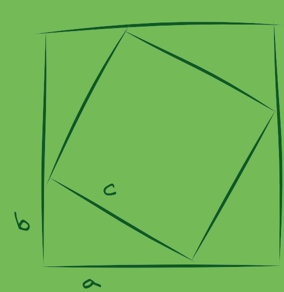
mathematical sciences news 2014



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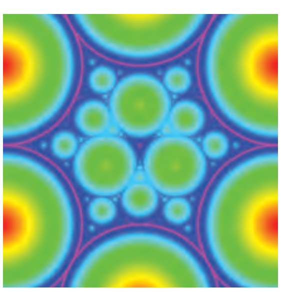
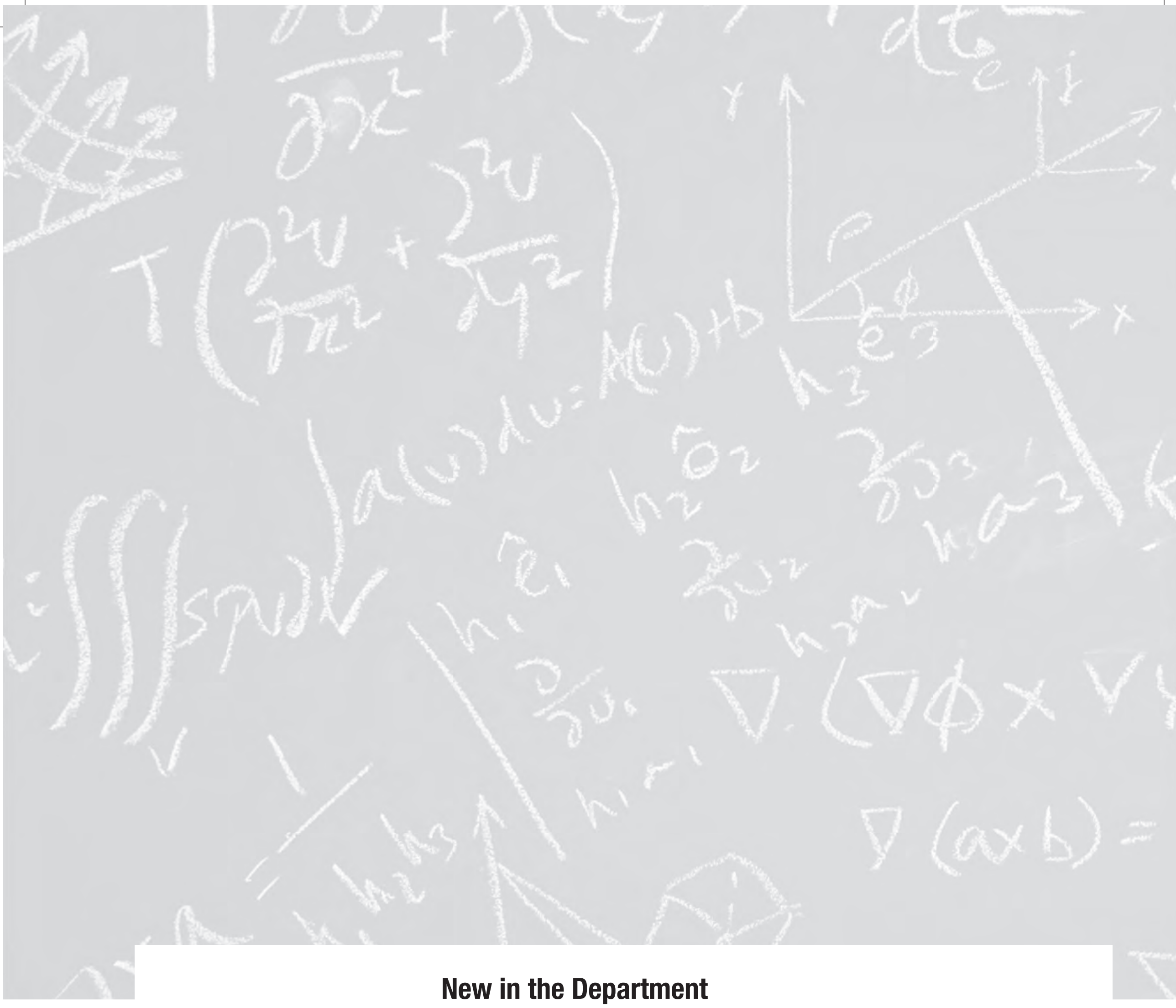


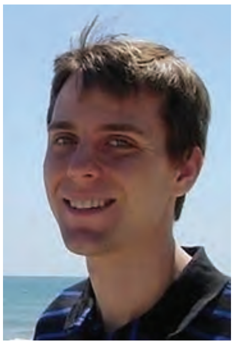
About the cover

The featured story in this issue concerns a process known as the *Abelian Sandpile*. The discussion we present (page 10) considers the process only on the lattice $\mathbb{Z}^2$. The process can be defined on other lattices, but beyond the square lattice, the behavior of the sandpile remains a mystery. We have no mathematical proofs characterizing fractal limits. The cover shows the set γ for the hexagonal lattice (the analogous set for the square lattice is discussed on page 11). This is a computationally produced image; we do not (as of yet) have a proof characterizing the precise structure.

A visual proof of the Pythagorean Theorem can also be found on the cover.



New in the Department



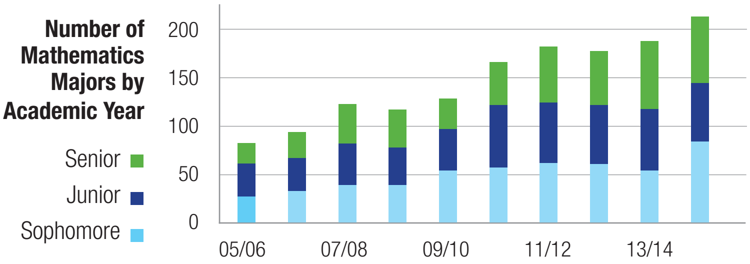
Clinton Conley joined the CMU faculty in fall 2014 as an assistant professor of mathematical sciences after completing postdoctoral appointments at the University of Vienna and Cornell. He received his doctorate in mathematics from UCLA in 2009. Professor Conley works primarily in the area of descriptive set theory. This is an area in which ideas from set theory (for example from the theory of infinite games) are applied to analyze “simply definable” sets, of the type that often arise in problems from analysis. Descriptive set theory has recently found several applications in ergodic theory, harmonic analysis and operator theory. Professor Conley is particularly interested in “Borel combinatorics,” which is the study of simply definable combinatorial objects such as graphs or graph colorings.

