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Peridynamics, Fracture, and Nonlocal Continuum Models

By Qiang Du and Robert Lipton

Most physical processes are the result of collective interactions across disparate length and time scales. The dynamic fracture of brittle solids is a particularly interesting collective interaction connecting large and small length scales. With the application of enough stress or strain to a sample of brittle material, atomistic-scale bonds will eventually snap, leading to fracture of the macroscopic specimen.

The classic theory of dynamic fracture [7, 10] is based on the notion of a deformable continuum containing a crack. The crack is mathematically modeled as a branch cut that begins to move when an infinitesimal extension of the crack releases more energy than needed to create a fracture surface. Classic fracture theory, together with experiment, has been enormously successful in characterizing and measuring the resistance of materials to crack growth—and thereby enabling engineering design. However, the capability to quantitatively predict the dynamics of multiple propagating cracks that are free to nucleate, change course, bifurcate, and, indeed, stop if they choose lies completely outside the classic approach.

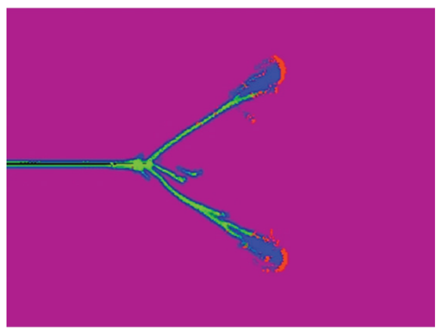

Figure 1. *Peridynamic simulation of dynamic fracture starting from a short edge crack. Areas where damage has occurred are shown in blue and green. The active process zones where damage is increasing are shown in red. Because the plate is stretched at a constant rate, the cracks see a higher and higher strain field ahead of them as they grow.*

Armed with supercomputers, contemporary science is engaged in the quest for a multiscale framework for quantitatively predicting the dynamics of multiple cracks that freely propagate and interact. Investigators realize the importance of quantifying the influence of macroscopic forces on the dynamics at the length scales at which atomic bonds are broken. Bottom-up approaches, recognizing the inherent discreteness of fracture through lattice models, have provided penetrating insight into the dynamics of the fracture processes [2,12,13,20]. Nevertheless, numerical simulations of fine-grained atomistic models, while offering important and necessary insight into the fracture process, do not scale up to finite-size samples with multiple freely propagating cracks.

Complementary to the bottom-up approaches are top-down computational ap-

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Math of Planet Earth Takes Up Challenges Set by Successful Predecessor

By Fred S. Roberts

With the human population recently having surpassed 7 billion, protecting the earth and its resources is a shared challenge facing all of humanity. People need food, housing, clean water, and energy; yet the earth's systems and dynamics are unpredictable, and its resources are limited. We need to understand the impact of our actions on the environment, and we need to learn how to adapt those actions to lessen our impact, how to predict and respond to catastrophic events, and how to plan for changes to come. The most pressing problems are inherently multidisciplinary, and the mathematical sciences have an important role to play.

A large community of mathematical scientists from around the world, often joined by scientists from other disciplines, stepped forward to embrace this role through participation in Mathematics of Planet Earth 2013. With scientific activities directed both to the mathematical sciences community and to their potential collaborators in other disciplines, MPE2013 proved that many issues related to weather, climate, ecology, sustainability, public health, natural hazards, and financial and social systems lead to interesting mathematical problems. MPE2013 came to a highly successful close on December 31, 2013.* Planning is now under way for a variety of continuing activities in the extended project known as Mathematics of Planet Earth.

Moving Forward: MPE2013+ in the United States

In the U.S., with support from the National Science Foundation, we have initiated Mathematics of Planet Earth 2013+, which aims to involve mathematical scientists in sustained long-term MPE activities. MPE2013+ will operate under the auspices of the DIMACS Center, based at Rutgers University, under the leadership of Fred Roberts, a professor of mathematics and director emeritus of DIMACS. Activities will be organized around six clusters of topics: *Management of Natural Resources, Sustainable Human Environments, Natural Disasters, Data-aware Energy Use, Global Change,* and *Education for the Planet Earth of Tomorrow*.

A kickoff workshop will be held for each cluster, in 2014 or 2015 at a location somewhere in the U.S. Follow-up activities extending into 2016 and beyond will include focused research workshops, small group meetings, collaborative programs, and educational efforts, each organized by one of the six cluster organizing committees. Funds are available for participation in both the workshops and the follow-up activities of the clusters, with an emphasis on involvement of graduate students, postdocs, and junior faculty. Information about the workshops and other cluster activities can be found at http://mpe2013.org/mpe2013index/.

*A survey of MPE2013 activities by Hans Kaper, which appeared in the October 2013 issue of *SIAM News*, can be found at http://www.siam.org/news/news.php?id=2099. Detailed information about MPE2013 is available at http://mpe2013.org/.

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Maths Goes Underground

As the UK's Institute of Mathematics and its Applications looked forward to its 50th anniversary (in 2014), Chris Budd reminded readers of the IMA's Mathematics Today *of a maths-related anniversary that fell in 2013: The London Underground's 150th. The following article is an adapted version of Budd's IMA article.**

The first London Underground train (which was gas lit and powered by steam) travelled on the Metropolitan line on January 10, 1863. Since then, the Underground has grown considerably: It consists today of 270 stations joined by 249 miles of track. It has inspired other metro systems all over the world.

There are many close links between the London Underground and mathematics. In particular, an important landmark was the creation of the Tube map by Harry Beck in 1931. Because the railway ran mostly underground, Beck recognised that the physical locations of the stations were irrelevant to a traveller wanting to know how to get from one station to another. Accordingly, Beck simplified the network based on the interactions of the lines themselves, rather than their actual locations relative to one another. Beck's genius in creating the Tube map was to compress the essential information into a diagram, which was not only clear and informative but also had great artistic appeal. (See page 8 for a recent version.)

For many travellers on the Underground, this is their first (and often only) introduction to topology. The Tube map is also a famous example of a network, in which the nodes are the stations and the edges the train connections between them. The Tube map helped to make complete sense of the complex system of lines in the Underground system. The map has been emulated widely and serves as a constant reminder of the importance of topology in real life!

The mathematics of labyrinths led to an inspiring artistic project, called *Labyrinth*, that has been a major feature of the 150th-anniversary celebrations of the London Underground. For the project, Art on the Underground commissioned Turner Prize-winning artist Mark Wallinger to respond to the rich environment and history of the Tube. In a long, considered artistic process, Wallinger created 270 unique labyrinth artworks for permanent installation, one in every station on the network. Each artwork has its own reference number, acknowledging the order in which its station was visited during the 2009 Guinness World Record Tube Challenge (see Note).

A labyrinth is different from a maze, in that it has only one route to the centre and out again, although that route may be very long. Labyrinths have a history

Labyrinth, 2013, one of 270 unique artworks created by the artist Mark Wallinger for installation in the stations of the London Underground to mark its 150th anniversary. © the artist, courtesy Anthony Reynolds Gallery, London. Commissioned by Art on the Underground. Photograph © Thierry Bal.

*The original appeared in *Mathematics Today*, 49:5 (2013), 198–199.

See **Underground** *on page 8*

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SciDAC: Accelerating Scientific Discovery, Transforming Computational Science

The Office of Science at the U.S. Department of Energy created the SciDAC (Scientific Discovery through Advanced Computing) program to address challenging large-scale scientific problems that are central to the mission of DOE. Given the scale of these scientific problems, progress requires high-performance computing platforms, such as those at the National Energy Research Scientific Computing Center, the Argonne Leadership Computing Facility, and the Oak Ridge Leadership Computing Facility. Established in 2001 as a five-year program, SciDAC is now in its third five-year cycle; its longevity can be attributed to both the increasing scale of the scientific problems to be solved and the growing complexity of computer architectures.

At the time of the June 2001 launch of SciDAC, the fastest machine in the world (at Lawrence Livermore National Laboratory) attained 7.2 teraflops per second across 8192 cores. Twelve years later, the fastest machine (the Tianhe-2 in China) has achieved 33,800 teraflops per second across 3.12 million cores, representing an almost 5000-fold increase in computing power. At the same time, computer architectures have become much more elaborate, with increasingly heterogeneous design and deepening memory hierarchies. In this setting, a multidisciplinary approach is needed for solving large-scale scientific problems.

A defining aspect of the SciDAC program has been its strong emphasis on partnerships among domain scientists, applied mathematicians, and computer scientists; a reorganization of the program at the beginning of its current cycle reinforces the importance of partnerships. The goal is to leverage expertise in computer science and mathematics, as well as state-of-the-art mathematical algorithms and software libraries for advanced computing, in solving large-scale scientific problems and thus making possible and accelerating scientific discoveries. Understanding the current SciDAC program begins with a look at the structure of DOE's Office of Science.

