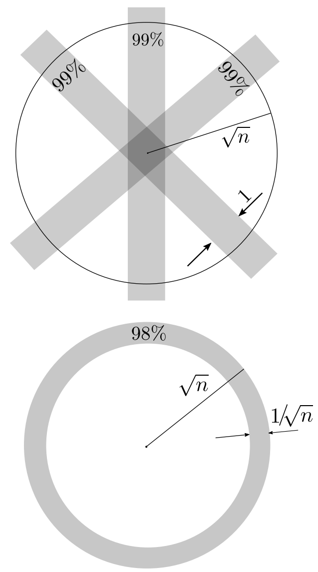


Figure 2: Most of volume is in any slab and near the surface.

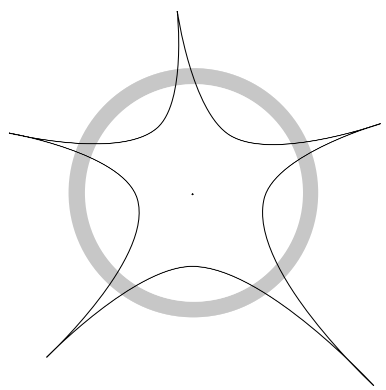


Figure 3: In a convex set in high dimensions volume decays exponentially in almost every direction and concentrates in a thin shell.

So, where is the volume concentrated? By the 3σ-rule, $\int_{-3\sigma}^{3\sigma} f(x)\mathrm{d}x > 0.99$, so more than 99 percent volume of B is within a symmetric slab $\{ x \in \mathbb{R}^n,\ |x_1| \leq 3\sigma \}$ of width 6σ. In high dimension n, this width of constant order becomes tiny in comparison with the radius r of B, which is of the order $\sqrt{n}$. To challenge our high dimensional intuitions more, remark that the choice of the axis $0x_1$ was arbitrary and by symmetry the above remains true for any other direction, so 99 percent volume of B is within any symmetric slab of width 6σ.

Let us have a look at how much volume there is near the surface of B, say in an annulus of the inner radius $r - 1/\sqrt{n}$ and the outer radius r. Plainly, this volume equals,

$$1 - \left(\frac{r - 1/\sqrt{n}}{r}\right)^n = 1 - \left(1 - \frac{1}{r - \sqrt{n}}\right)^n \approx 1 - e^{-\frac{n}{r\sqrt{n}}} \approx 1 - e^{-\sqrt{2\pi e}} \approx 0.98$$

This means that on one hand, almost all the volume of B is within any symmetric slab of constant width (hence also in the intersection of many of those), and on the other hand, almost all the volume of B is concentrated near its surface (in an annulus of width $1/\sqrt{n}$).

Asymptotic convex geometry is concerned with quantifying such high dimensional phenomena for arbitrary convex sets. One of the major breakthroughs was Klartag's central limit theorem, which guarantees that the same phenomenon that we observed above for the ball holds for an arbitrary convex set (properly *normalised*): the distribution of volume (function f) is Gaussian along *most* of directions. It was explained by Antilla, Ball and Peresinaki that such a central limit behavior comes from the volume being concentrated in a thin annulus, as readily observed above for the Euclidean ball. Klartag established estimates of this type, called thin-shell bounds, for an arbitrary convex set K in $\mathbb{R}^n$, showing that there are sequences δ_n, ε_n such that $\longrightarrow 0$ as $n \longrightarrow \infty$ such that,

$$\frac{1}{\mathrm{vol}(K)} \mathrm{vol} \left\{ x \in \mathbb{R}^n,\ 1 - |\,\varepsilon_n \leq 1 - \frac{|x|}{\sqrt{n}} \leq 1 + \varepsilon_n \right\} \geq 1 - \delta_n$$

provided that K is properly normalised (its inertia matrix being the identity). Historically, asymptotic convex geometry grew out of Dvoretzky's theorem, which says that n-dimensional symmetric convex sets admit sections with roughly log n-dimensional subspaces which are almost Euclidean balls. Interestingly, such Euclidean subspaces are not easy to find constructively, however, Milman's probabilistic proof of Dvoretzky's theorem shows that most subspaces yield Euclidean sections.

Of course, many problems remain unsolved. A central one, the slicing problem posed by Bourgain, asks whether there is a universal constant c such that for every dimension n, every n-dimensional convex set with volume 1 admits a codimension 1 section through its barycentre of volume at least c. (Currently the best dimension dependent bound on c is of the order $n^{-1/4}$). The slicing problem is related to many other natural questions in convex geometry and beyond. For example, the Busemann-Petty problem asked the following: if symmetric convex sets K and L in $\mathbb{R}^n$ satisfy $\mathrm{vol}(K \cap H) \leq \mathrm{vol}(L \cap H)$ for every codimension 1 subspace H, does it follow that $\mathrm{vol}(K) \leq \mathrm{vol}(L)$? After a bit of dramatic history, the problem was solved completely and the answer is affirmative if and only if $n \leq 4$ (for $n \geq 10$, a cube and a ball give a counter-example). Proving that $\mathrm{vol}(K) \leq C\,\mathrm{vol}(L)$ for a universal constant C would also solve the slicing problem in the affirmative. Another example concerns information theory: the slicing problem is equivalent to showing that the relative entropy per coordinate of every uniform distribution on a convex set does not exceed a universal constant. The links with information theory were also fruitful to establish unexpected connections between the slicing problem and other major open problems, such as the Kannan-Lovász-Simonovits conjecture (which in turn has its roots in devising efficient algorithms for computing volumes of convex sets).

Further reading

Giannopoulos, A., Milman, V., Asymptotic convex geometry: short overview. Different Faces of Geometry, 87{162, Int. Math. Ser. (N. Y.), 3, 2004.

In Memoriam:
Jim Greenberg

James (Jim) M. Greenberg, former head of the Department of Mathematical Sciences, died on August 3, 2018. He was 78. Greenberg was born July 30,1940, in Chicago, Illinois.

Greenberg was at Carnegie Mellon at its start. As a fellow at the Mellon Institute of Industrial Research, he became an assistant professor of mathematics in 1967 when the institute merged with the Carnegie Institute of Technology to form Carnegie Mellon University. He left in 1969 to pursue opportunities at other universities, including Case Western Reserve University, the State University of New York at Buffalo, the Ohio State University and the University of Maryland, Baltimore County, where he served as department head.

