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Spectral Analysis of Nonstationary Dynamics

By Gary Froyland

Fluid mixing is key to many man-made and natural processes, such as food and mineral processing, paint manufacture, blood flow, micro-electronic heat exchange, the propulsion of aquatic animals, and the dynamics of Earth's ocean and atmosphere. Scientists and engineers are increasingly able to use experimental techniques—like particle-tracking velocimetry and laser-induced fluorescence—to observe the fine fluid motions that bring about mixing. Here I outline some mathematical approaches to analyse and manipulate transport and mixing caused by autonomous and time-dependent dynamics.

Transport and Mixing

Broadly speaking, transport is the bulk movement of parcels of fluid within the fluid domain, and mixing refers to the extent of these parcels' intertwining over time. Figure 1 displays four frames of carbon dioxide levels in Earth's atmosphere, spaced a couple of days apart.

For the purposes of illustration, let's overlook the fact that carbon dioxide is continually injected and removed from the atmosphere. Over a period of eight days, there is considerable change in the location of carbon dioxide peaks (red) in Figure 1; these peaks have been transported. The overall carbon dioxide distribution also changes. In the absence of carbon dioxide injection and removal, one would expect the distribution to begin "evening out" due to mixing processes.

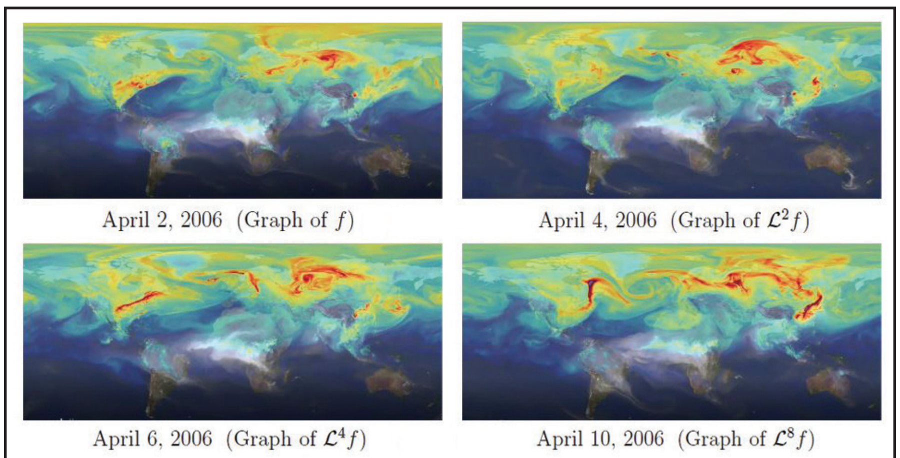

Figure 1. *Stills from NASA's "A Year in the Life of Earth's CO2." See http://svs.gsfc.nasa.gov/goto?11719 for more detail.*

The Transfer Operator

A simple linear operator—associated with the nonlinear dynamics—can conveniently analyse transport and mixing in the phase space X of a nonlinear dynamical system $T: X \to X$. This linear operator $\mathcal{L}$ is the transfer operator [8] and acts on real functions $f: X \to \mathbb{R}$. It is a composition operator, and for invertible volume-preserving dynamics in particular, is simply composition with the backward-time nonlinear dynamics:

$$\mathcal{L}f = f \circ T^{-1}.$$

For the dynamics of compressible fluids, the transfer operator includes an additional scaling term to ensure that $\mathcal{L}f$ is a density if $f: X \to \mathbb{R}$ is a density. For demonstration purposes, assume that the wind field is unchanging over eight days, X is the domain shown in Figure 1, and $T: X \to X$ describes the daily evolution of air particles. If the initial concentration of carbon dioxide is given by a density f, then the figures at April 4, April 6, and April 10 are graphs of $\mathcal{L}^2 f$, $\mathcal{L}^4 f$, and $\mathcal{L}^8 f$ respectively.