SciDAC as Nexus

The DOE Office of Science comprises six program offices: Along with Advanced Scientific Computing Research (known as ASCR, and the most familiar to the SIAM community) are Basic Energy Sciences (BES), Biological and Environmental Sciences (BER), Fusion Energy Sciences (FES), High Energy Physics (HEP), and Nuclear Physics (NP). Most projects of the Office of Science are funded by individual program offices; the SciDAC projects have a different structure.

The current SciDAC program has two components: *institutes* and *science partnerships*. The four institutes, which are focused on applied mathematics and computer science, are funded entirely by ASCR. Each science partnership, focused on a distinct set of scientific problems, is funded jointly by ASCR and one of the five other program offices.

Almost all SciDAC projects are large, multi-institutional collaborative efforts. Overall, 13 DOE laboratories, 44 universities, and three companies receive funding under the current SciDAC program.

The SciDAC Institutes

FASTMath—the Frameworks, Algorithms, and Scalable Technologies for Mathematics Institute—develops scalable mathematical algorithms and software for reliable simulation of complex phenomena. Its focus is on structured and unstructured meshing, linear and nonlinear equation solvers, time integrators, variational inequality solvers, and eigensolvers.

QUEST—the Quantification of Uncertainty in Extreme Scale Computations Institute—is focused on uncertainty quantification (UQ) in large-scale scientific computations. The overarching goal of QUEST is to provide modeling, algorithmic, and general UQ expertise, together with software tools, to other SciDAC institutes, SciDAC science partnerships, and Office of Science projects in general, thereby enabling and guiding a broad range of UQ activities in their respective contexts.

SUPER—the Institute for Sustained Performance, Energy, and Resilience—seeks to ensure that computational scientists are able to exploit the emerging generation of leadership-class computing systems. To this end, SUPER addresses performance portability for new systems, management of energy consumption, resilient computation, and end-to-end optimization.

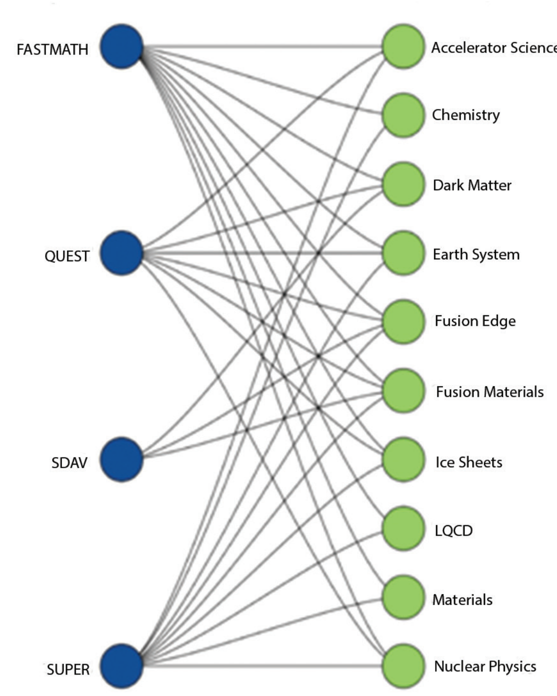
SDAV—the Institute of Scalable Data Management, Analysis, and Visualization—addresses the explosive growth of data in scientific computing. SDAV provides solutions in three areas: data management, including the infrastructure for efficient indexing, compression, and organization of datasets; data analysis, with a focus on in situ analysis, filtering, and data reduction; and data visualization, for identifying features in multiscale and multiphysics datasets.

The main goals of the institutes are the development of scalable algorithms and tools for core components of scientific simulation, and the distribution of these capabilities through portable high-performance libraries. At the same time, the institutes work to deploy general mathematics and computer science expertise and algorithms, tools, and libraries in the science partnership projects.

Science Partnerships

Scientific discovery is the focus of the 18 science partnership projects, each of which is supported jointly by ASCR and one of the five other science program offices.

The BES program office supports seven projects. The application areas include energy-related advanced materials for photovoltaic and photocatalysis, nanoscale materials, superconductors, and lithium cell batteries. Many of these projects require algorithmic advances in tensor decomposition, sparse linear equation solvers, eigensolvers, and quantum Monte Carlo methods.



Connections between the four SciDAC institutes (left) and the science partnerships (right). A program of the Office of Science at the Department of Energy, SciDAC was reorganized in 2011, at the beginning of its third five-year cycle.

The BER program office supports three projects aimed toward a predictive understanding of climate and environmental systems. Activities include simulating the dynamics of the atmosphere, ocean, and ice sheets, as well as biogeochemical responses and feedback.

Three projects span the energy, intensity, and cosmic frontiers of the HEP program office. The projects focus on accelerator modeling and design, lattice quantum chromodynamics for moving beyond the standard model, and cosmological simulations of dark energy/matter.

Through large-scale simulations, the three NP program office projects study the strong interaction of low-energy physics, lattice QCD calculations for heavy-ion/medium-energy physics, and connections between the two.

Two projects are funded by the FES program office. One project is developing simulation tools capable of predicting the performance of tungsten-based plasma-facing components and divertor components in extreme conditions in a burning plasma environment. The other is working

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Seriously Fun Math!

Noticing the approach of December 5, 2013, Glen Whitney and Cindy Lawrence, co-executive directors of the National Museum of Mathematics in NYC, together with chief of design Tim Nissen, went into action. It was time for a public event, one that would draw people into a celebration of an accessible, well-known piece of mathematics.

Readers will realize the significance of 12/5/13. For Lawrence and Whitney, the numbers translated into the need for 450 glow sticks. And 450 people, presumably lovers of mathematics, who would turn out on a December evening to line up, one glow stick each, to measure the three sides of a local landmark, the Flatiron Building, demonstrating that they make up a Pythagorean triangle.

That's a lot of people for a math event. Maybe, Lawrence and Whitney thought, they could tape two glow sticks together. . . . Or bring some people to the city for a board meeting. . . .

In the end, a message to MoMath's mailing list drew some 2000 volunteers. On the evening of December 5, a Thursday, 450 of the volunteers—of all ages, sizes, and walks of life—carried out their mission, with a backdrop of projections on each side of the Flatiron, as shown in the accompanying photos.

Lawrence and Whitney, describing the event to *SIAM News* at their booth at the 2014 Joint Mathematics Meetings, looked forward to future public-participation events. The topics are secret for now, they said.

MoMath co-executive directors Glen Whitney (left) and Cindy Lawrence with Tim Nissen, the museum's chief of design. Photos courtesy of the National Museum of Mathematics.

Meanwhile, Lawrence mentioned another MoMath activity that should be of interest to college students—summer internships at the museum (which overlooks Madison Square Park and is just a few blocks from its triangular neighbor). Interns divide their time between working on the floor, where they guide visitors through the exhibits; honing their administrative skills; and working in the retail shop. Interns' preferences are honored to some extent, Lawrence says, but they're choosy about the people they trust to work the exhibits. Clearly, a good grasp of the mathematical concepts is required, but it must be accompanied by an understanding that not everyone thinks like a math major. The museum is currently accepting applications for the summer internship program (collegeinternship@momath.org).

SciDAC

continued from page 2

on first-principles physical models that can provide insight into edge plasma physics.

As indicated earlier, the partnerships seek to advance understanding of basic science. Each partnership includes a team made up of domain scientists, applied mathematicians, and computer scientists who work closely together. In some cases, the collaborations leverage and build on what the applied mathematicians and computer scientists have developed. In other cases, the collaborations require the development of new techniques so that specific computational challenges can be tackled in the solution of the science problems.

The domain scientists in all the science partnership projects are funded by their respective science program offices. Some of the applied mathematicians and computer scientists in these partnership projects are also part of SciDAC institutes and serve to bridge the institutes and partnership projects.

Multidisciplinary Meetings

A hallmark of the SciDAC program is its annual meeting, at which principal investigators interact, communicate their partnership experiences, exchange ideas, and highlight successes. The third incarnation of SciDAC having begun in 2011, the 2012 meeting had the goal of introducing the projects to the entire SciDAC community. The second annual meeting of the current SciDAC program, held in Rockville, Maryland, July 24–26, 2013, focused on connections between the domain scientists and applied mathematicians and computer scientists, as well as the links between science partnerships and institutes. Approximately 150 researchers participated in each of those meetings.

SciDAC and the Mystery of Carbon-14's Role in Carbon Dating

One of the scientific discoveries made possible by the SciDAC program concerns carbon-14 (^{14}C), the isotope used in carbon dating. The effectiveness of carbon-14 in determining the age of organic materials lies in its half-life of more than 5000 years, as compared with a maximum of 21 minutes for all other unstable carbon isotopes. Why this one particular form of carbon has such a long half-life was long a mystery.

As part of a SciDAC-2 project supporting nuclear physics research, a team of nuclear physicists, applied mathematicians, and computer scientists collaborated to produce a scalable and efficient code that, used in large-scale simulations, unraveled this mystery. Participating scientists determined simultaneous interactions of three nucleons (i.e., protons and neutrons in the atomic nucleus) to be an important factor. Their result appeared in a paper titled "Origin of the Anomalous Long Lifetime of ^{14}C" (*Physical Review Letters*, May 2011).