He returned to Carnegie Mellon in 1995 when, under the leadership of Robert Mehrabian as university president, Greenberg was selected from a field of competitive candidates to head the mathematics department.

Greenberg emphasized the importance of faculty research and worked to reduce the teaching loads of research active faculty. He deployed a strategy for targeted faculty hiring that developed the areas of research focus that are present in the department today.

“Jim was very successful in his research but was an even better academic administrator and program administrator. He listened well, did not have a large ego, deferred the spotlight to others and avoided direct disputations. He used his brash personality to charm both the administration and the faculty to obtain the best for the department. In the naturally slow-motion university setting, Jim shocked results into being by his insistence on instant decision and subsequent action,” said William Williams, professor emeritus of mathematical sciences and a friend of Greenberg’s for more than 50 years.

Carnegie Mellon colleagues described Greenberg as a strong leader, loyal and colorful. David Kinderlehrer, alumni professor of mathematical sciences, remembers Greenberg talking with faculty members at La Prima Espresso in Wean Hall.

“Everyone in the department had a personal relationship with Jim. He knew us, was interested in us and was accessible,” Kinderlehrer said.

In September 2002, Greenberg stepped down as department head to accept the role of associate director for mathematical sciences for the U.S. Office of Naval Research, Global and European Office of Aerospace Research and Development. He remained on the Carnegie Mellon mathematical sciences faculty. He continued to participate in CMU seminars weekly in his retirement.

In addition to his administrative impact, Greenberg was widely known for his research contributions.

Bill Hrusa, professor of mathematical sciences, first met Greenberg in the early 1980s.

“Jim was very interested in mathematical models and worked in many different areas, but one common theme was a strong relevance to real-world phenomena. He was very good at striking a balance between finding models that were rich enough to be relevant and yet simple enough to obtain results,” Hrusa said.

Hrusa added: “He is missed already. The department is not the same without him.”

Greenberg's broad range of research interests included hyperbolic conservation laws, fluid and solid mechanics, continuum limits of particle systems, cellular automata (CA) and metastable systems.

Among his best-known work is the Greenberg-Hastings CA, a two-dimensional cellular automaton proposed as a model of excitable media named after his work with Stuart Hastings, who is now on faculty with the University of Pittsburgh. The CA created the striking image that appears on the cover of this newsletter.

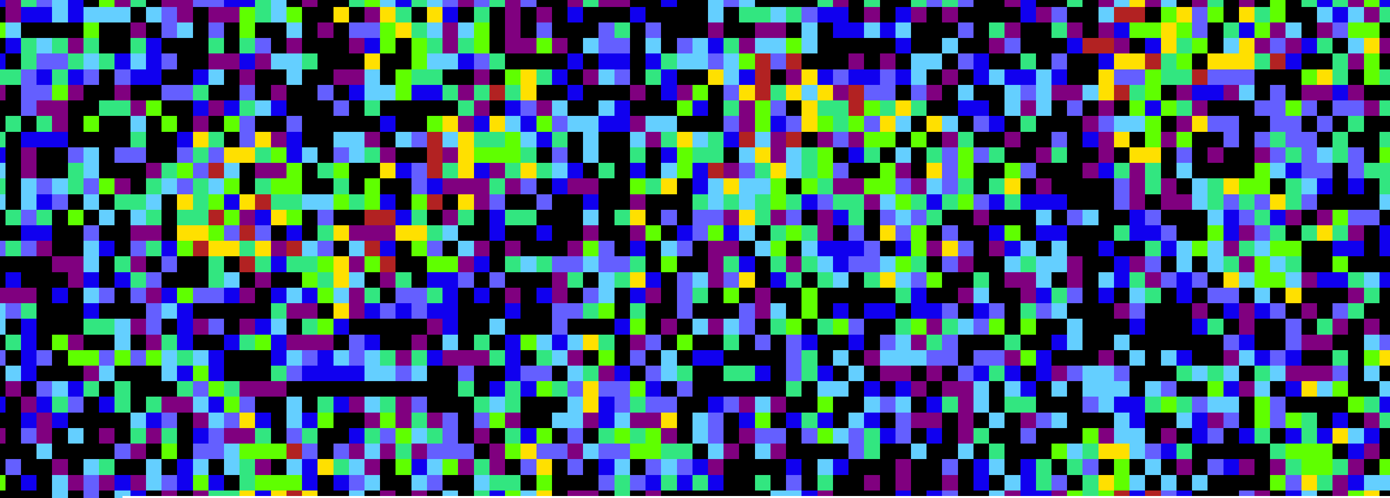
Hastings first met Greenberg at Case Western in 1968 and became well acquainted at SUNY Buffalo.

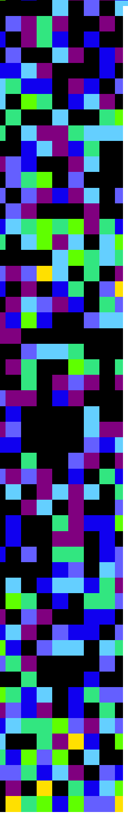
“Jim Greenberg was outrageous — in the positive senses of that word: bold, unusual, startling,” Hastings said. “He was outrageous in his generosity. To this outsider at least, he appeared outrageous in his ability to get what he wanted for the mathematics departments he chaired (two of them). He was outrageous in his openness and his non-compliance with academic conventions.”

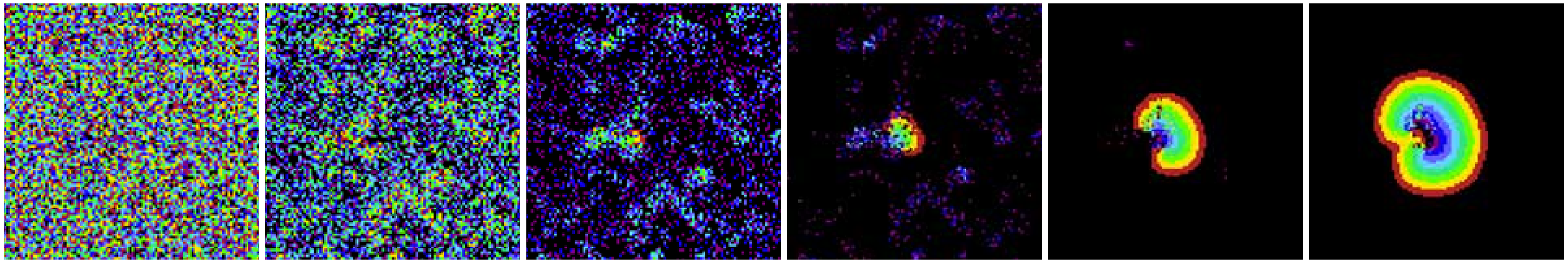
Hastings also remembered Greenberg for his genuine interest in others.