Why composition with T^{-1}? Suppose we wish to track the transport of a subset $A \subset X$ under an invertible volume-preserving map T. We can identify the set A with function 1_A, which takes the value 1 on A and the value 0 outside A. Then

$$\mathcal{L} 1_A = 1_A \circ T^{-1} = 1_{T(A)}.$$

Thus, the forward-time image of 1_A under $\mathcal{L}$ leads to the function $1_{T(A)}$, identified with $T(A)$, the forward image of A under T. The following diagram summarises this set/function correspondence.

$$\begin{array}{ccc} A & \xrightarrow{T} & T(A) \\ \text{set/function correspondence} \downarrow & & \downarrow \text{set/function correspondence} \\ 1_A & \xrightarrow{\mathcal{L}} & 1_{T(A)} \end{array}$$

Therefore, we can use the transfer operator to *linearly* evolve the functional rep-

See **Nonstationary Dynamics** *on page 4*

Uncertainty in Climate Science: Not Cause for Inaction

By Juan M. Restrepo and Michael E. Mann

"The climate has changed and is always changing," Trump administration spokesman Raj Shah said when asked about the evidence for climate change reported in the Fourth National Climate Assessment from the U.S. Global Change Research Program. Shah echoed prior assertions by climate contrarians that current changes in climate and weather are not unusual. Fluctuations—some of which have been extreme—have occurred prior to the industrial era. In more technical terms, this claim intimates that climate has a stationary statistical distribution, one that does not change with time. Additionally, it suggests that samples of this distribution have manifested as possibly rare, extreme highs in recent years. Shah also implied that the presence of uncertainties makes climate forecasting unreliable.

To explore the assertion of a static climate distribution, we propose a null hypothesis: that record values of a stationary time series occur with a specific frequency. A record is defined as the largest (or smallest) value to date. We also examine how incorporation of historically-informed uncertainties in natural and anthropogenic factors, including human-generated greenhouse gases (GHG), modifies climate predictions; we do so via a simple model that captures the essential phenomenology of the radiation balance described by more complete state-of-the-art climate models. This *energy balance model* (EBM) is used to determine whether uncertainties in GHG emissions or other factors lead to climate projections that differ qualitatively from those obtained without accounting for uncertainties.

Records in Time Series

We invoke the null hypothesis that surface temperatures are samples from a stationary distribution. We then test whether a theorem that applies to stationary distributions—such as one about record highs and lows—is borne out by the data [2].

We draw a time-ordered sequence of independent and identically-distributed samples $X_1, X_2, \ldots$ from a stationary distribution and define a sample from the sequence as a *record* high (or low) if its value is higher (or lower) than the preceding samples. The probability of a record high is $P_n := \mathrm{Prob}[X_n > \max\{X_1, X_2, \ldots, X_{(n-1)}\}]$ (with obvious modifications for a record low). In a sample set of size n, each value has an equal chance of being the highest or lowest—thus, $P_n = 1/n$. $\mathbb{E}(R)$ represents the expected number of records for a stationary random