To achieve their result, the team performed 25 simulations, each running for about six hours on 215,000 processing cores of a Cray XT5 supercomputer (named Jaguar) at Oak Ridge National Laboratory. The heart of each simulation was the solution of a sparse eigenvalue problem with a dimension of about 1 billion. The matrix has approximately 40 trillion nonzero elements, and eight eigenpairs were needed. Although the original simulation code was developed prior to the SciDAC collaboration, the multidisciplinary collaboration under SciDAC resulted in new algorithms, and some computer science issues were resolved. This led to performance improvements to the code, making it run several orders of magnitude faster. Without these improvements, our understanding of carbon-14 would not be as advanced as it is today. Indeed, in the words of Jeremy Holt of the Technical University of Munich, in an article in *New Scientist*, "One can now say confidently that the problem is solved."—*Eduardo D'Azevedo, Oak Ridge National Laboratory; Esmond G. Ng, Lawrence Berkeley National Laboratory; and Stefan M. Wild, Argonne National Laboratory.*

Further information on the SciDAC program can be found at http://www.scidac.gov.

NSF–CBMS Research Conferences for 2014 and 2015

The National Science Foundation and the Conference Board of the Mathematical Sciences have announced eight NSF–CBMS Regional Research Conferences for 2014:

■ **Combinatorial Zeta and L-Functions**
Sundance Resort, Utah, May 12–16
Wen-Ching Winnie Li, lecturer
Jasbir S. Chahal and Michael D. Barrus, organizers
math.byu.edu/cbms

■ **Inverse Scattering and Transmission Eigenvalues**
University of Texas at Arlington, May 27–31
David Colton, lecturer
Tuncay Aktosun, organizer
fermat.uta.edu/cbms2014

■ **Mathematical Foundations of Transformation Optics**
Howard University, June 10–15
Allan Greenleaf, lecturer
M.F. Mahmood and Anjan Biswas, organizers
www.coas.howard.edu/mathematics/cbms2014.html

■ **Quantum Spin Systems**
University of Alabama at Birmingham, June 16–20
Bruno Nachtergaele, lecturer
Shannon Starr, Paul H. Jung, and Gunter Stolz, organizers
www.uab.edu/cas/mathematics/events/nsf-cbms-conference-2014

■ **Fast Direct Solvers for Elliptic PDEs**
Dartmouth College, June 23–27
Gunnar Martinsson, lecturer
Alex H. Barnett, Min Hyung Cho, Adrianna Gillman, and Leslie F. Greengard, organizers
www.math.dartmouth.edu/~fastdirect/

■ **Mathematical Phylogeny**
Winthrop University, June 28–July 2
Mike Steel, lecturer
Joe Rusinko and Trent Kull, organizers
www.birdnest.org/phylogeny/

■ **Higher Representation Theory**
North Carolina State University, July 6–10
Raphael Rouquier, lecturer
Naihuan Jing, organizer
www.math.ncsu.edu/~jing/conf/CBMS/cbms14.html

■ **Problems of PDEs Related to Fluids**
Oklahoma State University, July 21–25
Peter Constantin, lecturer
Jiahong Wu, organizer
www.math.okstate.edu/nfs-cbms_constantin

NSF provides support for about 30 participants, and conference organizers invite both established researchers and interested newcomers, including postdoctoral fellows and graduate students, to apply. Information about specific conferences can be obtained by contacting conference organizers.

The proposal deadline for 2015 conferences is April 25, 2014; in subsequent years, the deadline will be the last Friday in April. Information about the submission process can be found at http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504930&org=DMS&from=home.

Readers can direct questions to: CBMS, 1529 18th Street NW, Washington, DC, 20036; (202) 293–1170; Ron Rosier, CBMS director, rosier@georgetown.edu; or Jennifer Slimowitz Pearl, NSF program director, jslimowi@nsf.gov.

Martin Gardner's Mathematical Grapevine

Undiluted Hocus-Pocus: The Autobiography of Martin Gardner. *By Martin Gardner, Princeton University Press, Princeton, New Jersey, 2013, 233 pages, $24.95.*

Martin Gardner in the Twenty-First Century. *By Michael Henle and Brian Hopkins, editors, MAA Publications, Washington DC, 2012, 350 pages, $40.00.*

BOOK REVIEW
By James Case

Martin Gardner is known to generations of mathematicians as the author—from 1957 through 1981—of the Mathematical Games column in *Scientific American*. Among other things, the columns introduced readers to fractals, Penrose tiling, public-key cryptography, John Horton Conway's Game of Life, the board game Hex (independently invented by Piet Hein and John Nash), mathematical aspects of the work of M.C. Escher, the Soma cube (also invented by Piet Hein), tangrams, polyominoes, and flexagons. Gardner also published at least 70 books (100 if you count pamphlets) on a variety of subjects, along with countless columns and magazine articles.

Through the columns, and the articles he continued to contribute until late in life (he died in 2010) to various MAA publications (mainly the *College Mathematics Journal* and *Math Horizons*), Gardner is credited with the rebirth of recreational mathematics in the U.S. And because he defined recreational math as any mathematics undertaken "in a spirit of play," it is hardly surprising that much of his mathematical writing concerns games.

One of the simplest is the Nim-like amusement known as Wythoff, named for Dutch mathematician Willem Abraham Wythoff, who invented it in 1907. To play, Bob and Alice are confronted with two piles of playing cards. Each in turn may either (1) remove one or more cards from one of the piles, or (2) remove equal numbers of cards from both piles. The first player unable to move—because both piles are empty—loses. Gardner's column on the subject revived interest in this and other "take-away games," of which many have since been invented.

About twenty-five years ago, Steven Brams turned his interest in map coloring into a game—the map-coloring game. First Alice, then Bob, is allowed to color a single region of a given planar map M. The rules specify that each successive region must receive a color different from that previously assigned to any contiguous region. Alice wins if she is able to complete the coloring, and she loses if unable, at some intermediate stage, to color any as yet uncolored region. The "game chromatic number" $\chi_g(M)$ is the smallest number of colors affording Alice a winning strategy on M, and it was quickly established, after Gardner's 1981 column on the subject, that $\chi_g(M) > 5$. However, it took another 13 years to show that $\chi_g(M) < 3044$ for all M, and longer still to reduce that bound to 44, and later to 33.*

By far the most successful of Gardner's *Scientific American* columns, in terms of the response it generated, was the one he wrote in 1970 describing Conway's Game of Life. Played on a rectangular grid, akin to an infinite Go board, the rules of the (one-player) game cause an initial configuration of occupied cells to "evolve" deterministically over time, sometimes dying out, sometimes cycling among a fixed number of configurations, and, in rare instances, growing without bound. The Game of Life is now known to be a universal Turing machine; Andrew Adamatzky commemorated the 40th birthday of the game by editing an extensive collection of papers† from a number of prominent mathematicians and computer scientists who were inspired by the game.

Over time, Gardner developed what Doris Schattschneider later called "Martin Gardner's mathematical grapevine." Late in life, he described the process to an interviewer as follows:

> "When I first started the column, I was not in touch with any mathematicians, and gradually mathematicians who were creative in the field found out about the column and began corresponding with me. So my most interesting columns were columns based on the material I got from them, so I owe them a big debt of gratitude."

The MAA volume contains 41 articles, including eight by Gardner himself. Most concern subjects he introduced (or reintroduced) to the mathematical community, and attest to the vitality of his grapevine.

The title of Gardner's autobiography reflects his lifelong addictions to poetry and magic, as united in verse by Piet Hein:

> We glibly talk of nature's laws
> But do things have a natural cause?
> Black earth turned into yellow crocus
> Is undiluted hocus-pocus.

Gardner's interest in magic was, like most of his interests, primarily intellectual.

*H.A. Kierstead and W.T. Trotter, *Planar graph coloring with an uncooperative partner*, J. Graph Theory, 18 (2003), 569–584.

†*Game of Life Cellular Automata*, Springer, 2010.

Although he practiced magic tricks throughout his life, and invented more than a few, he performed in public only once. Shy by nature, he sought not audiences to surprise and delight, but rather understanding for its own sake.