Letter from Mathematics Department Head, Tom Bohman

The Department of Mathematical Sciences at Carnegie Mellon has a long tradition of excellence in both research and education, stretching back to the 1940s when John Nash was an undergraduate student in the department. In recent years, the department, in keeping with Carnegie Mellon's overall strategy, has developed and maintained research groups in targeted areas, with an emphasis on areas of mathematics that are most natural to application. We currently have research groups in applied analysis, combinatorics, logic and mathematical finance. This research profile positions the department to contribute to the emergence of new applications of mathematics and naturally generates close links with the many technical disciplines in which Carnegie Mellon has a significant presence and a strong international reputation. We utilize these connections to strengthen a curriculum that prepares mathematics majors for success in a wide range of careers both in academia and beyond while providing excellent support to educational activities across the university.

This tradition has played a role in driving the dramatic increase in interest in mathematics at the undergraduate level in the last few years. The number of students enrolling in key mathematics courses and choosing mathematics as a major continues to grow. Of course, Carnegie Mellon mathematics majors have always been very strong, but there are indications that we are now attracting even more students at the highest level into the major. Our recent success on the Putnam exam is one indication of the strength of our students.

Number of Mathematics Majors by Academic Year



In this newsletter we highlight some of the recent developments in the department. This includes detailed discussion of Assistant Professor Wes Pegden's work on the cellular automata known as the *Abelian Sandpile*, which produces striking fractal images including the image on the cover of this newsletter. We highlight other faculty news and awards as well as recent activities of students, including Math Club Booth, undergraduate research and the Putnam exam.

Our successes in drawing students to the mathematics degree bring many challenges to the department. Through the generous contributions of several alumni, we recently initiated an endowed Innovation Fund for the Mathematical Sciences that will help the department meet these challenges. In the near term, proceeds from this fund will be used to support undergraduate research in mathematics as well as the Math Club. In the longer term, we hope to use this fund to assist in faculty recruiting and retention.

I hope that you'll reconnect with the department by visiting **www.math.cmu.edu/alumni**. Let us know what's new with you!

Alumna Shafi Goldwasser Wins A.M. Turing Award

Shafi Goldwasser, along with long time collaborator Silvio Micali, won the 2012 Association for Computing Machinery's (ACM) A.M. Turing Award for their transformative work that laid the complexity-theoretic foundations for the science of cryptography, and, in the process, pioneered new methods for efficient verification of mathematical proofs in complexity theory. Goldwasser completed the department's Math Studies course sequence and went on to earn a B.S. degree in applied mathematics from CMU in 1979. She earned M.S. and Ph.D. degrees in computer science from the University of California, Berkeley, in 1984. She is the RSA Professor of Electrical Engineering and Computer Science at MIT, and a professor of computer science and applied mathematics at the Weizmann Institute of Science in Israel.

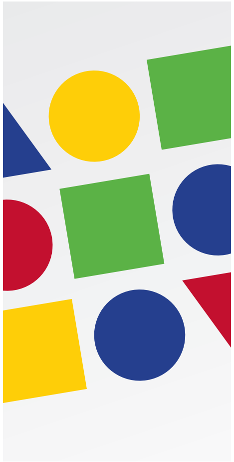
Master of Science in Computational Finance Ranked #1

QuantNet, a leading online news outlet in the field of financial engineering, has recognized the Master of Science in Computational Finance (MSCF) program at Carnegie Mellon University as #1 in its 2013 ranking of financial engineering programs. This is the second #1 ranking in a row for the MSCF program, which was also ranked first in the 2011 QuantNet ranking.

"We created the first professional degree in computational finance almost 20 years ago, and now there are scores of them, including at Columbia, NYU, Princeton and UC-Berkeley," said Steve Shreve,

professor of mathematical sciences and one of the founders of the CMU MSCF program. "I believe we owe our leading position to the fact that Mathematical Sciences chose to create this degree jointly with the Tepper School of Business, the Department of Statistics and the information technology faculty in the Heinz College. To succeed in the finance industry, one needs a strong foundation in math, but one also needs to deal with data, write computer code and understand the business environment. Interdisciplinarity is a hallmark of Carnegie Mellon."

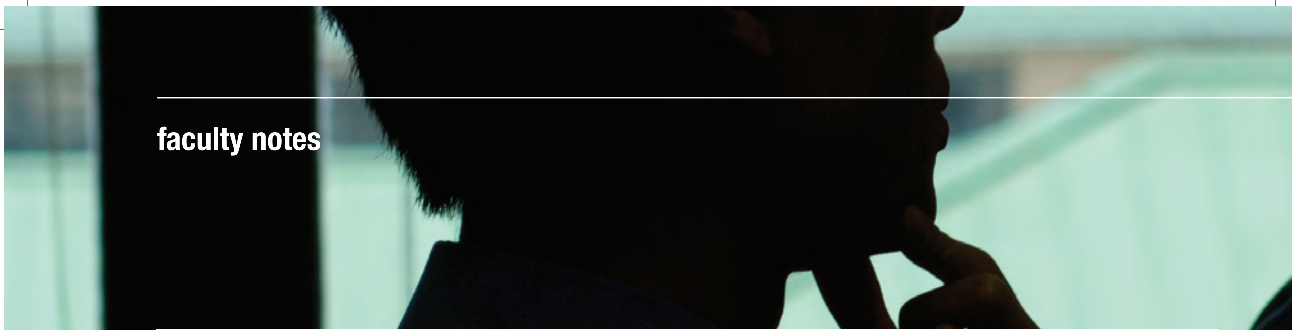
Although MSCF is interdisciplinary, the Department of Mathematical Sciences plays a critical role, teaching a third of the curriculum and providing leadership in policy matters. The department is deeply invested in the applications of mathematics to finance. It is home to the bachelor's program in computational finance and graduates a steady stream of Ph.D. students whose research treats mathematical problems arising in finance.



Math Department Partners with Pittsburgh Public Schools

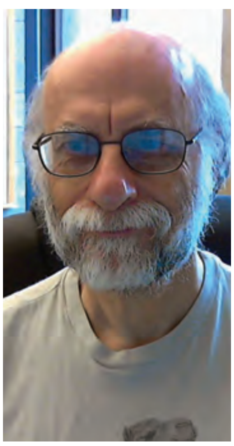
Researchers from local universities, including Carnegie Mellon's Department of Mathematical Sciences, and teachers from the Pittsburgh Public Schools have embarked on a new project to determine if revitalizing content and instructional techniques can benefit students who have been historically marginalized by traditional mathematics education. Under the National Science Foundation's (NSF) Math and Science Partnership program, the NSF has funded the project with an $8 million grant to the Pittsburgh Public Schools (PPS) and the Education Development Center, a Massachusetts-based nonprofit partnering with Carnegie Mellon, the University of Pittsburgh and Duquesne University. John Mackey (pictured above), a teaching professor, associate department head and director of undergraduate studies in the Department of Mathematical Sciences, is a co-principal investigator on the grant, which brings together public school teachers from grades 6-12 with mathematicians from area universities to understand new ways to engage students in math. Mackey said they are excited to work on mathematics instruction with the educators.