See **Climate Science** *on page 5*

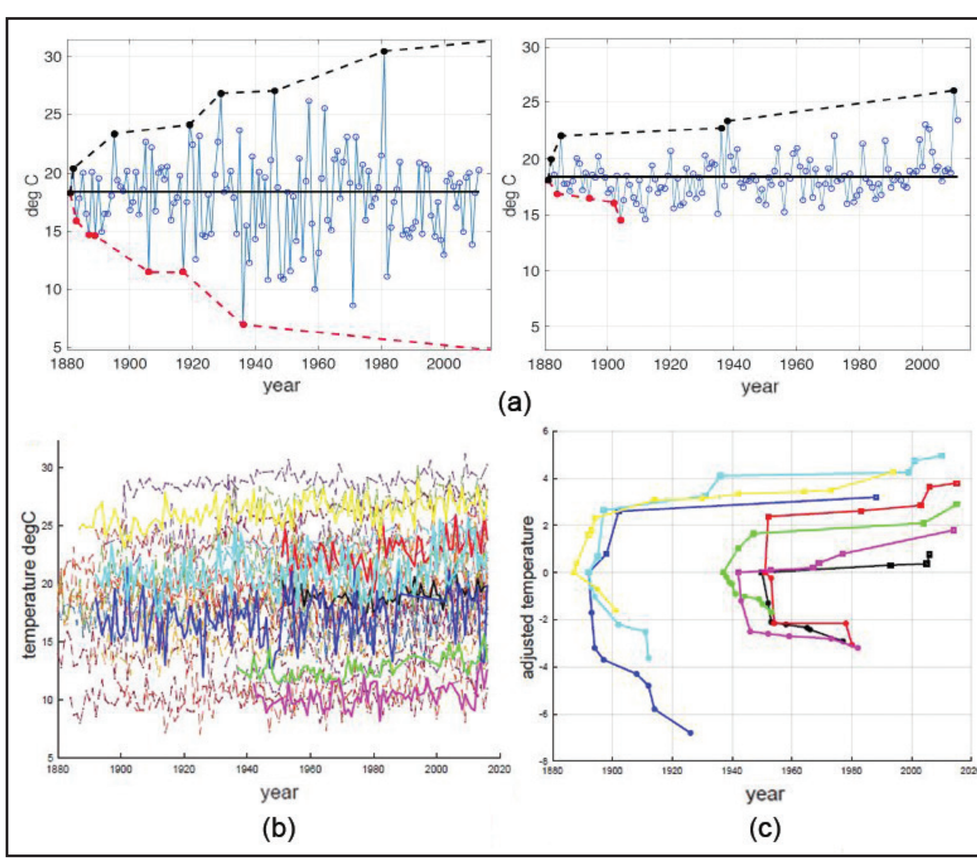

Figure 1. *Records in Northern Hemisphere temperature time series.* **1a.** *Records in a synthetic stationary distribution (left) and of July monthly temperatures at the Moscow station (right).* **1b.** *Temperature data, as a function of time, for 30 arbitrary locations in the Northern Hemisphere.* **1c.** *Record values for the seven temperature time series highlighted in 1b. The adjusted temperature subtracts the first temperature value in the time series. The data is taken from the Goddard Institute for Space Studies (GISS) repository, and temperature is recorded in Celsius. We note that there is a time in each data set beyond which no new lows occur, whereas new highs continue to appear as time progresses. Figure created by Juan Restrepo and Michael Mann using data from GISS.*

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Why to Write a Book

Have you ever thought about writing a book? Today's technology makes doing so easier than ever, thanks to portable computers, powerful editing and typesetting software, and file-sharing and collaboration tools. On the other hand, writing a book may seem less necessary, given the many outlets for survey articles and the ease of self-publication on one's own website or blog. I would like to explain why you should consider writing a book, with particular reference to SIAM as a publisher and my own experience in writing four SIAM books.

A printed book is something you can hold in your hand, give to your friends, family, and colleagues, and keep on your desk or bookshelf. A physical book is available in libraries and will potentially outlast digital storage (it is certainly immune to hard disk crashes and cyber attacks). A journal paper published in PDF form does not have these benefits. Nevertheless, most SIAM books are also accessible in digital form via the "e-books for Institutions" program, "e-books for Individuals" program, or both; this maximizes availability.

As a (SIAM) book author, you have control over length, format, design, and content, with few constraints. You can include marginal notes [1], exploit color however you wish [3], or generate the book from MATLAB scripts [4] or Jupyter notebooks. Whatever the format and content, you must convince reviewers that the book is worth publishing. However, criteria are very different from those of a research paper. Reviewers will focus on whether the book is sufficiently different from existing publications and if a market exists for it, rather than whether it contains significant new results.