“He could relate to all ages,” Hastings said. “Some years ago, the young daughter of a colleague was overjoyed when Jim took over for her at a recalcitrant CMU Carnival game and won her a prize. And during his final illness, around half a dozen grad school friends from over 50 years ago made the effort to visit or contact him.”

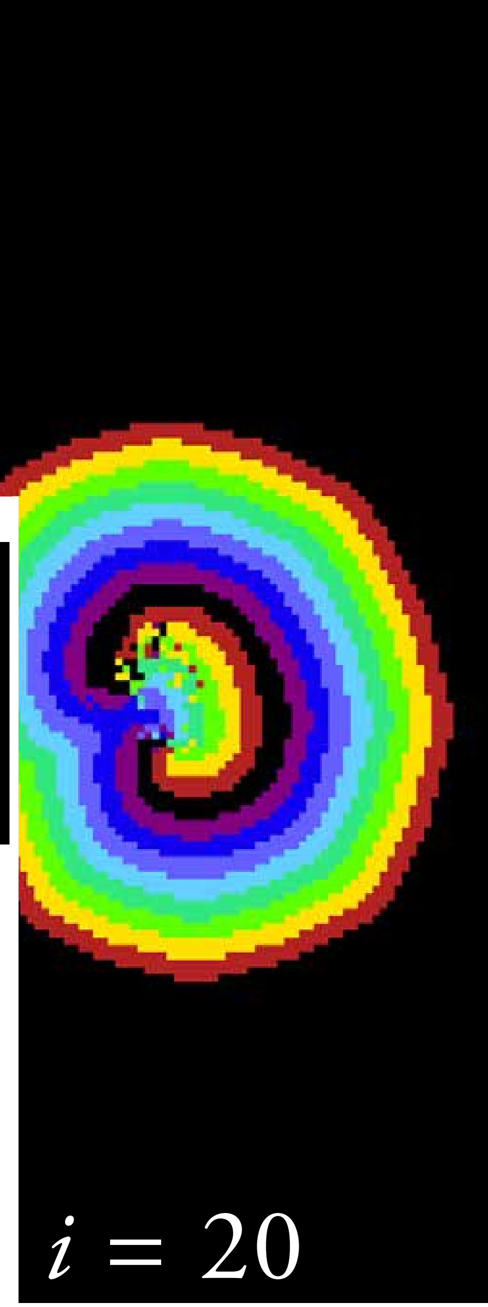
Hastings added: “As my daughter, who knew Jim from her childhood put it, 'he bucked the stereotype of ‘mathematician’ with consistent irreverence and humor.' He was smart, an innovative researcher, and fun to work with. I will miss him.”







$i = 0$ $i = 3$ $i = 6$ $i = 9$ $i = 12$ $i = 15$



The Greenberg-Hastings Cellular Automaton

by Tom Bohman and Janko Gravner

The image on the cover was generated by the Greenberg-Hastings model. This cellular automaton was introduced by Jim Greenberg and Stuart Hastings as a simple discrete model that generates the complex spatial patterns observed in excitable media such as nerve tissue and the Belousov Zhabotinsky chemical reaction. These patterns are generally spontaneous, self-exciting, spatially homogeneous oscillations. The fact that this simple model generates such striking complexity inspired interest in cellular automata as models of complex systems. We placed this image on the cover in honor of Jim Greenberg.

The classical Greenberg-Hastings model evolves in discrete time on the 2-dimensional integer lattice. The model has three parameters: a finite set $N \subset \mathbb{Z}^2$, which defines the neighborhood of the origin, a positive integer k, which is the refractory period for the model, and a positive integer t, which is the excitation threshold.

The state space for the model is $\{0, 1, \dots, k+1\}$ and the neighborhood of a site $x \in \mathbb{Z}^2$ is $x + N$. State 0 is the **resting state**, state 1 is the **excited state**, and states $2, \dots, k+1$ are the **refractory states**. We begin with an initial configuration,

$$f_0 : \mathbb{Z}^2 \longrightarrow \{0, 1, \dots, k+1\}$$

Given the configuration f_i, the configuration f_{i+1} is determined for all points in the integer lattice simultaneously and in parallel. If x is excited or is in one of the first $k-1$ refractory states then x proceeds to the next refractory state; to be precise, if $f_i(x) \in \{1, \dots, k\}$ then $f_{i+1}(x) = f_i(x) + 1$. If x is in the last refractory state at time i then it is in the resting state at time $i + 1$; that is, if $f_i(x) = k+1$ then $f_{i+1}(x) = 0$. A position x that is resting becomes excited if a sufficient number of its neighbors are excited.

$$f_i(x)=0 \Longrightarrow f_{i+1}(x)=\begin{cases} 1 & \text{if } |\{y \in x + N : f_i(y) = 1\}| \geq t \\ 0 & \text{otherwise} \end{cases}$$

The sequence of images depicted above are generated by Greenberg-Hastings using the following parameters. The neighborhood is a range three box (i.e., the neighborhood of a point x is the set of 49 points of l_∞ distance at most 3 from x), the excitation threshold is $t = 5$, and there are 9 states (so there are $k = 7$ refractory states). This sequence begins with a random configuration and shows how local stationary periodic configurations spontaneously emerge and generate waves in the dynamics.

The correspondence between the states and colors in these image are indicated in this key.

black	state 0	resting state
orange	state 1	excited state
yellow	state 2	refractory state
light green	state 3	refractory state
aqua	state 4	refractory state
light blue	state 5	refractory state
lavender	state 6	refractory state
dark blue	state 7	refractory state
purple	state 8	refractory state

(We also use colors to indicate the states in the image on the cover, but in a slightly different way. Black again indicates the resting state. The orange squares are again the excited states — these are raised on the cover. The refractory states are in successively darker shades as the refractory states progress toward the resting state.)