> *"We will all get to learn new techniques and gain perspective on the teaching of mathematics," he said. "We anticipate that lasting partnerships will be formed and that more students will be energized to pursue mathematics at the university level."*
>
> *– John Mackey*



Irene Fonseca Leads SIAM

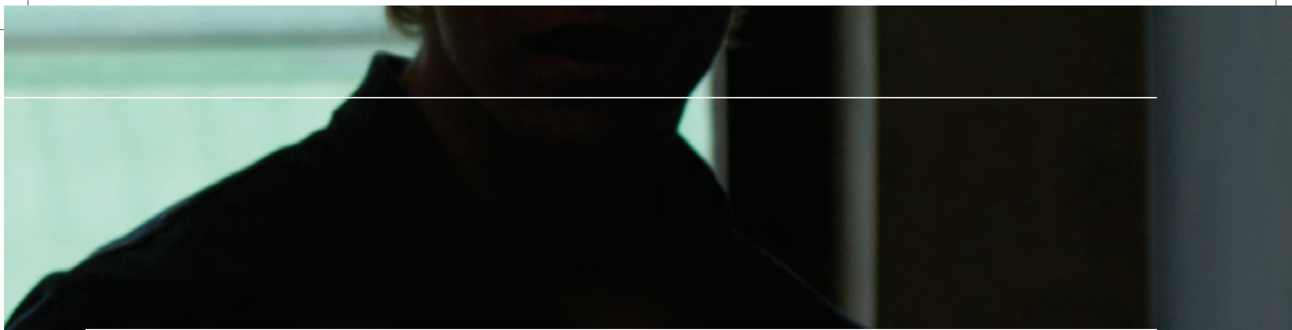
Irene Fonseca is currently serving as president of the Society for Industrial and Applied Mathematics (SIAM), which boasts more than 13,000 individual members and almost 500 institutional members. Of SIAM's 35 presidents, Fonseca is only the second woman to hold this leadership role. Fonseca, the Mellon College of Science Professor of Mathematics and director of the Center for Nonlinear Analysis, is an internationally respected educator and researcher in applied mathematics. Her research lies at the interface of applied analysis with materials and imaging sciences. In particular, her work focuses on the mathematical study of a variety of novel man-made materials, including ferroelectric, magnetic and magnetostrictive materials, shape memory alloys, composites and liquid crystals. She also studies the variational analysis of denoising, detexturing, inpainting and recolorization in computer vision. Fonseca has a strong international presence in the mathematics community. She sits on committees and the boards of several major international universities and research centers. In 1997, she was bestowed knighthood in the Military Order of St. James by the president of Portugal in recognition of her contributions to scientific progress in the European Union.



Alan Frieze Delivers Plenary Lecture at the International Congress of Mathematicians

The International Congress of Mathematicians (ICM) is one of the largest and most prestigious international congresses in the mathematics community. A number of major prizes, including the Fields Medal, are awarded during the congress's opening ceremony, and many important events in the history of mathematics have taken place at the ICM. For example, during the 1900 congress in Paris, France, David Hilbert announced his famous list of 23 unsolved mathematical problems, now termed Hilbert's problems. At the 2014 ICM in Seoul, South Korea, Mathematical Sciences Professor Alan Frieze delivered an invited plenary address, "Random Structures and Algorithms." As the ICM is held only once every four years, only a very select group of mathematicians who have had a major impact on the field are invited to deliver plenary lectures.

Professor Frieze is a pioneer in the study of random combinatorial structures and the use of randomness in algorithms. His polynomial-time algorithm for approximating the volume of a convex body (joint work with M. Dyer and R. Kannan) has had a lasting impact on theoretical computer science. Another major contribution (also in joint work with R. Kannan) is a weak version of the Szemeredi Regularity Lemma. This weak regularity Lemma is a critical tool in combinatorics.



Fonseca and Shreve Named University Professors

Irene Fonseca and Steven E. Shreve received the elite distinction of University Professor, the highest academic accolade a faculty member can achieve at Carnegie Mellon. The rank of University Professor recognizes a faculty member for representing the intellectual leadership of Carnegie Mellon through their expertise and accomplishments in their respective fields of study.

Fonseca, the Mellon College of Science Professor of Mathematics, has been a member of the Carnegie Mellon faculty since 1987. She is an internationally respected educator and researcher in the field of applied mathematics. Her research lies at the interface of applied analysis with materials and imaging sciences. Fonseca directs Carnegie Mellon's renowned Center for Nonlinear Analysis, a center devoted to research and training in applied mathematics at the intersection of mathematics and the physical sciences and engineering.