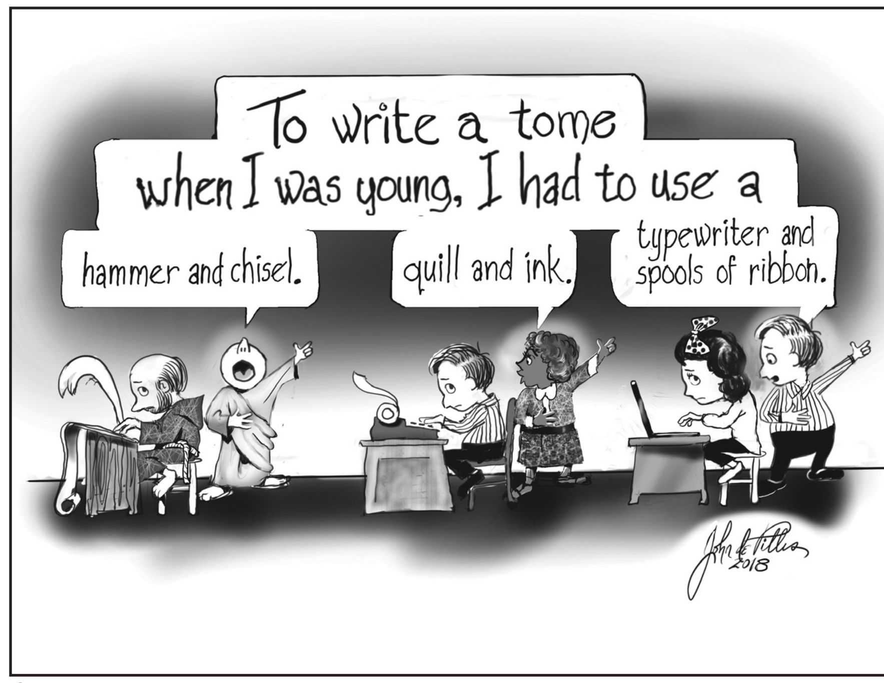
FROM THE SIAM PRESIDENT
By Nicholas Higham

The marketing efforts of the publisher—such as actively encouraging adoption as a course text—can help your book (and thus your work) reach a diverse audience. By contrast, your papers are probably most often found via citations or Google searches nowadays.

A book can cement your reputation as a subject matter expert, especially if you are the first to write a book on a particular topic. My 2008 *Functions of Matrices: Theory and Computation* [2] was the first book on matrix functions and is already my second most-cited publication. Indeed, many authors find that books are among their most-cited works. Writing a book is therefore one strategy for increasing both your citations and the impact of your work.

Opportunities for new books abound, especially in the area of data science. SIAM has recently started a new *Data Science* book series with Ilse Ipsen as editor-in-chief, and is keen to hear from potential authors.

Even in disciplines saturated with books, there is always scope for one that presents new approaches and ideas. This is why new textbooks on calculus, linear algebra, and numerical analysis are published every year (I have previously written about the elusive search for the perfect numerical analysis textbook).[1]



Cartoon created by mathematician John de Pillis.

When publishing a book with SIAM, you receive individual attention from when you first approach an acquisitions editor until after publication. You will have some of the best copy and production editors polishing your manuscript, a designer who can work with you to produce an attractive cover, a fully-developed marketing plan, and the opportunity to help promote your book.

Although monetary gain is not usually a motivation for writing an academic book, SIAM authors do receive royalties, which some donate to the SIAM Student Travel Fund. By publishing with SIAM, you will be helping the organization fulfill its goal of communicating mathematics to applied mathematicians, engineers, and scientists—including students and researchers—across universities, laboratories, and industry.

If this article has piqued your interest in writing a book, take a look at SIAM's online book page[2] (in particular, see the "Author Handbook"). Also check out the video "From Authors: Why Publish a Book with SIAM"[3] on the SIAM YouTube channel for perspective from SIAM authors. Once you have an idea of what your book will look like, contact one of SIAM's acquisitions editors.

Writing a book is not easy (I've provided some tips on my blog[4,5]), but in my experience it is great fun and extremely rewarding.

[1] https://sinews.siam.org/Details-Page/in-search-of-the-perfect-numerical-analysis-textbook
[2] http://www.siam.org/books/
[3] https://youtu.be/eCmREqW4TWM
[4] https://nickhigham.wordpress.com/2014/09/18/top-five-tips-on-book-writing/
[5] https://nickhigham.wordpress.com/2014/12/22/more-tips-on-book-and-thesis-writing/

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Obituary: Philip J. Davis

With deep sorrow, we announce the passing of Philip J. Davis on March 14, 2018, at the age of 95. Phil was one of the founding fathers of SIAM and a prolific contributor to *SIAM News*; he was an innovative mathematician, an inspiring teacher, an entertaining and wide-ranging author, and a profound thinker on the nature and significance of mathematics.