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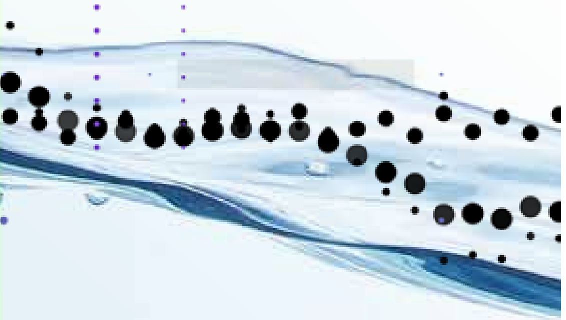
Janko Gravner, Hanbaek Lyu and David Sivako, Limiting behavior of 3-color excitable media on arbitrary graphs, Ann. Appl. Probab. 28 (2018), 3324-3357.

James Greenberg and Stuart Hastings, Spatial patterns for discrete models of diffusion in excitable media. SIAM J. Appl. Math. 34 (1978) 515-523.



Mathematician Dives into the Startup World

Alumnus Mark Kovscek has developed a smart water technology through his company Conservation Labs

Mark Kovscek built his career on solving other people's problems, using his skills in mathematics and analytics to address multi-billion-dollar challenges. But when it came to a problem in his own home — a leaky heating system — a few drops of lost water became an unexpected wave of entrepreneurship.

Kovscek is the founder and CEO of Conservation Labs, a company whose mission is grounded in both economic and environmental conservation. He's gearing up to bring the company's first product, H2know, to market next year. H2know is a low-cost, smart water monitor that aims to save consumers money by detecting water leaks in the home and helping them manage their water use.

It all started in late summer 2014 when the Kovscek household began having higher than normal water bills. A leak in the family's heating system was causing water to go right down the overflow drain. These kind of every day leaks — a dripping faucet, a bad water valve, a leaky toilet — aren't uncommon and can easily go unnoticed at the owner's expense.

"H2know and Conservation Labs started as an intellectual curiosity — Is this a problem I can solve?" Kovscek said. When looking for a solution to prevent future leaks, the products on the market were incredibly expensive, well over $1,500. "I thought there has to be a better way to do this."

Inspired by his family's favorite television show, Shark Tank, Kovscek pitched his children an idea — a device that could attach to your water pipe to prevent leaks and tell you about your water consumption for only $100.

Over the course of the next three years, Kovscek devoted much of his time to researching sensor technologies to develop a noninvasive device that could fit over the outside of a water pipe while measuring the water flow inside the pipe. To reach the price point he wanted, Kovscek invested his energy in using machine learning to translate sound signatures to accurate water flow estimates, leak alerts and water insights. Customers can access the data and information through an app to save money and have peace of mind.

"H2know can tell you how long your showers are, how many times the toilet was flushed, how many times the washing machine was used. We can tell you about the whole house from that device, and we can detect micro leaks down to a drop or two a second."

The strength of H2know lies in its algorithms and analytic capabilities, a strength that comes from Kovscek's background in mathematics. He earned his bachelor of science in mathematics from Carnegie Mellon University in 1992, and he says he's used math every day since.

"A lot of what I do is problem-solving with mathematics. Whether it's building an algorithm through machine learning or building financial models, math has stuck with me every day of my career in some way shape or form. I get to use my degree every day; it was an investment well made for me.

"My courses not only taught me the mathematics, they taught me how to think and problem solve, and so there was always an added complexity that I really liked at CMU."

In January 2018, Conservation Labs and H2know were officially unveiled at the Consumer Electronics Show (CES) in Las Vegas and garnered widespread attention. Conservation Labs was one of six companies to receive the Innovation Award, which is sponsored by the Environmental Protection Agency and the Computer Technology Association, for their potential to reduce energy use and carbon emissions.

The company also caught the eye of a representative from the Alexa-Techstars Accelerator, a 12-week immersive program in Seattle, funded by Amazon and managed by seed accelerator Techstars. Conservation Labs was one of nine startups selected from among hundreds of applications. As part of the program, companies receive funding from the Alexa Fund and access to business strategy, the investor community and Alexa-enabled devices to incorporate in their products and services.

Conservation Labs has reached a number of milestones this year, from debuting at CES to conducting field tests and moving from prototypes to beta units. While Kovscek is excited for what's to come, he won't forget where everything started — in his basement, working as a team of one and holding company meetings at the dinner table before leaving his job as president of software marketing firm Velocidi to follow his dream.

"It's been a healthy dose of fear. The level of risk is really high for someone with a mortgage and a family of six to take care of, but it's the excitement, the adrenaline rush of taking a risk on this, on what I believe in, that is worth it," Kovscek said.

H2know is only the beginning for Conservation Labs. The next step will focus on creating a shut off device that can turn your water off automatically in the case of a catastrophic situation in the home.

"We remain passionate about conservation and what this combination of sensor technology, machine learning and analytics can do for conservation," Kovscek said. "If you think about those three things and how they come together, the ideas are limitless."

Alumna Shafi Goldwasser Receives Honorary Degree at Commencement

Turing Award winner and Mathematical Sciences alumna Shafi Goldwasser received an honorary doctor of science and technology at Carnegie Mellon's 121st Commencement on May 20. Goldwasser earned her bachelor's degree in applied mathematics from Carnegie Mellon University in 1979.

Goldwasser joined Nobel Laureate Ada Yonath, philanthropist and investment icon David Tepper and award-winning actor Ted Danson in receiving honorary degrees.

"It is a CMU tradition to award honorary degrees to exemplary leaders, who serve as role models for our graduates and the entire Carnegie Mellon community," said CMU President Farnam Jahanian. "This year's esteemed honorees embody this tradition, having received preeminent levels of distinction in their fields and exhibited a record of extraordinary contributions to society."

Goldwasser is among the world's elite computer scientists. In 2012, she received the Association for Computing Machinery's Turing Award, the highest honor in computer science given to an individual for their contributions "of lasting and major technical importance to the computing field."

Her pioneering contributions include the introduction of probabilistic encryption, interactive zero knowledge protocols, elliptic curve primality testings, hardness of approximation proofs for combinatorial problems and combinatorial property testing. She is also a two-time winner of the Gödel Prize for outstanding papers in the area of theoretical computer science.

Early in 2018, Goldwasser took over as the director of the Simons Institute for the Theory of Computing at the University of California, Berkeley. The institute is the world's leading venue for collaborative research in theoretical computer science and brings together leading researchers and the next generation of young scholars to explore deep unsolved problems about the nature and limits of computation. She had previously been the RSA Professor at the Massachusetts Institute of Technology.

Image: Shafi Goldwasser speaking at the Mathematical Sciences diploma ceremony during commencement in May.