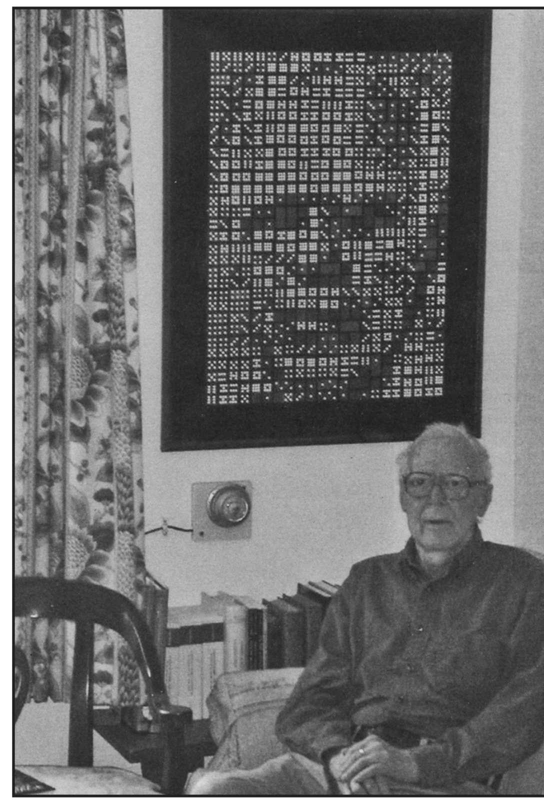
Gardner's interest in magic led to enduring friendships with mathematician Persi Diaconis, who contributed a foreword to the autobiography, and with magician James Randi, who contributed an afterword. Gardner and Diaconis first met in 1958 at a magician's hangout in New York City, where actual and would-be performers were wont to gather on Saturday afternoons. While the 13-year-old Diaconis gravitated toward his contemporaries, Gardner hobnobbed with the professionals to whom he was known for the tricks he'd invented. Somehow the two became acquainted, and began to correspond. Diaconis estimates that he received about twenty letters a year from Gardner over a fifty-year period, many of them seeking assistance in discrediting the sloppy statistics and inadequately controlled experiments alleged to support the pseudoscientific claims Gardner never tired of discrediting. As Diaconis put it, "Martin interacted." The entire autobiography can be viewed as a record of his many interactions—with mathematicians, with debunkers of pseudoscience, with boyhood friends, college professors, navy colleagues, and more. Diaconis's foreword alone is worth the price of the book.

Less well known to the mathematical community is James "the amazing" Randi, who suspects that he and Gardner first met in the offices of *Scientific American* during the late 1950s. They were drawn to each other by their shared interest in pseudoscience, and the debunking thereof. Gardner's first venture into the field had been an article in the *Antioch Review* titled "The Hermit Scientist," about cranks who work in isolation from other scientists. A friend persuaded him to expand the article into a book, which, although the original sold poorly, became an instant classic when reissued by Dover under the title *Fads and Fallacies in the Name of Science*.

The dramatic resurgence of interest in astrology, faith healing, ESP, psychokinesis, and other supernatural beliefs that took hold around 1970 prompted Gardner and Randi to help found an organization called Resources for the Scientific Evaluation of the Paranormal. Its membership was later absorbed—along with TV personality Steve Allen, Carl Sagan, Isaac Asimov, B.F. Skinner, and other champions of evidence-based belief—into the similarly inclined Committee for the Scientific Investigation of Claims of the Paranormal. From 1983 to 2002, Gardner wrote a column called Notes of a Fringe Watcher for the organization's flagship publication *Skeptical Inquirer*. Randi was also a regular contributor.

The early and middle chapters of the book are a roughly chronological account of the author's life and times, from his God-fearing boyhood in Tulsa, Oklahoma, through his undergraduate years as a (sometimes religious) philosophy major at the University of Chicago, his entry into the Depression-era workforce on graduation in 1936, his four years in the Navy during World War II, his year of graduate school—funded by the GI bill—back at Chicago (which he left without an advanced degree after deciding that he wanted to become a writer, rather than a philosophy teacher), and his hungry years as a youthful free-lance. Only in the 15th of his 21 chapters does he begin to describe his 44-year career as a columnist, first at *Scientific American* and later at *Skeptical Inquirer*.

He reports that he could still, at the age of 95, recite poems he learned in elementary school, including some not-so-great ones written by his favorite teacher. In childhood he devoured the works of Frank Baum, author of *The Wonderful Wizard of Oz*, along with those of Lewis Carroll and Arthur Conan Doyle. In high school—which he considered a complete waste of time—his hobbies were magic and chess.



Martin Gardner in person and in a domino portrait by Ken Knowlton. From Undiluted Hocus-Pocus, The Autobiography of Martin Gardner.

Examples of his early writing are interspersed throughout the book, with thoughts on religious matters. The writing samples include excerpts from both his high school newspaper and the college literary magazine he co-edited for a time.

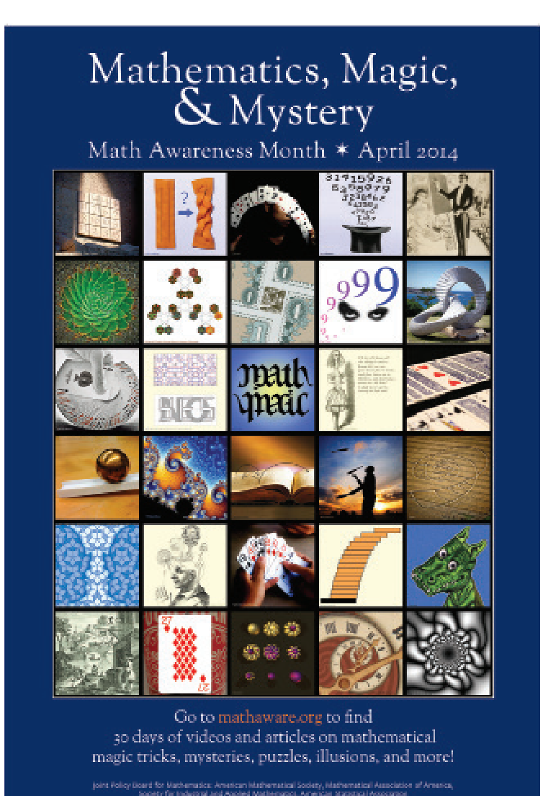
Because he studied no mathematics in college, Gardner was obliged to learn what he needed for his *Scientific American* columns as he went along. As a result, they exhibit progressively greater mathematical sophistication. The series began with a single stand-alone article on hexahexaflexagons, large cloth structures that could be manipulated to reveal differently colored faces. Their creators were a group of Princeton graduate students that included John Tukey, Richard Feynman, Bryant Tuckerman—inventor of the Tuckerman traverse, a method for exposing all faces in sequence—and Arthur Stone. The hexahexaflexagons were, for a time, the Rubik's Cubes of their day. Gardner's article about the structures was a huge success, and he was promptly asked to consider a regular monthly column on "recreational mathematics." The results have been collected in 15 volumes by Cambridge University Press.

Along with Tukey, Diaconis, Conway, and Schattschneider, the mathematicians on Gardner's grapevine included Solomon Golomb, Raymond Smullyan, Roger Penrose, Benoît Mandelbrot, Donald Knuth, Frank Harary, Paul Erdös, Ronald Graham, and Fan Chung. Gardner regarded Diaconis as a top card magician, routinely performing "the cleanest second and bottom deals" in the business, and among the first to master the difficult Zarrow shuffle. The latter, which defied Gardner's own efforts, looks just like an ordinary shuffle but leaves the deck unaltered. At one point in their acquaintance, Diaconis was an undergraduate math major at Manhattan's City College, working as a shipboard poker hustler in the summer. Learning of his wish to acquire a Harvard PhD, Gardner recalled that Frederick Mosteller, founding chair of the Harvard statistics department, was an ardent magic buff. An interview was arranged and a notable career launched.

Martin Gardner was a valuable friend to the mathematical community. The MAA volume contains a number of acknowledgements from mathematicians whose careers and investigations he helped inspire, while his matter-of-fact autobiography reveals the sources of his own inspiration.

James Case writes from Baltimore, Maryland.

Celebrate Math Awareness Month



Each April the Joint Policy Board for Mathematics sponsors Mathematics Awareness Month to recognize the importance of mathematics and its applications.

This year's theme is "Mathematics, Magic, and Mystery." The theme was chosen, in part, to celebrate the centennial of the birth of Martin Gardner.

Throughout the month, readers who visit the event's website (http://www.mathaware.org/index.html) will learn more about 30 magical and mysterious topics—a new one will be unveiled each day. Each topic is introduced by a short video and features supporting materials developed for a wide audience.

The Scientist–Reporter Collaboration: A Guide to Working with the Press

By Rachel Levy, Flora Lichtman, and David L. Hu

Communicating science, technology, engineering, and mathematics (STEM) to the public can be challenging. Often, the language that researchers use among themselves is technical and difficult for non-experts to decipher. But as you probably know, communicating your research to non-experts is becoming mandatory. In a direct sense, funding agencies often require outreach for grant fulfillment. There are indirect benefits as well: Conveying the joy of discovery and the relevance of scientific results builds scientific literacy among the public—which of course includes both students who will eventually do research of their own and people who elect the policy makers who allocate funding. How many people know that what scientists do can be fun *and* interesting?

Benefits of Working with the Press

A well-crafted message. Working with reporters can help you distill your work to its essence, give you ideas for framing your research that might be useful in lectures, and help you see how your work relates to other research.