Phil was born in Lawrence, Mass., on January 2, 1923. He majored in mathematics at Harvard College and graduated in 1943. In 1940, he met Hadassah Finkelstein—a student at Radcliffe College—at an anti-Lindbergh rally in Boston. They were married on their joint 21st birthday: January 2, 1944. For the remainder of World War II, Phil worked for the National Advisory Committee for Aeronautics in Langley Field, Va., performing mathematical calculations on dangerous instabilities in flight. He returned to Harvard after the war and earned his Ph.D. in 1950 under the supervision of Ralph Boas, Jr. He then remained at Harvard for several more years, conducting postdoctoral research with Stefan Bergman and Joseph Walsh.


Philip J. Davis, 1923-2018.

From 1954 to 1963, Phil worked in the Numerical Analysis division at the National Bureau of Standards (now the National Institute of Standards and Technology). Along with colleague Phil Rabinowitz, he carried out numerical computations on the SEAC, a first-generation electronic computer; they were awarded the mock title "Heroes of the SEAC" for writing a program for Gaussian integration that ran correctly on the first trial. Phil played a prominent role in writing and planning the *Handbook of Mathematical Functions*, also known as "the big red book," and authored the chapter on the Gamma function.

In 1963, Phil moved to Brown University as a faculty member in the Division of Applied Mathematics, and remained there for the rest of his life. He was a popular and entertaining lecturer, enlivening his classes with striking physical demonstrations, a sharp sense of humor, and a gift for storytelling. Together with colleague Charlie Strauss, he created one of the first courses on computer graphics. After his retirement, Phil continued to deliver an annual lecture on mathematical topics every Thanksgiving. His magnetic charm and conversational brilliance, combined with Hadassah's hospitality and warmth, brought them many close friends among faculty and students at Brown.

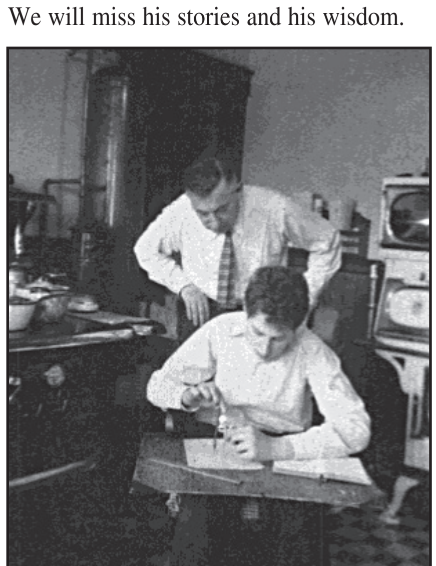
In 2004, Phil took part in the SIAM project to collect oral histories of applied mathematics. He interviewed colleagues such as Walter Gautschi, Paul Garabedian, and Eugene Isaacson. Phil was also a prolific author; his bibliography[1] includes 22 books, 52 technical papers, 92 essays, and 185 book reviews, most of which were published in *SIAM News*. He received the Chauvenet Prize in 1963 for a paper on the history of the Gamma function and the Paul R. Halmos-Lester R. Ford Award in 1982 for his paper about mathematical coincidences.

In his early years, Phil's books were focused mostly on technical mathematics. Selected titles include the following: *Interpolation and Approximation* (1963); *The Mathematics of Matrices: A First Book on Matrix Theory and Linear Algebra* (1965) (he always preferred the phrase "matrix theory" to "linear algebra"); *The Schwarz Function and its Applications* (1974); *Methods of Numerical Integration*, coauthored with Phil Rabinowitz (1975); *Circulant Matrices* (1979); and *Spirals: From Theodorus to Chaos* (1993).