Junior Andrew Kwon Recognized as Goldwater Scholar

Mathematical Sciences honors student Andrew Kwon received a 2018 Barry Goldwater Scholarship. Given by the Barry Goldwater Scholarship and Excellence in Education Foundation, the award supports undergraduate students interested in pursuing research careers in the fields of science, engineering and math.

Kwon was one of 211 students to receive the scholarship, selected from among 1,280 sophomores and juniors nationwide. The scholarship provides up to $7,500 per year for tuition, fees, books and room and board for up to two years.

Kwon, who plans to pursue a career in academic research in number theory and algebraic geometry, said he is excited to have his potential as a scholar and researcher recognized through the scholarship.

Most of his undergraduate research has focused on number theory and additive combinatorics, a branch of number theory that studies how sets of integers behave under addition. Last summer, through the Research Experiences for Undergraduates program funded by the National Science Foundation, Kwon conducted research under Joe Gallian at the University of Minnesota, Duluth, on a newer line of inquiry in additive combinatorics. Kwon examined a recent mathematical paper that showed the existence of minimal additive complements in special cases. He developed a conjecture that identified a new, relatively general property of complementable sets that provides insight into what distinguishes complementable sets and sets that are not complementable. Kwon submitted his results for publication in a professional journal, and, if justified, his conjecture could explain all observed phenomena in this area of study.

Working with younger students is another passion of Kwon's. As a first-year student, he took on the ambitious goal of starting a math competition for high school students from scratch. Along with six close friends, he established the Carnegie Mellon University Informatics and Mathematics Competition. The annual one-day competition brings high schoolers from across the country to campus to compete in a number of subject tests, written by Kwon and the competition's organizing team.

"It's something that I'm very proud of because it has really grown," Kwon said. Participation has nearly doubled every year for the past three years, starting with 120 competitors in 2016, 230 in 2017 and 400 in 2018.

Some of the competition's former participants are now students at Carnegie Mellon. "They've told me 'your competition made CMU really stand out to me and it's why I'm here now," Kwon said. "And I think that's really incredible to be able to have that kind of impact."

Throughout the scholarship process, Kwon worked closely with Carnegie Mellon University's Fellowships and Scholarships Office. "Andrew is both extremely talented and also very humble. That is an especially powerful combination," said Stephanie Wallach, assistant vice provost for undergraduate education. "He has used his time at Carnegie Mellon and elsewhere to deepen his understanding of mathematics and to build relationships with faculty mentors. We have enjoyed the chance to work with him and we are very pleased that he received this prestigious scholarship."

Taking the time to write about his research and interests, personally and intellectually, helped Kwon prepare for the road ahead in applying for graduate school and fellowships. "The process took a lot of self-examination because it was the first time that I had to think about the math I liked doing and why it's worth doing," he said.

Andrew Zucker's Love of Math Takes Him to the City of Love

Andrew Zucker can't remember a time when he didn't love math. Growing up in Greeley, Colorado, pursuing an education and career in mathematics just seemed natural to him.

When he began his undergraduate studies at the California Institute of Technology, Zucker initially thought he wanted to study combinatorics, but quickly found that his heart was in logic.

"When I took my first course in logic, it seemed to use all the parts of combinatorics that I liked while putting everything into a beautiful theoretical framework," said Zucker.

As an undergraduate, Zucker made his first contributions to the field of topological dynamics, publishing in the journal *Fundamenta Mathematicae*.

After graduating from CalTech, Zucker came to Carnegie Mellon's highly regarded logic program to continue his studies. Under the tutelage of Associate Professor

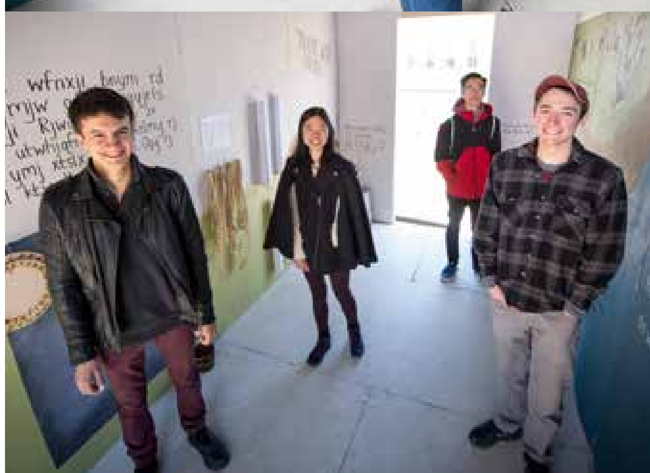
Clinton Conley and Professor James Cummings, he researched the interactions between logic, dynamics and descriptive set theory. As a doctoral student, he continued to make impressive contributions, particularly refining the connections between Ramsey theory and topological dynamics.

“Andy’s work around metrizable universal minimal flows and the generic point problem are his most impressive contributions to the field, but they are not his only ones,” said Conley. “In general, Andy has a very strong research program connecting combinatorial regularity principles with their dynamical counterparts and had remarkable success advancing this program while still a graduate student.”

His work was so impressive, Conley said, that it caught the attention of international experts in the field. When attending a set theory conference at the Centre International de Rencontres Mathématiques near Marseille, France, Conley heard Zucker’s theorems referenced in two separate talks.

After completing his Ph.D. program in the spring, Zucker moved to Paris. His graduate work earned him a prestigious National Science Foundation post-doctoral fellowship to study at the Université Paris Diderot, which has a large logic group and brought him closer to collaborators in Paris, Lyon and Marseille, France.

“Mathematically, I feel like I’ve been more productive than ever, and I get to explore France and elsewhere in Europe, too,” said Zucker.