Power to reach a broad audience. Reporters have access to platforms that can reach audiences far larger than those for a scientific paper—often by many orders of magnitude. After press publicity, David Hu's YouTube video (Google: fire ant raft) had 2 million viewers; the original journal article has been cited by 25 scientists. Rachel Levy's Grandma Got STEM blog, picked up by boingboing and Slate, drew more than 10,000 viewers in one day. Press coverage can lead to invitations to give scientific lectures and help raise the profile of your home institution. Media coverage can have a dramatic effect on funding, because people (a) become familiar with your work and (b) understand what you do.

Connection to established researchers. Reporters often seek the opinions of highly respected and well-established scientists—colleagues who, for a junior researcher, could be intimidating to approach. We can learn from scientists' interactions with the press, both about the scientists' work and about how they communicate. When we meet a researcher we admire, their press articles can be an icebreaker, giving us a comfortable way to engage them in scientific conversation.

Inspiration for future scientists. Reporters sometimes create STEM-related articles and videos for children. An elegantly told scientific story can inspire the next generation of scientists.

Guiding Principles for Science Communication

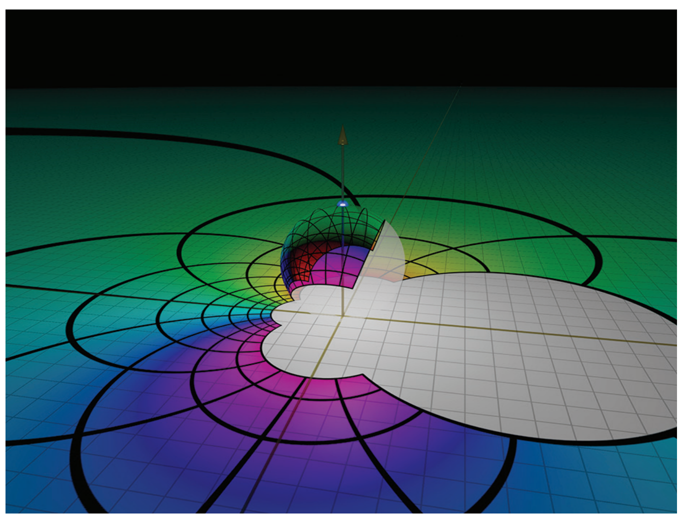
The following methods for communicating science are inspired by approaches reporters take. They are great principles for scientists to keep in mind when creating visuals and preparing talks.

Embrace the idea that science is entertaining. "Entertainment" can have a bad rap—the connotation is that the material is necessarily trivial. We would argue the opposite: It means that the subject engages you, makes you curious about the world around you, and helps you understand your world better. Strive to be entertaining.

Tune your level of precision to your audience. Figure out a way to be accurate while providing a level of detail that is appropriate to the people you're addressing. In speaking to people outside your field, find a way to relay the meaning of findings rather than the details of your methodology. Find metaphors for your work that make it relatable, and use language that anyone can understand.

Surprise the audience. When you tell a story about your research or a particular finding, structure the ideas with a surprise in mind. In a video, you might do this by setting up a cognitive dissonance between the visuals and the audio. A story that asks viewers to think about the fastest organisms in the animal kingdom might have them envisioning cheetahs or peregrine falcons. If instead they see a small crustacean (a mantis shrimp) or a trap jaw ant, the structure of the story has subverted their expectations. This draws them in and sparks their curiosity.

Take your audience on a trip. Science stories are almost always travel stories—to the most exotic worlds. You can travel inside your own body, shrinking down to immerse yourself in a community of microbes; visit other planets or even other galaxies; go back in time, to when dinosaurs lived or when the universe was created. When you frame a research story this way, it's hard to imagine not wanting to go along for the ride.



Frame from "Möbius Transformations Revealed," courtesy of Doug Arnold and Jonathan Rogness. The short video was a winning entry in the 2007 Science and Engineering Visualization Challenge sponsored by the National Science Foundation and Science*, and has had millions of viewers on YouTube.*

Identify the mystery. Questions can be even more fun than answers. And in the pursuit of scientific ideas, you never run out of questions! Help your audience understand how your discovery prompts new questions. Take time to identify and share the mysteries in your own research.

Show that scientists are people too. This will seem obvious to most readers of this article. Yet pop culture representations make mathematicians and scientists alarmingly dopey and one-dimensional. Ugly glasses. White lab coat. Awkward. Narrow-minded. Not to mention usually Caucasian and male. Subvert this notion! Videos are an effective way to convey your personality and passion. If people see you as a relatable human and see first hand your excitement about your work, they will be more likely to be excited about it as well. Being interested in your own work doesn't make it less important or less serious. It offers an inroad for people who may not initially understand why [insert your research topic here] is cool.

Find ways to let people share in your discovery. With more and more researchers using video as data, there's more opportunity to let people see how the applied mathematics sausage is made. That's because the primary tools scientists use to analyze video are tools we all have: our eyes and our brains. If you can provide video data and give your audience enough context to know what to look for, they also can experience the joy of discovery. You may not know how to compose an entire video, but if you provide the pieces and the explanations, reporters and other science communicators can take it from there.

Tips for Visualizing Research Results

Read books on instructional design. The field of instructional design is all about working with a subject matter expert to communicate ideas. In this case you are the subject matter expert; taking advantage of instructional design principles can help make your message more visually appealing and clear.

Shop your ideas with the intended audience. Find people who will take the time to give you constructive feedback about what they understand and what they don't. Try more than one approach and look for the one with the widest appeal.

Consider the interplay between text, pictures, and sound. These elements should complement and reinforce each other. For example, it is not interesting to listen to someone read from a slide. At the same time, you can't easily listen to a string of words and simultaneously read a different string of words. But you can look at an image and listen to words that describe the image.

Preparing for the Rapid Press Cycle

You want your research to be shared accurately and compellingly. Reporters want the same things, and often have the added constraint of a short turnaround time. When reporters cover your research, you become subject to the same deadlines. Preparation helps, in terms of both thinking through the story of your study and assembling materials—raw images, fact sheets, videos, PDFs of papers, and supplements. Consider the following suggestions for preparing for a reporter's call.

Prepare talking points. Whether for a radio show, a print story, blog post, or tweet, you should be aware of the message you want to convey and be ready to convey it at different levels of detail. Consider not only the question that fascinates you, but also the relevance of the research to the larger field or to the public generally.

Ask for questions in advance of interviews. Reporters often have a sense of the questions they want to ask in an interview and will share them ahead of time. This gives you a chance to think through the best way to communicate your ideas and helps you understand the reporter's intended focus for the story.

Ask for permission to check the quotes before publication. You may not be allowed to read the story before it is published, but most reporters will allow you to review your quotes. It is prudent to arrange for this before the interview; afterward, you should respond right away to confirm your quotes or make any necessary factual corrections.

Work with your institution's public relations staff. Public relations officers can advise you which interviews to accept, help you practice for radio and television interviews, write press releases, and help you create visuals, such as a poster for a conference. Take advantage of these experts: Enlist their help to communicate the importance of your research, ways in which it advances the field and fits into a larger context.

See **Scientist/Press** *on page 6*

SIAM PolyU Chapter Goes Live at International Computational Math Conference in Hong Kong

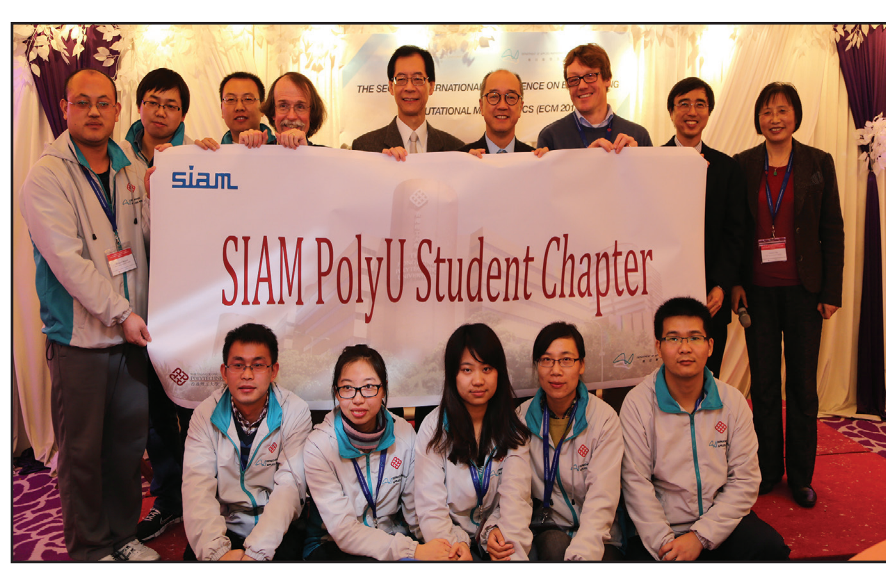
By Hong Wang

"It's our great honor to serve at such an exciting event," said a student helper at the Second International Conference on Engineering and Computational Mathematics (ECM 2013), held December 16–18, 2013, at Hong Kong Polytechnic University (PolyU). "It provides us a good opportunity to communicate with academic scholars from around the world." The conference, for which SIAM was a cooperating society, attracted more than 300 participants from 21 countries. The volunteer student helpers were from the SIAM PolyU Student Chapter.