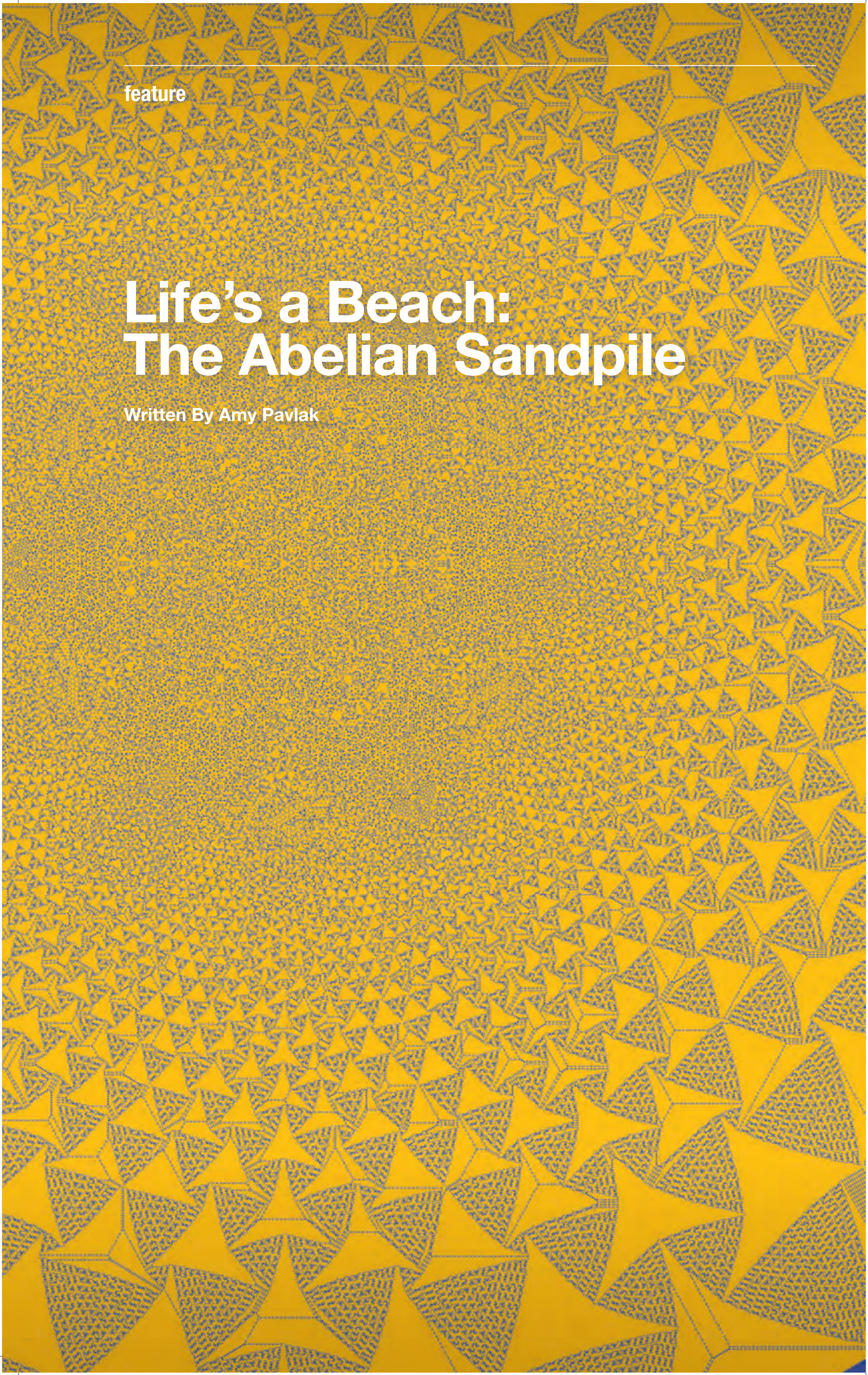
Shreve, the Orion Hoch Professor of Mathematical Sciences, has been a member of the Carnegie Mellon faculty since 1980. He is internationally recognized for his role in laying the foundations for the modern mathematical theory of optimal portfolio construction in the presence of market uncertainty and his other work in mathematics applied to finance, including the development of models for pricing exotic derivative securities and convertible bonds. Shreve helped found Carnegie Mellon's highly regarded bachelor's, master's and doctoral programs in computational and mathematical finance.

David Kinderlehrer Named SIAM Fellow

The SIAM Fellows Program honors mathematicians who are recognized by their peers as distinguished for their contributions to the discipline. David Kinderlehrer was recently named a SIAM Fellow in recognition of his contributions to nonlinear partial differential equations, the calculus of variations and mathematical aspects of materials science. Professor Kinderlehrer joins CMU Department of Mathematical Sciences faculty Irene Fonseca, Alan Frieze and Bob Pego among the ranks of SIAM Fellows.

Life's a Beach: The Abelian Sandpile

Written By Amy Pavlak



Every child who's ever played in a sandbox or on the beach knows a little something about a deep mathematical truth: Pour sand out of a bucket a little at a time, it will build up into a pile. If the pile gets too steep, grains of sand will tumble away from the peak in a mini-avalanche.

In 1987 physicists developed a model of a sandpile and used it to detail a mechanism that explains how complexity arises in nature, whether it's a forest fire, an earthquake or an avalanche.

In their model, piles of sand automatically even themselves out to a stable organization by continually moving sand away from the steepest areas. Model this on a computer and you get very intricate fractal images (see the image below). Rigorous analysis of this complex structure has been remarkably illusive. Some have gone so far as to claim that traditional mathematics is not at all suited to the task of analyzing this kind of complexity.

"You have this crazy, complex picture that's been around for a long time, and we didn't have any explanation, mathematically," said Wes Pegden, assistant professor of mathematical sciences. "Now we understand some of what's going on here."

For the past few years Pegden has been working on the sandpile problem with CMU alumnus Charles Smart (S'02, CS'02), an assistant professor of mathematics at Cornell University. They met as postdocs at New York University and were intrigued by the problem.

"For me, the most interesting thing about it is that you can have a simple rule that produces incredible complexity."

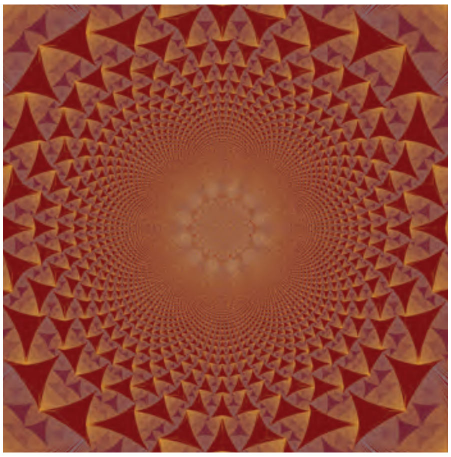
– Wes Pegden

The simple rule is this: Imagine an infinite chessboard. At one of the vertices you place 1,000 grains of sand (or chips). When there are more than four chips at a vertex, they topple, with one chip sliding down each edge to a neighboring vertex. Then a neighboring vertex might spill over, causing a chain reaction. Whether you start with 1,000 chips or 1 billion, they topple and spread out to form the same configuration.

"One of the striking things about the sandpile is that it looks like there's some limit of this process. When I increase the number of chips, I still get basically the same picture. I just get a higher resolution version of it," Pegden said. Pegden and Smart work in different fields — combinatorics and partial differential equations — but they combined their expertise to prove that there is a limit to the toppling process. They also developed a mathematical explanation for why there are triangular shapes in the image and why they're arranged in the way that they are.

"Having a simple rule that produces complexity is already a mystery," Pegden said. "We had no idea what was going on with this for 25 years. Now, we can say a lot about it mathematically."

For more details on the sandpile process and the mathematics of the scaling limit see the article on the next page.



The Mathematics of the Abelian Sandpile

Written by Wes Pegden

Simple rules have the potential to produce striking complexity. One process based on a simple rule that produces a lot of complexity is the *Abelian Sandpile* model. It works like this: We begin with any initial configuration $\eta : \mathbb{Z}^2 \rightarrow \mathbb{N}$ of *chips* on the integer lattice $\mathbb{Z}^2$; that is, there is some nonnegative number $\eta(x)$ of chips at each vertex $x \in \mathbb{Z}^2$ of the lattice. Any vertex x with $\eta(x) \geq 4$ is *unstable* and can *topple* sending 1 chip to each of its 4 neighbors in the lattice. If we assume that

$$\sum_{x \in \mathbb{Z}^2} \eta(x) < \infty$$

then toppling unstable vertices will, after finitely many steps, produce a *stable configuration*, in which every vertex satisfies $\eta(x) \leq 3$.