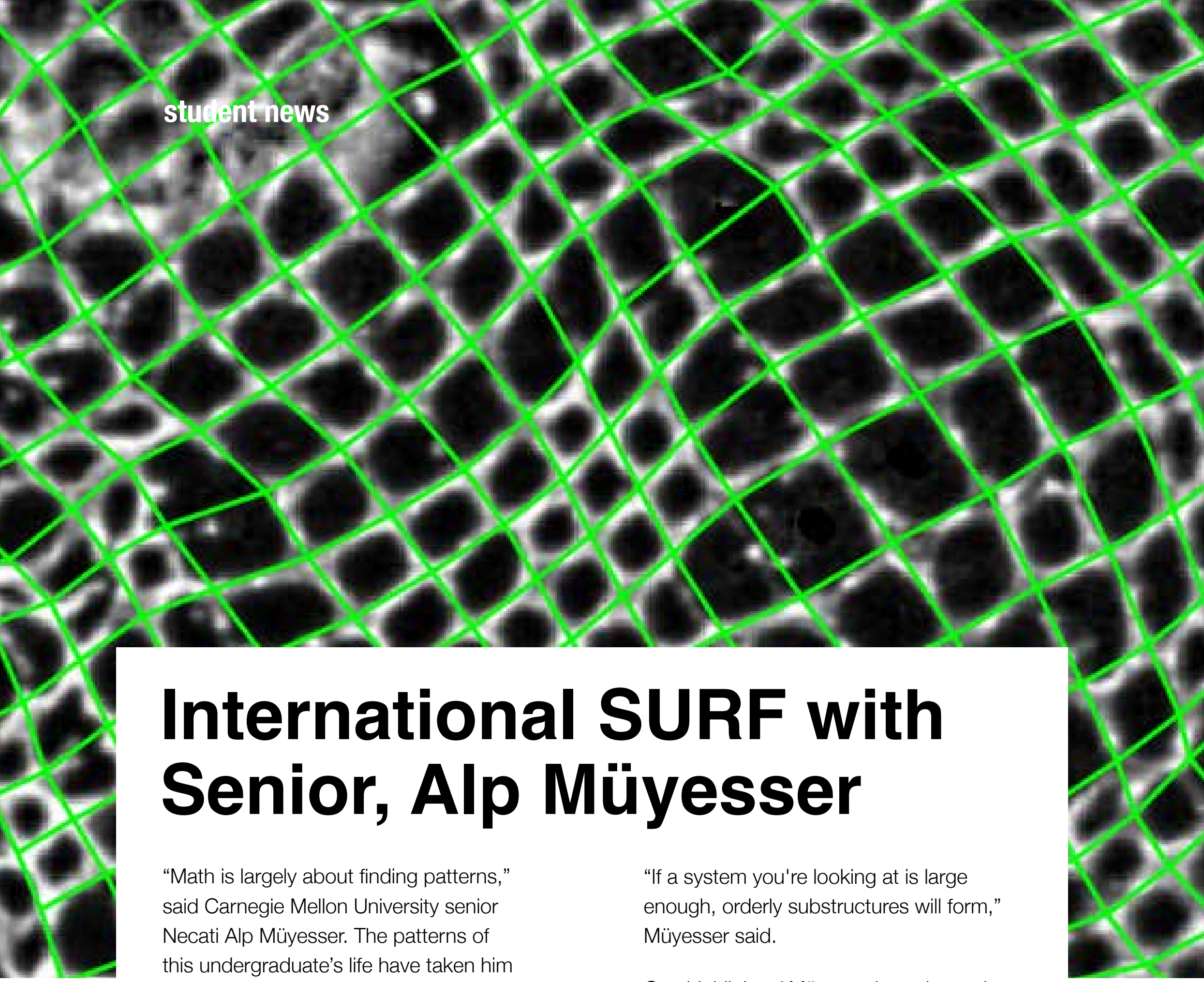
Math Club Wins Top Awards Among Blitz Booths at Spring Carnival

This year’s Spring Carnival brought to life Myths and Legends throughout history. The Carnegie Mellon Math Club combined both magic and historical legend as it transported Carnival-goers back to a time of castles, kings and mathematical sorcery with its award-winning booth, Merlin’s Quest.

The design was based around scenes from the lessons that Merlin taught the young King Arthur, which took first place among all “blitz” booths — booths that are contained in an 8’x18’ plot. The group also won the environmental award among blitz booths for their attention to energy efficiency, recycling and reusing of building materials.

Upon entering, visitors encountered Arthur’s first meeting with Merlin at his hut in the forest. From there, the surrounding walls laid out four “quests,” as introduced by Merlin’s owl Archimedes, that Arthur must complete on his quest to become king. Visitors could help by solving a few mathematical riddles along the way. Tasks included determining relationships within a flock of geese as friends or strangers, taking on Zeno’s paradox and decrypting a secret message using a scytale. The journey ended with the ultimate kingly challenge — pulling a sword out of the stone, or in the Math Club’s case, pulling a sword out of a box to open the lid and collect a small prize.

“Some of our favorite visitors were those that came in and thoughtfully did our activities, sometimes for as long as an hour,” said Elliot Haney, mathematical sciences senior and Math Club booth chair. “We also enjoyed seeing people’s reactions to our booth. On the back wall, we had a fire extinguisher and a light switch. As a joke, we wrote above them ‘some gifts Merlin brought from the future.’ To our surprise, that was one of the most popular additions we made.



International SURF with Senior, Alp Müyesser

"Math is largely about finding patterns," said Carnegie Mellon University senior Necati Alp Müyesser. The patterns of this undergraduate's life have taken him from Turkey to Berlin to Pittsburgh, and from a completely separate college to the Department of Mathematical Sciences.

When Müyesser, a native of Istanbul, entered Carnegie Mellon, he did so as a student in College of Engineering's Department of Electrical and Computer Engineering.

"I realized quickly it wasn't for me."

Instead, through his first-year classes, he found himself drawn to mathematics and particularly a field known as Ramsey Theory.

"The catchphrase for the field could be 'complete chaos is impossible,'" Müyesser described. "It is completely opposed to anything I would have thought of as math from my high school background."

Essentially, Ramsey Theory looks at the conditions that mean "order" that must exist in a certain set, whether that be a group of numbers or even a collection of people.

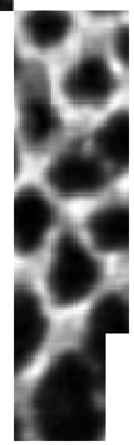
"If a system you're looking at is large enough, orderly substructures will form," Müyesser said.

One highlight of Müyesser's undergraduate career at Carnegie Mellon was his time as an International Summer Undergraduate Research Fellow. The program funds roughly two months of full-time research under a faculty member in a foreign country. Müyesser's ISURF grant took him to the Free University of Berlin, where he said he got to meet many well-known mathematicians. "It was a good simulation of what my graduate school experience will be like," Müyesser said.

As a senior, Müyesser is looking forward to continuing in academia and mathematical research. "I'm confident that I will want to do this for a long time," he said.

Along with rock climbing, one of Müyesser's favorite extracurricular activities is just walking around the campus and the city, he said. Even then, math is never far from his mind.

"It's a good way to do homework," Müyesser noted of his time walking, in which he can think through equations in his head. "It's easier not to get distracted."