The chapter was officially founded on July 5, 2013, with support from the Department of Applied Mathematics at PolyU. As of the beginning of 2014, the chapter had 20 members, all postgraduate students at PolyU. The first order of business was the election of officers: Yang Zhou, president; Xuenan Feng, vice president; Jin Yang, treasurer; and Qiujin Peng, secretary.

As our first activity we served as student helpers at ECM 2013. Conference participants and organizers congratulated us on the creation of our chapter and recognized our contribution to ECM 2013 at the conference banquet.

At the banquet, some of us had the opportunity to gather for a photograph with several distinguished conference attendees—Tim Kelley (chair of the SIAM Board of Trustees), Timothy W. Tong (president of PolyU), Tony Chan (president of Hong Kong University of Science and Technology), Sven Leyffer (vice president of SIAM), Kwok-yin Wong (dean of the Faculty of Science and Textiles, PolyU), and Xiaojun Chen (head of the Department of Applied Mathematics, PolyU).



At the ECM 2013 banquet, from left, back row: Haibin Chen, Jin Yang, Shujun Wang, Tim Kelley, Timothy W. Tong, Tony Chan, Sven Leyffer, Kwok-yin Wong, and Xiaojun Chen; front row: Hong Wang, Cong Xie, Yu Bai, Huili Zhang, and Yang Zhou, president, SIAM PolyU Student Chapter.

Looking ahead, we plan to sponsor a series of activities designed to enhance members' understanding of mathematical applications in real settings: talks by distinguished scholars from science and engineering departments, seminars with graduates from other universities, and field trips to financial and IT companies.

Up-to-date information about the chapter can be found at http://www.polyu.edu.hk/~ama/SIAMChapter.

Hong Wang is a PhD student in the Department of Applied Mathematics, Hong Kong Polytechnic University.

Peridynamics

continued from page 1

proaches that use cohesive zone elements [9, 22]. More recently, cohesive zones have been applied within the extended finite element method [1] to minimize the effects of mesh dependence on free crack paths. Current challenges facing these methods (indeed, all computational methods) include multiple growing cracks interacting in complex patterns.

What remains elusive is an underlying continuum model that can seamlessly evolve both smooth and discontinuous deformation in a way that is useful for predicting free crack propagation. To be applicable, a model must be able to deliver quantifiable results and recover the classic results of fracture mechanics in situations in which it is known to hold.

The peridynamic continuum model [17,18], a spatially nonlocal continuum theory, was introduced recently to fill this gap. Each material point interacts through short-range forces with other points inside a horizon of prescribed diameter δ. The short-range forces depend on the relative displacement between material points and are derived from a peridynamic potential specifying a kinematic constitutive relation. Within the recently developed nonlocal vector calculus framework [4], peridynamics can be viewed as nonlocal balance laws involving nonlocal fluxes defined between material domains that might not have a common boundary. This provides an alternative to standard approaches for circumventing the technicalities associated with the lack of sufficient regularity in local balance laws; by avoiding the explicit use of spatial derivatives, the approach allows for both smooth and discontinuous deformations. For short-range forces akin to elastic bonds that break when stretched beyond a critical point, the peridynamic formulation delivers remarkable simulations, capturing both crack branching (Figure 1) and multiple crack interactions (Figure 2).

To test the theory of the peridynamic model, investigators have developed new mathematical results on its well-posedness and have assessed its connection to accepted continuum field theories. In a recent study, for linear elastic short-range forces and up-scaled linear peridynamics, which sent the peridynamic horizon δ to zero, the macroscopic limit of peridynamics was found to satisfy the classic equations of linear elasticity, with the macroscopic elastic moduli given by moments of the peridynamic nonlocal interaction kernel. Such relations can be established formally for smooth functions via simple Taylor expansions [6,19] and more rigorously in functional-analytic settings for solutions with minimal regularity [5,14].

Progress has also been made in developing a nonlocal calculus of variations for the analysis of variational and time-dependent problems subject to various nonlocal boundary conditions or, more precisely, conditions constraining the solutions on sets of nonzero measure. These results also make possible numerical analysis of discretizations of various types, and offer insight into the convergence and compatibility of numerical approximations in both nonlocal regimes and local limits under minimal regularity assumptions [21]. This, in turn, has influenced the development of robust and efficient numerical simulation tools for peridynamics, such as EMU, PDLAMMPS, and Peridigm [15,16].

Peridynamics provides a new tool for understanding the multiscale and nonlocal features of crack propagation. In a recent development, the peridynamic formulation was used to connect the dynamics associated with bond-breaking at small length scales to dynamic free crack propagation inside a brittle material as observed at macroscopic length scales [11]. Motivated by the short-range forces associated with simulations (Figures 1 and 2), a nonlinear peridynamic medium was considered with short-range forces that are initially elastic and soften beyond a critical relative displacement [11]. The peridynamic model was up-scaled to identify the macroscopic dynamics. It was shown rigorously [11] that the limiting macroscopic evolution has bounded energy given by the bulk and surface energies of classic brittle fracture mechanics. The macroscopic free crack evolution corresponds to the simultaneous evolution of the fracture surface and linear elastic displacement away from the crack set. The elastic moduli, wave speed, and energy release rate for the macroscopic evolution are explicitly determined by moments of the peridynamic potential energy. This delivers an interesting new connection between nonlocal short-range forces acting over small length scales and dynamic free crack evolution inside a brittle medium at the macroscopic scale. It also provides a second theoretical test of peridynamics and mathematically demonstrates that energies for nonlinear peridynamics converge to those of classic elastic fracture mechanics in the macroscopic limit. An unexpected twist in this investigation is that tools from the theory of image segmentation [8] can be brought to bear on this problem.

The latter typifies many interesting instances in which investigation of nonlocal peridynamics can cross over into other subject areas. For example, one can not only draw the analogy of nonlocal vector calculus with the traditional calculus, but also find similarities and connections with fractional calculus, discrete calculus, and calculus on graphs developed for subjects like the anomalous diffusion [3]. Indeed, nonlocality is ubiquitous in nature. By encoding spatial nonlocality explicitly at the continuum level while maintaining consistency to traditional local continuum equations when local models are well defined, nonlocal continuum models like peridynamics show much promise as effective alternatives to local convectional models.

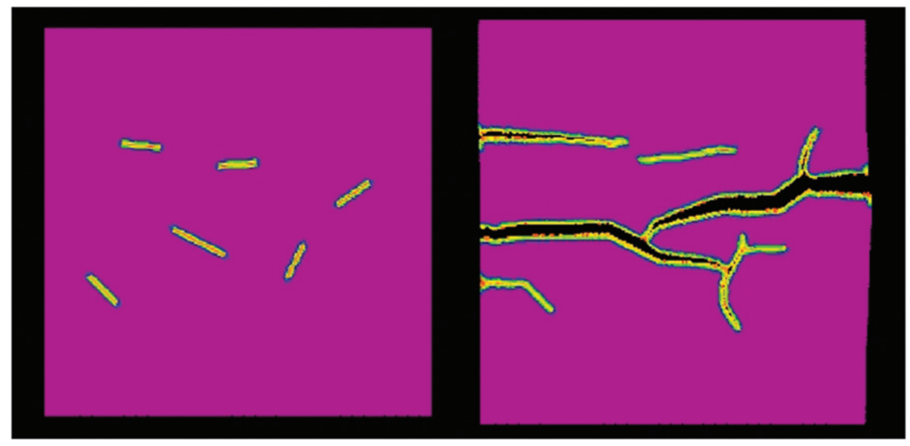


Figure 2. *Simulation of the interaction of defects in a brittle plate stretched at a constant rate in the vertical direction. Left: initial defects. Right: growth and merging of defects, leading to macroscopic failure.*

Signs of growing research activity in the area include recent workshops at Oberwolfach, the Statistical and Applied Mathematical Sciences Institute, Brown University, and the University of Texas at San Antonio; various minisymposia at national meetings of SIAM and other organizations; and the new MURI center for material failure predictions through peridynamics funded by the Air Force Office of Scientific Research. The study of peridynamics is inspiring new mathematics and offers a valuable opportunity for applied mathematicians to team up with materials scientists and engineers to take a crack at developing new modeling and simulation capabilities for fracture and other interesting problems.

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Inaugural SIAM Symposium To Be Held at Materials Research Society's Fall Meeting

The inaugural SIAM symposium on Computational Aspects of Materials Science will be part of the program for the fall 2014 meeting of the Materials Research Society. The meeting will be held in Boston, November 30 to December 5, 2014; details can be found at the conference website (http://www.mrs.org/fall2014/). The SIAM symposium (number NN), is included in the cluster of symposia titled Theory, Characterization and Modeling. The symposium is sponsored by the SIAM Activity Group on Mathematical Aspects of Materials Science.