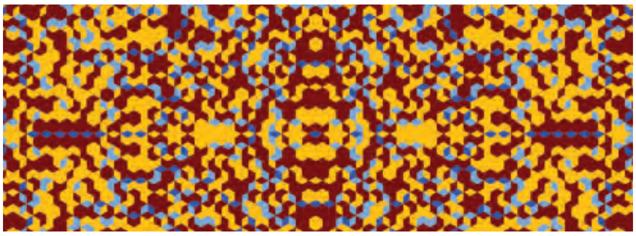
In the example below, we begin with an initial configuration η consisting just of 25 chips at the origin. We begin by toppling this origin (0,0) vertex 6 times; this sends 6 chips to each of the four lattice neighbors of the origin, and the origin itself is left with $25 - 6 \cdot 4 = 1$ chips. At this point, each neighbor of the origin is unstable; in the sequence shown below, we choose to topple the neighbor at (0,1), directly above the origin. We then topple at (-1,0), then (0,-1), then (1,0). Meanwhile, the origin has become unstable again; it now has 5 chips. After one final topple of the origin, we find that we have a stable configuration.

$$\begin{matrix} 0&0&0&0&0\\ 0&0&0&0&0\\ 0&0&25&0&0\\ 0&0&0&0&0\\ 0&0&0&0&0 \end{matrix} \qquad \begin{matrix} 0&0&0&0&0\\ 0&0&6&0&0\\ 0&6&1&6&0\\ 0&0&6&0&0\\ 0&0&0&0&0 \end{matrix} \qquad \begin{matrix} 0&0&1&0&0\\ 0&1&2&1&0\\ 0&6&2&6&0\\ 0&0&6&0&0\\ 0&0&0&0&0 \end{matrix} \qquad \begin{matrix} 0&0&1&0&0\\ 0&2&2&1&0\\ 1&2&3&6&0\\ 0&1&6&0&0\\ 0&0&0&0&0 \end{matrix}$$

$$\begin{matrix} 0&0&1&0&0\\ 0&2&2&1&0\\ 1&2&4&6&0\\ 0&2&2&1&0\\ 0&0&1&0&0 \end{matrix} \qquad \begin{matrix} 0&0&1&0&0\\ 0&2&2&2&0\\ 1&2&5&2&1\\ 0&2&2&2&0\\ 0&0&1&0&0 \end{matrix} \qquad \begin{matrix} 0&0&1&0&0\\ 0&2&3&2&0\\ 1&3&1&3&1\\ 0&2&3&2&0\\ 0&0&1&0&0 \end{matrix}$$

Of course, in the course of the stabilization procedure, there is not always a unique choice of which vertex to topple next, but nevertheless, it is possible to prove that the **final configuration reached** (and also the number of times each vertex will topple in stabilization) **does not depend on the choice of toppling order**. (In this sense, the sandpile is *Abelian*.)

The stable configurations arising for an initial configuration consisting of $n = 10^3$, 10^4, 10^5, or 10^6 chips placed at the origin is shown in Figure 1. In particular, in the limit, it seems that a fractal pattern is appearing.



Abelian Sandpile detail.

With Charles Smart, we showed that there really is a limiting image $s_\infty : \mathbb{R}^2 \rightarrow [0, 3]$, and that it is governed by a certain partial differential equation (PDE). To define this PDE, recall that second derivative of a function f on $\mathbb{R}^2$ is the 2 x 2 (symmetric) *Hessian matrix.*

$$H(f)(x) \begin{bmatrix} \dfrac{\partial^2 f(x)}{\partial x_1^2} & \dfrac{\partial^2 f(x)}{\partial x_1 \partial x_2} \\[2ex] \dfrac{\partial^2 f(x)}{\partial x_1 \partial x_2} & \dfrac{\partial^2 f(x)}{\partial x_2^2} \end{bmatrix}$$

Given any 2 x 2 symmetric matrix $A = \begin{bmatrix} \alpha & \beta \\ \beta & \gamma \end{bmatrix}$,

the quadratic form: $\frac{1}{2} x^t A x = \frac{1}{2} \alpha x_1^2 + \beta x_1 x_2 + \frac{1}{2} \gamma x_2^2$
is the quadratic form whose Hessian is A everywhere.

Recall now that the Laplacian $\Delta f(x)$ is the trace of the matrix $H(f)(x)$; that is,

$$\Delta f(x) = \frac{\partial^2 f(x)}{\partial x_1^2} + \frac{\partial^2 f(x)}{\partial x_2^2}$$

For a function g defined on $\mathbb{Z}^2$ instead of $\mathbb{R}^2$, there is a discrete analog of Δ, defined by:

$$\Delta^1 g(x) := \sum_{y \sim x} (v(y) - v(x)).$$

Here, the summation is taken over the four lattice neighbors $y \sim x$.

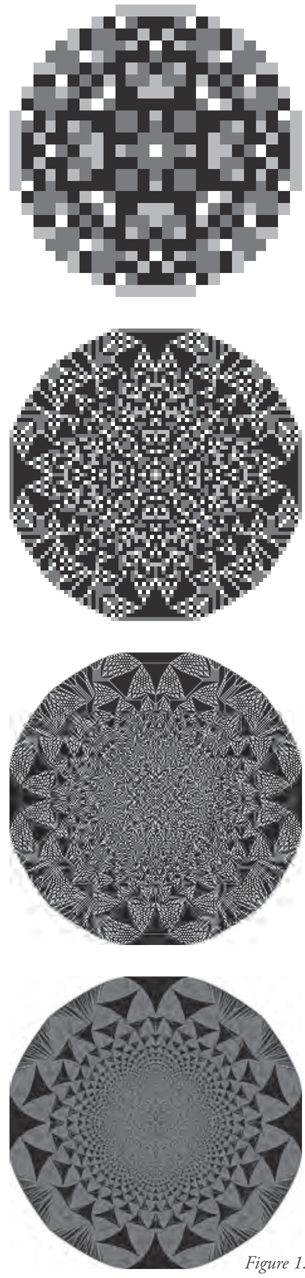


Figure 1.

Figure 1 *Sandpiles started from $n = 10^3$, $n = 10^4$, $n = 10^5$, and $n = 10^6$ chips placed at the origin of Z^2, rescaled by factors of $n^{1/2}$. Sites with 0, 1, 2, and 3 chips are represented by white, light gray, dark gray, and black, respectively.*

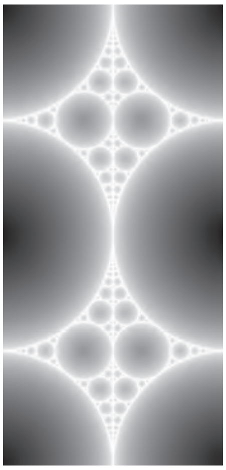


Figure 2a.