Later in life, Phil's attention turned to the philosophy of mathematics in a broad sense. Among his most important works were two books with Reuben Hersh: *The Mathematical Experience* (1981), which won a National Book Award in Science, and *Descartes' Dream: The World According to Mathematics* (1986). These two beautifully-written books expound an expansive view of mathematics, grounded in real-world applications but transcending far beyond them. Interwoven with the lives, experiences, and social interactions of mathematics practitioners, they are bright threads in the fabric of intellectual history, connecting us with thinkers of all ages. Phil's most influential essays—"Fidelity in Mathematical Discourse: Is One and One Really Two?" (1972) and "Visual Geometry, Computer Graphics, and Theorems of the Perceived Type" (1974)—similarly argue that mathematical knowledge and evidence are not limited to formal definitions and rigorous proofs, but rather can involve other forms of reasoning and apprehension. His later books in this genre—*Mathematical Encounters of the Second Kind* (1997), *The Education of a Mathematician* (2000), *Mathematics and Common Sense: A Case of Creative Tension* (2006), and *Unity and Disunity and Other Mathematical Essays* (2015)—combine philosophy, history, biography, and personal reminiscences.

And then there were books that were just for fun. *The Thread: A Mathematical Yarn* (1983) is an entertaining account of his search for the origin of Pafnuty Tschebyscheff's unusual first name. *Thomas Gray: Philosopher Cat* (1988) and *Thomas Gray in Copenhagen: In Which the Philosopher Cat Meets the Ghost of Hans Christian Andersen* (1995) are academic fantasies about a cat. *Ancient Loons: Stories Pingree Told Me* (2011), a memorial volume for Phil's friend David Pingree, is a collection of anecdotes about oddball intellectuals through the ages.

Phil was fond of the concrete details of history, biography, and mathematics. He disliked extreme abstraction and distrusted large, universal, intellectual schemes that claim to explain everything. He loved stories—long or short, pointed or meandering—and was a splendid raconteur. "Life," Phil often said, "is one story after another." We will miss his stories and his wisdom.


Phil Davis, age 14, works on Napoleon's Theorem in his family's kitchen during the winter of 1936. His father looks on and wonders what it's all about. This photo appears at the front of Phil's 1997 book, Mathematical Encounters of the Second Kind. Image courtesy of Birkhäuser.

[1] https://cs.nyu.edu/faculty/davise/personal/PJDBib.html

We first met Phil on the famous fifth day of the International Congress on Mathematical Education in Budapest during the summer of 1988. Phil, jet-lagged, had slept in and was late for his opening lecture on "Applied Mathematics as Social Contract." A huge audience waited respectfully. Then Phil appeared, his wild hair upraised, apologizing — with his special unforgettable blend of highly knowledgeable mathematician, wise old man, and brilliant youthful performer! From that day on our personal friendship grew, as did our admiration for his and Hadassah's human warmth and insight. We were lucky to enjoy Phil's inspiring friendship for many years. — Sussi and Bernhelm Booss-Bavnbek, Copenhagen, Denmark

I heard many of Phil's stories in the best possible way — told by Phil himself over coffee or dinner, at conferences, and most recently in his office at Brown. What a storyteller he was! Anyone who dips into any of his books will immediately agree. I'm a longstanding fan of Phil's writing. He drew on his extensive knowledge and interest in math but also philosophy, literature, art, and so much more. The arrival of those essays lit up my days as the editor of SIAM News, and many readers wrote in to say that his articles were the first thing they turned to upon receiving a new issue. I wish I could have had more conversations with him. — Gail Corbett, former managing editor of *SIAM News*

My first encounter with Phil was in a numerical analysis class he taught when I was a graduate student at Brown. He was a wonderful teacher. What set Phil apart from other applied mathematicians was his interest in and ability to communicate mathematics to a wide audience. I witnessed this when I attended his annual "holiday lecture" at Brown. Towards the end of the first term, Phil would give an afternoon talk that was partly a public lecture. These talks covered a wide variety of topics, showing his interest not only in mathematics and history but also cultural and philosophical subjects related to our discipline, such as philosophy, history of science, and pedagogy. This interest was evident in the many articles that Phil later wrote for SIAM News. We at SIAM will miss those great contributions, but will cherish those he left behind. — Jim Crowley, executive director of SIAM