Summer 2018 Math SURF Research Projects

David Altizio, Xinyu Wu and Taisuke Yasuda
Asymptotic Stability of the Faraday Wave Problem
Advisor: Ian Tice

Bryan Ding and Zilin Wang
Constructing Local Volatility Surfaces to Price Options
Advisor: Elnur Emrah

Wenxin Ding
Does Gaussian Noise Increase Entropy?
Advisor: Tomasz Tkocz

Shuyang (Serena) Gao and Novdano Dede Yusuf
Assessment of Discrete and Continuous Time Models for Pricing Options
Advisor: David Handron

Varun Gudibanda
Dynamics of the Inextensible Inverted Flag with Piston-Theoretic Forcing Term
Advisor: Jason Howell

Yong Gun Choe
Hidden Markov Model and Its Applications to Stock Price Prediction
Advisor: Yu Gu

Zhiyang He
Hypergraphs with Few Berge Paths of Fixed Length Between Vertices
Advisor: Michael Tait

Ruoyuan Liu and Yuepeng Yang
Recognizing Mesh Structure in Images
Advisor: Dejan Slepčev
(Image on left page)

Jung Joo Suh
Line Sections and Graph Homomorphisms for Graphs Induced by Actions of the Integer Lattice
Advisor: Clinton Conley

Emily Zhu
Multicolor Ramsey Numbers for Small Hypergraphs
Advisor: Tom Bohman

Meeting of the Minds Poster Competition

First Place — David Simmons Prize for Undergraduate Research in Mathematics
Zachary Singer
Sparse Polynomial Approximations with Unknown Random Sampling

Second Place
Matthew Bowen
The Sprague-Grundy Function for Some Selective Compound Games

Third Place (Tie)
Sidhanth Mohanty (CS major)
Sum-of-Squares Refutation Threshold for Regular SORT_4 Instances

Nicholas Sieger
Cycle Double Covers

Young Researcher Award
Zizhuo Chen, David Xu, Yuzhi Guo and Anni Huang
Utility Optimization in the Agency Problem

Other Math Major Award Winners:

First place in the Statistics Poster Competition
Chi Fang
Predicting Delay in Freight Transportation through Socioeconomic Events
(Joint with Yudi Jin, Frank Kovacs and Maria Rodriguez de la Cruz)

Dietrich Humanities Award
Ruth Scherr
Laborious

Honorable Mention in the Statistics Poster Competition
Qiuyu Wang
Assessing the Performance of the False Discovery Rate Procedure in Detecting Cointegrating Stock Pairs
(Joint with Emily Chen, Christian Manaog and Boyan Zhang)

Joseph Briggs Receives Graduate Student Teaching Award

Joseph Briggs was honored with the Mellon College of Science's 2018 Hugh Young Graduate Student Teaching Award.

"Joe Briggs embodies everything one could possibly want in a [teaching assistant]," Associate Teaching Professor Deborah Brandon wrote in a letter nominating Briggs for the award. "He is a gifted expositor. He is extremely reliable and very helpful, and he really cares about his students. In addition, he has that rare ability to make the learning experience memorable (in a good way)."

In his nearly five years at Carnegie Mellon University, Brandon said that Briggs' flexible teaching style allowed her to assign him to teach alongside many different instructors in a variety of courses.

"I have never had a TA that I would trust more than Joe to elegantly explain mathematical material to undergraduates," Associate Professor Wesley Pegden said in a letter supporting Briggs' nomination.

A dozen of Briggs' former students wrote in to confirm his teaching abilities.

"Before an exam, I would take advantage of his office hours to ask him several questions about the material," sophomore Shruti Murali wrote. "He answered all of them and was always excited when I had more questions because he's just that kind of instructor — always going above and beyond to make sure his students understood the material."

Junior Makayla Filiere echoed that sentiment about Briggs' energy and passion for instruction.

"He just loves math and gets so excited about math concepts and teaching others," Filiere wrote. "He would solve the problem and be jumping all around, pumped up at how it is that we just solved this problem! To see a TA so passionate about math naturally makes you more excited about it as well."

Briggs graduated in 2018 with a thesis on the subject of online algorithms and extremal structures. He is now a post-doctoral fellow in mathematics at the Technion Israel Institute of Technology.

Image:
Rebecca Doerge, the Glen de Vries Dean of the Mellon College of Science, presenting the MCS Graduate Student Teaching award to Joseph Briggs.

Senior April Li Receives Fugassi and Monteverde Award

April Li received the 2018 Dr. J. Paul Fugassi and Linda E. Monteverde Award. The award recognizes the graduating female senior in the Mellon College of Science with the greatest academic achievement and professional promise.

As part of the Department of Mathematical Sciences' Computational Finance program, Li was a dedicated student leader who enriched the experiences and opportunities for students in the program and across campus through her passion for computational finance. In 2016, Li co-founded the Quant Club, which has been an invaluable resource for students interested in quantitative finance.

In her role as a leader in the Quant Club, Li helped organize mock interviews on campus in fall 2017. She conducted resume workshops for students, where she used her own experience in finding internships to help students prepare for recruiting season.

Li was also president of the Sales and Trading Academy at Carnegie Mellon and a member of the Mortar Board Society of Scholars. In April 2018, the Department of Mathematical Sciences hosted an inaugural "Women and Mathematics at CMU" conference that included a mini-course on connections between partial differential equations and mathematical finance. Li helped organize the conference and served as a panelist.

In addition to her student organization leadership, Li was an accomplished teaching assistant and undergraduate researcher. She conducted extensive undergraduate research on utility indifference pricing in incomplete financial models with Professor of Mathematical Sciences Bill Hrusa from June 2015 through May 2016 and served as a teaching assistant in two of his courses.

"April is one of those extremely rare individuals who excels at everything she does. She is creative, her analytical ability is extremely high, she is very skilled at coding, she has excellent mathematical intuition, she understands the interplay between mathematical models and real-world phenomena and she is an outstanding communicator," said Hrusa. "I consider April to be more of a colleague than a student."

Li's potential for professional success was prominent since early in her undergraduate career. Following her sophomore year, Li landed an internship with Tudor Investments as a quantitative analyst in the global research department. It is unusual for a sophomore to get their foot in the door so early. Internships in the finance industry, which often lead to full-time job offers, are generally available to juniors and seniors who can begin working within a year of finishing their internships.