With Charles, we proved that the limiting sandpile s_∞ is given by $s_\infty = \Delta v_\infty$, where v_∞ is a function satisfying[1] the PDE, $H(v)(x) \in \Gamma$ for all x.

Thus, we view Γ as the set of allowable Hessians for the function v_∞. This Γ is a very special set of 2 x 2 symmetric matrices, defined by condition that $A \in \Gamma$ whenever $\exists\ u : \mathbb{Z}^2 \to \mathbb{Z}$ such that $\Delta^1(u) \leq 3$ and $u(x) \geq \frac{1}{2} x^T A x$ everywhere. (It is no accident that the 3 here is the same as the cutoff for a vertex in the sandpile process to be stable!)

What does the set Γ look like? It is actually possible to visualize it. Any 2 x 2 symmetric matrix A corresponds to a point (a, b, c) in $\mathbb{R}^3$ since there is a unique way of writing

$$A = \begin{bmatrix} c+a & b \\ b & c-a \end{bmatrix}$$

Thus we can view Γ as some subset of 3-dimensional space, and it turns out that Γ itself has a striking fractal structure (Figure 2). It is a union of slope 1 cones arranged in an *Apollonian circle packing* (look these up on Wikipedia!).

We proved this fractal characterization in joint work with Charles Smart and Lionel Levine. And, in a different paper, we used this structure to analyze the fractal structure of the sandpile. In particular, we determined a class of fractals — we call them *Apollonian triangulations* — produced by the sandpile process (Figure 3).

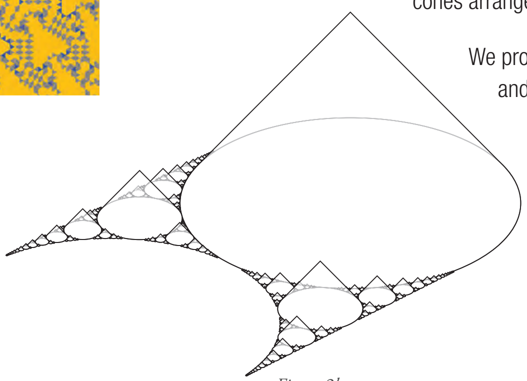


Figure 2b.

Figure 2 *Two different views of (finite regions of) the boundary of the set Γ.*

[1] Strictly speaking, v_∞ is not actually twice differentiable everywhere, so it is merely a viscosity solution to this PDE; nevertheless, viscosity solutions to this PDE are unique up to boundary conditions.

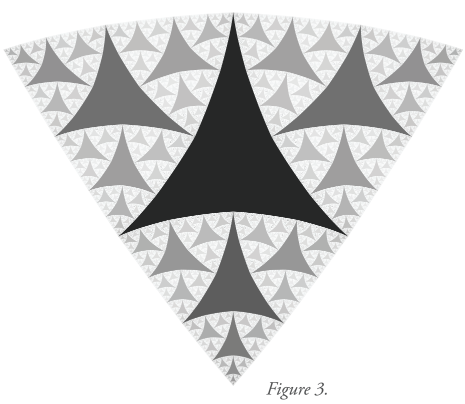
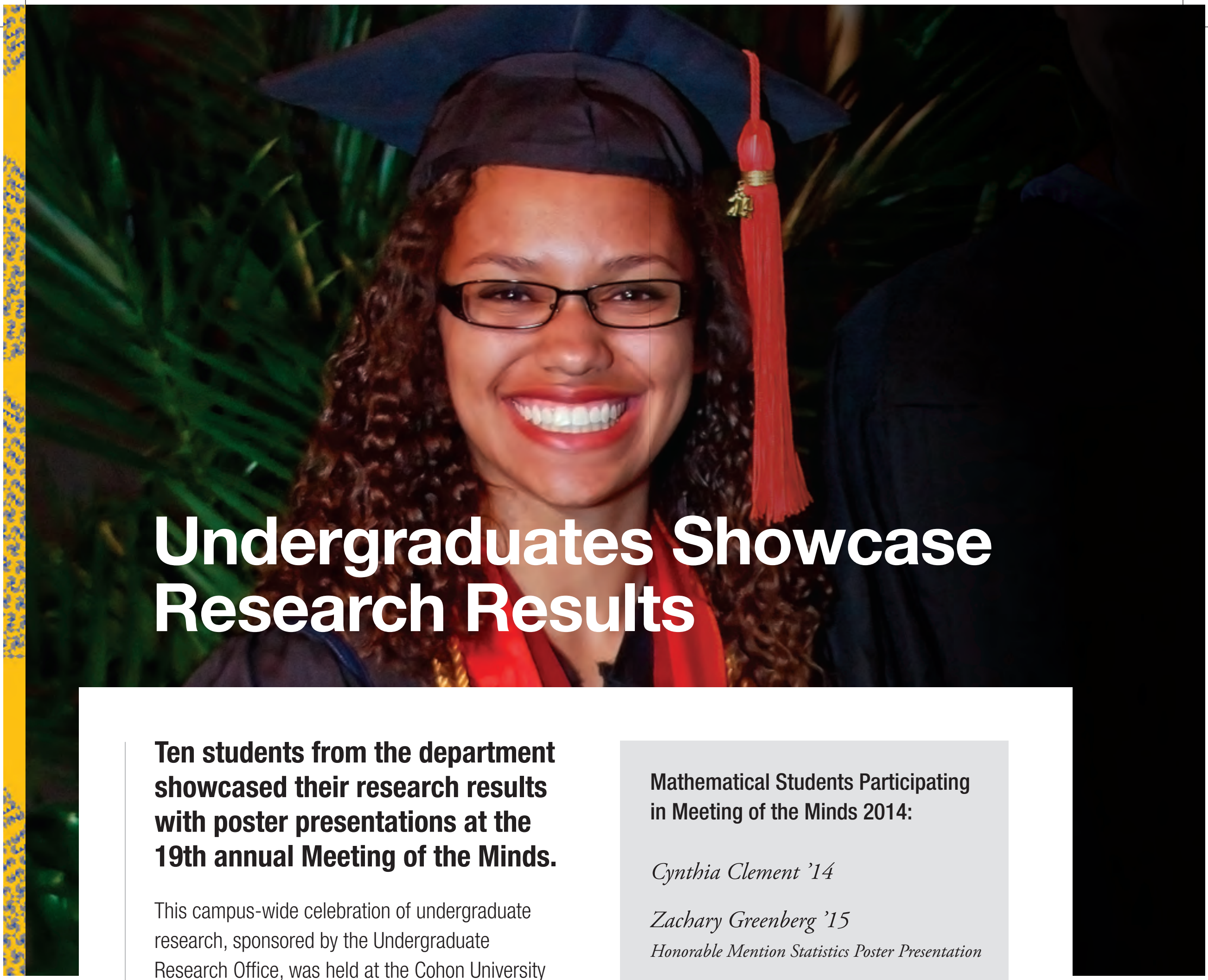


Figure 3.