The call for papers can be found at http://www.mrs.org/fall-2014-call-for-papers-nn/. Abstracts should be submitted through the MRS conference website; the window for abstract submission is May 19 to June 19, 2014.

The proceedings of the symposium will be published through the MRS Proceedings Series, both electronically and in print. The electronic publication is hosted on the Cambridge Journals Online platform.

The organizers especially encourage postdocs, pre-tenure faculty, and graduate students to participate by submitting contributed papers to the SIAM symposium. Subject to availability, we anticipate funds to defray lodging, registration, and travel costs for up to 16 postdocs, pre-tenure faculty, or graduate students at $1500 per individual.

The Materials Research Society holds its annual fall meeting at the Hynes Convention Center in downtown Boston. It is a comfortable venue, and the conference is well attended, with more than 6000 participants from different scientific disciplines. It is a forum for scientific interaction on contemporary problems in materials science.

For updated conference information as well as discounted hotel accommodations, set browsers to: http://www.mrs.org/fall2014/.

Scientist/Press

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Anticipate misconceptions. Try talking to people who have no knowledge of your work to get a sense of what the public might not intuitively understand. Later, when you present lectures about your work, give interviews, or write articles, you can address the misconceptions before they arise. You can also get a sense of possible misconceptions from the questions you get after a lecture.

Keep a treasure chest. Collect striking, high-resolution color images. When photos can't do the job, try making a few striking videos. The idea is to tell the story with as little printed text as possible. Your students can store a large variety of these images online—a task made easier by digital photography/videography and online storage services. Never delete digital material—a reporter might have some use for it down the road.

Create a template email. The email should contain a PDF of original articles, links to images and video, and a list of knowledgeable outside mathematicians who might wish to discuss your work. Often, that list will grow to include mathematicians who have been sought out by the press to comment on your work.

Be prepared for short turnaround times. It isn't unusual to be asked for an interview or for answers to a set of questions in less than 24 hours. And if your research topic captures the interest of the press, you may get multiple requests at once. The more material you have prepared ahead of time, the easier it will be to take advantage of these opportunities.

Deputize Your Students

Hire undergraduate or high school students. These days, the fastest way to communicate materials to reporters is online, and students often know how to do that efficiently. Tasks include video file conversion (e.g., Zamzar or mpeg streamclip converts all files online for free), uploading of images and videos (Dropbox, wetransfer.com, and

See **Scientist/Press** *on page 7*

Professional Opportunities

Send copy for classified advertisements to: Advertising Coordinator, SIAM News, *3600 Market Street, 6th Floor, Philadelphia, PA 19104–2688; (215) 382–9800; fax: (215) 386–7999; marketing@siam.org. The rate is $2.85 per word (minimum $350.00). Display advertising rates are available on request.*

Advertising copy must be received at least four weeks before publication (e.g., the deadline for the June 2014 issue is April 30, 2014).

Advertisements with application deadlines falling within the month of publication will not be accepted (e.g., an advertisement published in the June issue must show an application deadline of July 1 or later).

Scientist/Press

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Copy.com) and rapid response to messages (Smartphones, Skype). All these technologies will change in time, and undergraduates are likely to stay up to date.

Hire students who care about visual aesthetics. Artists and photographers can be the most helpful, but whatever their background, you need to find students who don't require convincing that a figure or a video should be aesthetically pleasing. Once you are confident about a scientific result, devote as much time as you can afford to produce images that tell the story in as visually appealing a way as possible.

Make a presskit webpage. Making materials for the press available on the web can save you time and help get your research to interested parties. You could include a press release and images or videos, with clear guidelines (such as a Creative Commons license) to the rights of others to use them.

Encourage students to make webpages publicizing themselves and the work. Student webpages encourage them to take ownership of the research and identify themselves online to potential employers. The websites store images and press materials so they can be easily retrieved.

The Interview: How to Talk to Reporters

Talking to a reporter is quite different from giving a scientific talk. The Royal Society's motto, "Nullius in verba," translates to "take nobody's word for it." Just like scientists, reporters are paid to be skeptical and to ask hard questions to arrive at the truth. It is your job as a scientist to convey why you believe that your work is interesting and worthwhile. Science reporters are often already interested in your work, and in communicating it as accurately as possible. The task at hand is to work *with* the reporter to "tell the story."

Reporters are expert communicators. Reporters are trained in the craft of storytelling. For science journalists, the job is to communicate scientific work broadly. They can have useful suggestions on how to present ideas, what kinds of examples to use, and how to get an idea across economically. You can use these ideas in your conference talks or invited lectures, or even incorporate them into journal papers.

Reporters ask terrific questions. With practice, talking to reporters can even be fun! A science reporter might have been thinking about your field as long as you have—but from a different angle. Questions from an interested outsider can lead to deep thinking about the material and the process of distilling the material. Explaining it in different settings—in speaking to a reporter or in writing a journal paper—can bring you closer to your work.

Prepare in advance for the application question. Think about directions your work *might* take and ways it *could* improve understanding of your field or the world (universe?). The work doesn't have to have direct applications, but a possibility, even far down the road, will help the audience see where your work might lead.

Be aware that the reporter may have a particular angle in mind. The reporter won't generally let you read the story ahead of time. But it's within your rights to ask about the focus or angle of the story: You will then have the opportunity to clear up misconceptions about your own research goals or results, or, if asked to comment on another mathematician's work, you will have an idea of how your quote will fit into the story.

Why We Like Scientist–Press Collaborations

By capturing the imagination of the public, media coverage can be a powerful facilitator of research funding. Never before could developments in applied mathematics and science be communicated so rapidly to audiences around the world. Collaborating with the press gives you agency in that process. Working with media also gives you an opportunity to reflect on your research, define and redefine your research style, and provide your audience with a broader appreciation of the wide world of STEM and your place in it.

Rachel Levy (levy@g.hmc.edu) is an associate professor in the Department of Mathematics at Harvey Mudd College. Flora Lichtman (flora.lichtman@gmail.com) is a freelance reporter. David Hu (david.hu@me.gatech.edu) is an assistant professor in the Schools of Mechanical Engineering and Biology at the Georgia Institute of Technology.

MPE

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Although MPE2013+ is planned primarily as a U.S. activity, discussions are under way with organizers of MPE activities in other countries. The cluster activities will be open (on a space-available basis) to participants around the world; organizers and speakers of some scheduled activities are from France, Australia, and other countries.

MPE2013+ was inaugurated in January 2014 at Arizona State University at a workshop titled Mathematics of Planet Earth: Challenges and Opportunities. The workshop exposed students and junior researchers to challenges facing our planet, the role of the mathematical sciences in addressing those challenges, and opportunities to get involved in the effort. The workshop introduced the six major themes of MPE 2013+, and participants engaged in lively dialogues as to suggested areas of emphasis for the different clusters.

The Six Main MPE2013+ Clusters

The Sustainable Human Environments cluster will have its kickoff workshop at DIMACS, April 23–25. The key themes will be data in "smart cities," the role of anthropogenic biomes (or urban ecosystems), security, and urban planning for environmental change. The cluster actually got an early start with the workshop Urban Planning for Climate Events, held at DIMACS in September 2013. A follow-up activity for the cluster is planned for the University of Paris–Dauphine (dates to be determined).

The second kickoff workshop, for the Global Change cluster, will be held at UC Berkeley, May 19–21. Overview talks will cover mathematics and global process modeling, massive data set management and analysis, methods for modeling and analyzing trophic food webs, and methods for analyzing and managing epidemic outbreaks. Each kickoff workshop will have a session on challenges in education, and the one scheduled for this workshop promises to be particularly interesting: How are the challenges of rapid global change to be communicated to the public?

Arizona State University hosted the launch of MPE2013+ in January with a workshop titled Mathematics of Planet Earth: Challenges and Opportunities. Speakers, including Carlos Castillo-Chavez, introduced the six major themes of MPE2013+, discussing the mathematical challenges and emphasizing ways in which students and early-career researchers can get involved.

The cluster on Data-aware Energy Use will begin with a kickoff workshop in September 2014 (dates to be announced) at UC San Diego. Themes will include alternative energy investment portfolios, smart grids, smart buildings, and electric vehicles.

The kickoffs for the remaining three clusters will be held in 2015, beginning with Natural Disasters at Georgia Tech, May 13–15, 2015. Specific themes are under discussion, but possible topics include quarantine and behavior change; hurricanes, tornadoes, and earthquakes; oil spills; health emergencies; stockpiling; evacuation modeling; and prediction of rare events.