Li managed a similar feat her junior year by applying for an internship at four major financial institutions — Goldman Sachs, JPMorgan Chase, Bank of America and Citigroup. She had offers from all four banks before mid-semester. She accepted Goldman Sachs' offer as a sales and trading summer analyst intern in their securities division.

Since graduation, Li is continuing at Goldman Sachs as a sales and trading analyst in interest rates products. She is part of a new breed of traders who make decisions based on the use of sophisticated mathematical and statistical models and who employ ideas from data analytics and machine learning, together with an understanding of financial markets and economics to guide their trading decisions.

"The scientific education that I have received at CMU will allow me to make more informed trading decisions," Li said. "In particular, the training that I have received in the BSCF program equips me to have a solid understanding of and to be mindful of the risks associated with trading complex financial instruments."

Class of 2018 Destinations

Firms that hired more than one member of the class:

amazon

CASTLETON COMMODITIES

citi

facebook

Google

Goldman Sachs

PETUUM

Doctoral Programs:

CalTech, Applied Math

Chicago, Math

Duke, Math

Illinois, Math (2)

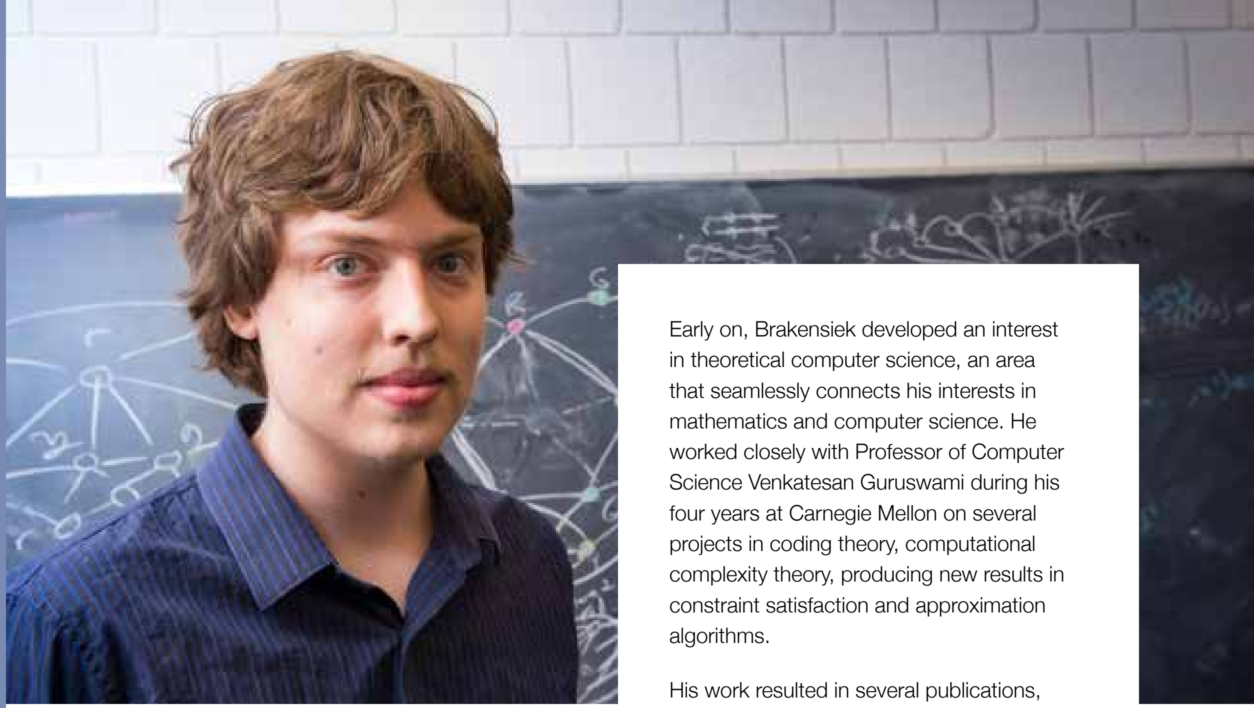
Minnesota, Economics

Stanford, Computer Science

UCLA, Biostatistics

UCSD, Math

Wisconsin, Math



Joshua Brakensiek's Undergraduate Success Leads to NSF Graduate Fellowship

During his time at Carnegie Mellon University, mathematical sciences graduate Joshua Brakensiek kept busy. He was a Goldwater Scholar, a Putnam Fellow and a member of the Carnegie Mellon Putnam Team that placed first in 2016. He conducted astrostatistical research with faculty working in statistics and cosmology and theoretical computer science research with faculty in the School of Computer Science. He published papers and presented at conferences around the world. All while working toward joint bachelor's and master's degrees in mathematical sciences through the Department of Mathematical Sciences' Honors Program.

"I am exceedingly thankful that I was able to call Carnegie Mellon my academic home for four years. The innovative opportunities I had access to changed my life," said Brakensiek, who graduated this past May.

Brakensiek came to Carnegie Mellon University as part of its Knaster-McWilliams Scholars program, which is one of only a few scholarship-supported programs in the United States that pairs an honors program with increased access to faculty and early research opportunities.

Early on, Brakensiek developed an interest in theoretical computer science, an area that seamlessly connects his interests in mathematics and computer science. He worked closely with Professor of Computer Science Venkatesan Guruswami during his four years at Carnegie Mellon on several projects in coding theory, computational complexity theory, producing new results in constraint satisfaction and approximation algorithms.

His work resulted in several publications, manuscripts and presentations at major computer science and mathematics conferences and symposia, including the Symposium on Discrete Algorithms, APPROX and RANDOM.

"I am thankful to Carnegie Mellon, especially the Mellon College of Science, for giving me the freedom and opportunity to explore research in such depth as an undergraduate," Brakensiek said.

During his senior year, Brakensiek continued to receive national awards and accolades for his research and academic performance. The Computing Research Association awarded Brakensiek one of four Outstanding Undergraduate Researcher Awards for his outstanding potential in computing research.

Following a national competition, Brakensiek was one of 2,000 awardees, selected from 12,000 applicants, to receive a Graduate Research Fellowship from the National Science Foundation. The fellowship is helping to fund his graduate studies at Stanford University as he pursues his Ph.D. in theoretical computer science.

"Looking back, I am amazed at how well Carnegie Mellon equipped me to pursue graduate studies in my field. As soon as I entered Stanford's program, I felt that I had much to contribute due to the many professors, mentors and friends who had helped me at CMU," Brakensiek said.

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