Undergraduates Showcase Research Results

Ten students from the department showcased their research results with poster presentations at the 19th annual Meeting of the Minds.

This campus-wide celebration of undergraduate research, sponsored by the Undergraduate Research Office, was held at the Cohon University Center on May 7. The research presented included projects in pure and applied mathematics like "**F-Decompositions of Integers**" and "**Mortgage Backed Security Prepayment Modeling**." Math majors also presented work on projects in computer science, robotics and statistics.

Shaina Mitchell (class of 2014, pictured above) earned first place Poster Presentation category in the Statistics for her project "**Modeling Psychosis Trajectories in Alzheimer's Patients Using Latent Class Analysis with Nested Hidden Markov Models**." Shaina, a Goldman-Sachs Scholar, is currently in her first year of a Ph.D. program in biostatistics at the University of North Carolina, Chapel Hill.

The demand for undergraduate research and capstone projects in mathematics is high, and creating more opportunities of this kind is a high priority for the department. Supporting undergraduate research projects in mathematics is one of the goals of the Innovation Fund for the Department of Mathematical Sciences.

Mathematical Students Participating in Meeting of the Minds 2014:

Cynthia Clement '14

Zachary Greenberg '15
Honorable Mention Statistics Poster Presentation

Alekhya Jonnalagedda '16

Archit Kulkarni '15

Shaina Mitchell '14
First Place Statistics Poster Presentation

Eun Ji Shim '14

Javier Vasquez-Trejo '15

Jordan Williams '14

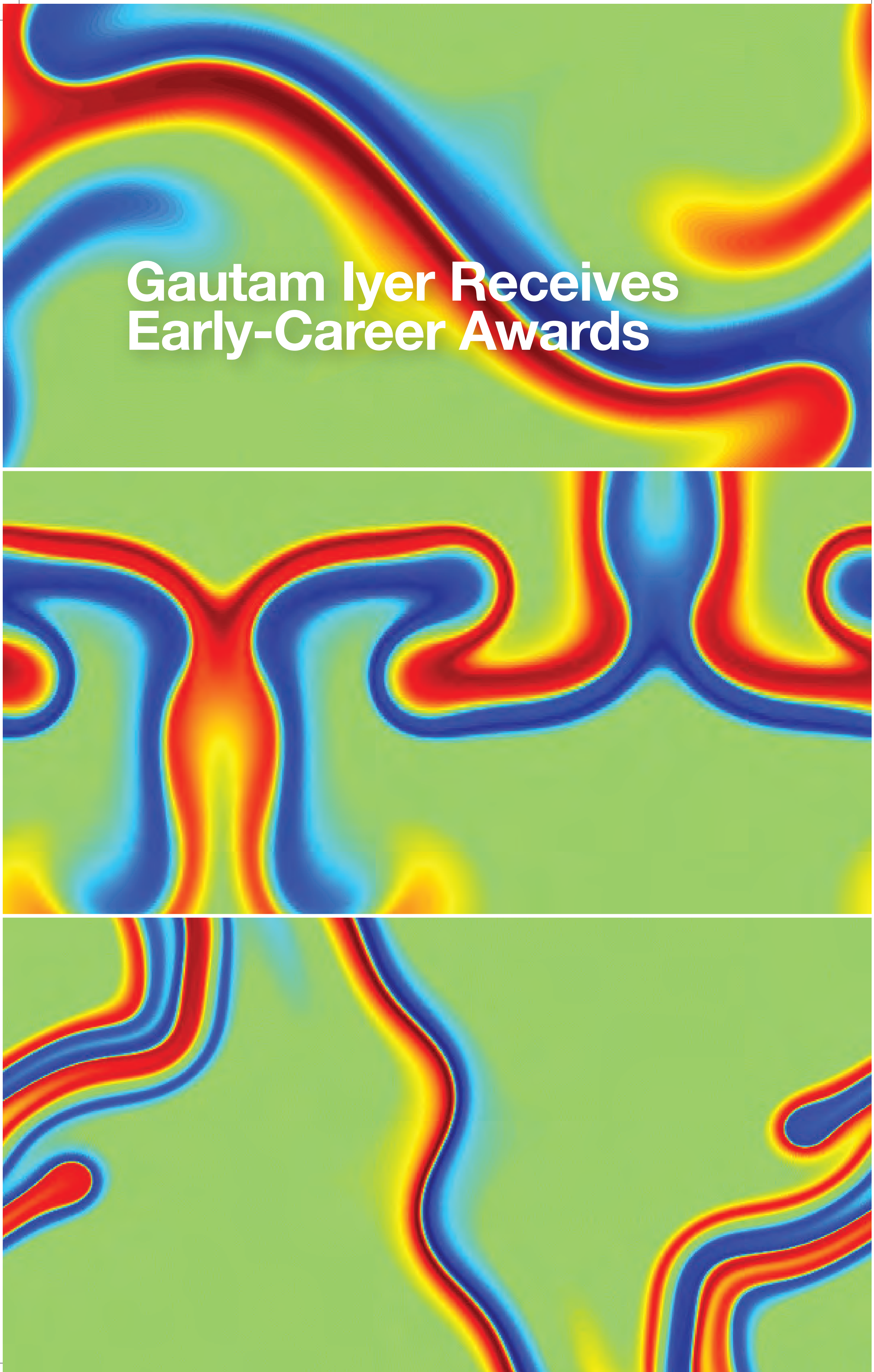
Hongyang Yu '14

Tony Zhang '14

Find more about the students' presentations at:

www.cmu.edu/uro/MoM/2014-abstract-booklet.pdf

Gautam Iyer Receives Early-Career Awards



Gautam Iyer, an assistant professor of mathematical sciences and member of the Center for Nonlinear Analysis, has received two of the most highly regarded awards given to outstanding researchers early in their academic careers.

Iyer, who joined the CMU faculty in 2009, was among 126 scientists and scholars to be honored with 2013 Sloan Research Fellowships, which seek to stimulate fundamental research by early-career scientists and scholars of outstanding promise. Iyer also received the National Science Foundation's most prestigious award for new faculty members, the Faculty Early Career Development (CAREER) award.

Gautam Iyer
Assistant Professor, Department of Mathematical Sciences

One part of Professor Iyer's research program is the mathematical study of the mixing of fluids. Suppose you have two different fluids in a given container. How much effort do you need to expend in order to mix to a certain degree? If you stir optimally, how well do you mix? The sequence of images on this adjacent page shows two fluids being stirred optimally. Professor Iyer's results provide theoretical bounds on how well you can mix when stirred optimally. Two groups of researchers, one at the University of Wisconsin and another consisting of researchers from Penn State, Universität Basel (Switzerland) and Università di Pisa, recently exhibited situations where these theoretical bounds are achieved.