Howard University will be the site of the Management of Natural Resources cluster kickoff, June 4–6, 2015, with discussion topics to include water, forests, fisheries, and food. The organizers plan to emphasize topics that cut across the different application areas, such as game theory or stochastic dynamic programming for management of uncertain resources. Other topics include sustainability and complex systems, rapid evolution and sustainability, and sustainable management of living natural resources. Cluster activities in collaboration with groups in Latin and Central America are under consideration.

NIMBioS (the National Institute for Mathematical and Biological Synthesis) at the University of Tennessee will host the kickoff for the cluster on Education of the Planet Earth of Tomorrow, in the fall of 2015. This cluster will build on the educational successes of MPE2013. As MPE education coordinator Mary Lou Zeeman of Bowdoin College points out, the curriculum material developed for MPE2013 has provided schools and educators with a wealth of free-of-charge material and will be used for many years to come. The initiative has already acquainted the public, schools, and media with challenging applications of mathematics, with significant answers to such questions as: What is mathematics useful for? Each of the other cluster workshops will include a session on education challenges relevant to its field, under the direction of the cluster's education chair; the chairs will bring ideas from the other clusters to the program for the education cluster.

Additional information about MPE2013+ can be found at mpe2013.org/mpe2013index/ and can also be obtained from DIMACS at mpe2013p@dimacs.rutgers.edu.

Moving Forward: Worldwide MPE Activities

Plans to continue MPE are under discussion in a variety of countries outside the US, including Canada, the UK, Portugal, France, Australia, and Tanzania. Through MPE, there will be efforts to coordinate these worldwide activities.

MPE Blog

The mission of MPE2013 was reflected in the Daily Blogs (one in English, the other in French), each of which has featured close to 300 posts. The blogs, under the dedicated leadership and editorship of Hans Kaper of Georgetown University (and *SIAM News*), have been receiving several hundred hits a day. They can be read at http://mpe2013.org/.

The blog continues (though not necessarily on a daily basis). We are especially interested in blog posts by students. SIAM will award a prize for the best student blog submitted between now and the end of May, with the winner to receive a Student Travel Award to a SIAM meeting. New posts can be sent to blog@mathplanetearth.org.

Underground

continued from page 1

that can be traced back 4000 years, and they appear in many cultures, the most famous example being in the mythological story of the Minotaur on the island of Crete. Labyrinths are thought to be associated with ceremonies involving dancing and movement. They were also used in defensive structures, such as Maiden Castle, where the attackers were forced to trace a very long route to the entrance, during which time they were under constant attack!

Why the labyrinth as the theme of the anniversary art? Along with its close links to mazes and networks, the labyrinth is a fitting analogy for the millions of journeys made across the Tube network every day. As explained on Art on the Underground's website (https://art.tfl.gov.uk/labyrinth/about/):

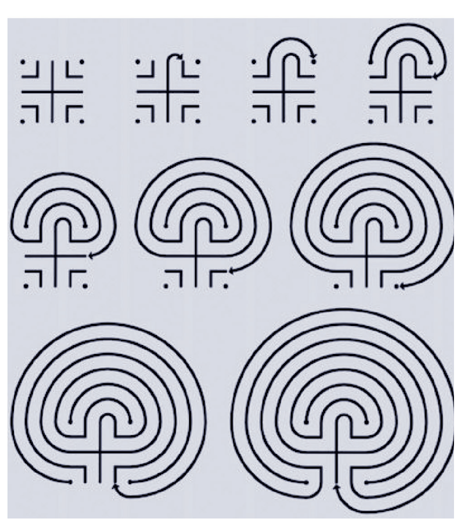
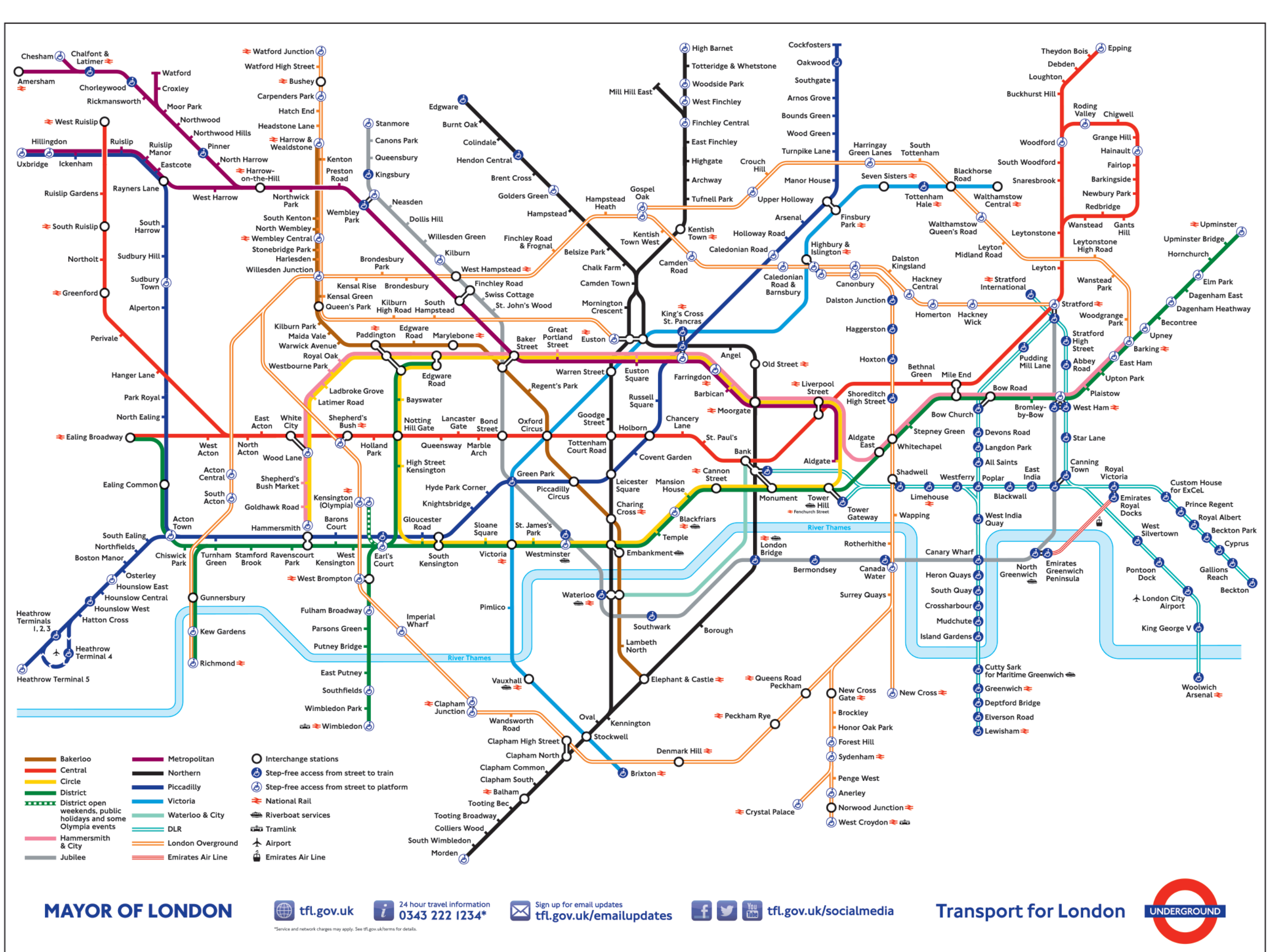


Figure 1. *Step by step, the "classical labyrinth" takes shape.*

"Rendered in bold black, white and red graphics, the artworks are produced in vitreous enamel, a material used for signs throughout London Underground, including the Tube's roundel logo, whose circular nature the labyrinth design also echoes. Positioned at the entrance of each labyrinth is a red X. This simple mark, drawing on the language of maps, is a cue to enter the pathway. The tactile quality of the artwork's surface invites the viewer to trace the route with a finger, and to understand the labyrinth as a single meandering path into the centre and back out again—a route reminiscent of the Tube traveller's journey."



The mathematical interest follows from the fact that a labyrinth can be created from a basic seed, followed by the application of a set of systematic rules. The design and classification of all possible labyrinths leads to many interesting mathematical questions. The long paths possible within a labyrinth are excellent examples of space-filling curves, which are themselves closely linked to fractals. Figure 1 illustrates the steps for drawing what is often called the "classical labyrinth."

The challenge facing Mark Wallinger was to find 270 unique designs, each of which would have a striking impact. This required a mathematical algorithm.

The labyrinths are currently being installed across the Underground network, with about 253 in place so far. The photo on page 1 shows one in situ.

I encourage readers who pass through London to visit the Underground, seek out the labyrinths, and enjoy this wonderful fusion of maths, art, and design.

Visit http://art.tfl.gov.uk/labyrinth/ for further information on the Labyrinth *project.*

Note

The Tube Challenge is a race to pass through all 270 stations on the network in the shortest time possible. The rules state that participants do not have to travel along all Tube lines, but must pass through all stations on the system. They may connect between stations on foot or by using other forms of public transport.

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