In some situations the mathematical study of mixing leads to surprising results. It is well known that when you stir your cup of coffee with a spoon, it tends to cool down. Is there a way to stir your coffee that will keep it hot for longer? It turns out that you can if and only if your cup is not circular! Iyer points out that, to prove such a claim rigorously, he needs to make some assumptions. He works with an idealized mathematical version of the problem in which you are capable of stirring your coffee using an arbitrary force field (i.e., you are a Jedi master). Furthermore, the coffee is incompressible, so your stirring "force field" can't have sources or sinks (i.e., must be divergence free). Iyer also neglects viscous effects in the coffee (i.e., stirring fast won't increase the temperature through viscous dissipation) and supposes that the stirring is planar (i.e., does not move the fluid in the vertical direction).

In addition to his work on the mixing of fluids, Iyer also carries out research on anomalous diffusion, homogenization, liquid crystals and coagulation. His research could help advance the understanding of mathematical models of a variety of phenomena, including physical and chemical processes.

Images: *Professor Iyer's research program, the mathematical study of the mixing of fluids*

CMU Places Second on the Putnam

Carnegie Mellon University has placed second in the Mathematical Association of America's 74th William Lowell Putnam Competition, the premier mathematics contest for undergraduate students.

Additionally, Carnegie Mellon had 35 students who scored among the top 10 percent, the second most of any university. This marks the third consecutive year that the Carnegie Mellon team has placed among the top five teams. Only 11 other universities have placed in the top five more than twice since 1990.

"Repeated success in the Putnam Competition makes Carnegie Mellon shine like a beacon, showing the extreme talent that gathers here," said Po-Shen Loh, assistant professor of mathematical sciences and organizer of Carnegie Mellon's Putnam seminar. "It is our hope that by bringing ambitious students together, they can work with each other to achieve success for themselves, the university and the region."

In December 2013 there were 4,113 American and Canadian undergraduates from 557 institutions who participated in the competition. The students were given six hours to solve 12 complex mathematical problems using a combination of creative thinking and concepts taught in college mathematics courses. Results were sent to participating universities the first week of April.

The second-place ranking reflects the scores of the three students selected to be on the Carnegie Mellon team. Students not on the official university team are able to participate and compete for individual rankings. In total, 163 Carnegie Mellon students participated in this year's competition and 35 placed in the top 442. Sophomore Science and Humanities Scholar **Linus Hamilton** and first-year mathematical sciences students **Thomas Swayze** and **Samuel Zbarsky** placed among the top 16 students.

2013 Putnam Competition Results

School	Number of students in the top 442
MIT	87
Carnegie Mellon	**35**
Harvard	34
Berkeley	21
Stanford	19
Waterloo	14
Toronto	12
California Institute of Technology	11
Princeton	11

The three students on the second-place team, Hamilton, Swayze and junior mathematical sciences major **Michael Druggan**, as well as

Samuel Zbarsky, are all Knaster-McWilliams Scholars. The Knaster-McWilliams Scholars program, which has been funded through the generosity of a physics alumnus and a mathematics and electrical engineering alumnus, is one of only a few scholarship-supported programs in the country that also is paired with an honors program that features increased access to faculty and early research opportunities.

"Our standings in the Putnam Competition paired with our innovative academic and scholarship program bring the best young minds to Carnegie Mellon. It's exciting for us to watch these students succeed, and we can only guess that they will continue to exceed our expectations not only while they are students, but also as they venture into the workforce," said John Mackey, associate head of the Mathematical Sciences Department.

The Carnegie Mellon team placed fifth in 2012 and second in 2011, and had top five finishes in 1987, 1949 and 1946.

Problem Solving Leads to Deeper Mathematics

Assistant Professor Po-Shen Loh organizes the Putnam seminar which now runs five days a week during the fall semester, with different days of the week dedicated to students with different levels of mathematical preparation and experience with contest mathematics.

> *"The Putnam Competition provides the excuse to run a problem-guided tour of mathematics, while also developing core problem-solving skills that enhance the ability to learn and use higher mathematics," said Professor Loh,*

whose enthusiasm for teaching mathematics through problems goes far beyond his work with the CMU Putnam seminar. He was recently appointed national lead coach for the USA International Mathematical Olympiad Team. The International Mathematical Olympiad is the premier math competition for high school students worldwide, and is the oldest of the International Science Olympiads. Since its inception in 1959, the Olympiad has developed a rich legacy, facilitating early talent identification and cultivation on nationwide scales. As the national lead coach ("team leader") for the United States of America, Professor Loh directs national team selection and training activities. He also is building upon the Olympiad platform to bridge the worlds of high school and research mathematics and to broaden interest in mathematics on the national level.

Pictured above left to right: *Michael Druggan, Linus Hamilton and Thomas Swayze*

Math Club Booth Takes Home Carnival Honors

The Math Club's booth-building team stood on the Midway, staring at the pile of lumber at their feet. It was the Math Club's first time building a booth for Carnival, ever.

They hadn't acquired construction knowledge or even a frame from their predecessors like many other groups on campus do. David Mehrle, now a senior math major, read about and got advice on booth construction, and construction in general, during the months leading up to Carnival, and he drew up a solid set of plans. They were ready to start building, although with tempered expectations. "If we have a booth that stands and passes inspection, we'll be happy," David recalls thinking.

The Math Club's booth, **To ∞ and Beyond**, did more than just stay upright. It won the Chairman's Choice Award and the Environmental Award, and invigorated the Math Club. "I got to know a lot of the other math majors," says Zachary Greenberg, the club's president. "It's been great. It's good to do non-mathy things." Building the booth may have been an engineering feat, but the booth itself certainly featured some mathy themes. As people moved through the booth, they got closer and closer to infinity — and things became mathematically weirder. Instead of the leafy green trees painted on the walls near the booth's entry, the trees closer to the exit, and infinity, were binary trees. The games inside the booth also had a mathematical flavor. Visitors tried their luck at Chalkboard Golf, where they attempted to draw a line, with their eyes closed, from the tee to the hole without crossing any of the course's lines.

The other game was the Math Club's take on the pigeonhole principle, including a Pachinko-like board with Ping-Pong balls made to look like pigeons. The games were a hit with visitors, especially the math professors who went through and their children.

> *"Participating in Booth was a great way to show the creative aspects of mathematics,"*
>
> *– Math Club secretary , Kate Borst*

The Math Club, buoyed by their success, is already gearing up for next year's booth — and this time they'll bring with them a lot of construction experience.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