I was one of Phil's early Ph.D. students at Brown. Phil was a special guy, easygoing and friendly. I liked his sense of humor. I once asked him if he did any physical exercise, and he said that whenever he had an urge to exercise, he would lie down until the urge went away. I do not know of anyone who was a better expositor of mathematics than Phil. May he rest in peace. — Frank Deutsch, Penn State University

I met Phil when I was 35 and he was 72. I'd seen a flyer advertising his seminar on "common sense and mathematics," which I thought might speak to my then-job. I was out of my league in that seminar, but Phil took an interest in me and my work and we became fast friends. I've never understood why Phil—world-renowned and surrounded by mathematical cognoscenti—had any use for me, a mathematical nobody. But he became my biggest supporter as I moved into academia and left for California three years later. I visited him every year when I traveled back east — visits that always ended with his crushing, grandfatherly bear hug. Phil made me feel as if I were among a handful of the most special people in his life. The amazing thing is that he probably made a hundred other people feel this same way. — Julie Gainsburg, California State University, Northridge

Phil was essential to my career in the philosophy of math. Collaboration with both him and Hadassah produced our 1981 prizewinner, The Mathematical Experience. —Reuben Hersh, University of New Mexico

What I loved about Phil were all the conversations engendered by our shared love of math history and math philosophy. I argued endlessly with him about Platonism, which I embraced and he totally rejected. It was great fun to reconcile our divergent views on Henri Poincaré in our joint Notices of the American Mathematical Society paper—"Henri's Crystal Ball"—and in "What Should a Mathematical Professional Know About Mathematics?" I miss his wide-ranging curiosity and insights so much. — David Mumford, Brown University

When Phil became my advisor in 1976, he stated the following "rules of conduct": I was responsible for choosing the topic of my thesis, writing it, and defending it, and could expect no help from him. On the other hand, I could discuss with him any topic at any time. That felt like a level of freedom given to very few graduate students at the time. Often after such a talk, Phil would come up with a stack of copied material related to our discussion; it did not feel like contradiction of his last rule. I kept in touch with Phil up until the last two weeks before his departure. I miss him very much. — Igor Najfeld, University of Vermont

In 1975, Phil invited me to join him at a computer calculus short course he was teaching for college-level mathematics teachers, in which we delved into various aspects of "meta" mathematics. This workshop was also unforgettable because many of us watched the seventh game of the epic 1975 World Series between the Red Sox and the Cincinnati Reds. I associate that best of games with Phil. I also thoroughly enjoyed his wit and clever turns of phrase; two of my favorites were his disparaging "the holy trinity of definition, theorem, and proof" that neither of us believed was all there was to mathematics, and his "infinitesimals are the ghosts of departed quantities." How fitting that Phil should pass away on 3.14, the ultimate approximation. — Edwina L. Rissland, University of Massachusetts Amherst

As a senior at Harvard in 1977, I was writing my undergraduate thesis with Garrett Birkhoff when a surprising effect turned up on the computer. Birkhoff suggested I drive down to Brown and talk to Phil Davis. I did that, and had a wonderful encounter. Phil pulled a journal off his shelf, pointed out a relevant article, and told me to read it. It was in German. "You should learn German!" he advised. An encounter like that means a lot to a 21-year-old. Phil has been an inspiration for me as both the author of my favorite approximation theory book and a founding father of Fourier and Chebyshev technologies in numerical computation. — Nick Trefethen, University of Oxford

Nonstationary Dynamics

Continued from page 1

resentation of a set forward in time. This functional approach is richer than the consideration of sets because we may employ the transfer operator to evolve *concentrations* of quantities forward in time (see Figure 1, on page 1). The transfer operator is thus an extremely convenient tool for studying transport; the same is true of the analysis of mixing properties.

The Spectrum and Mixing

The transfer operator is a *Markov* operator because of (i) positivity: $f \geq 0 \Rightarrow \mathcal{L}f \geq 0$ and (ii) integral preservation: $\int f(x)\,dx = \int \mathcal{L}f(x)\,dx$. By analogy to stochastic transition matrices of mixing (irreducible and aperiodic) Markov chains, where the second-largest eigenvalue λ_2 of the transition matrix controls the exponential rate of mixing, the second eigenvalue λ_2 of $\mathcal{L}$ also controls the rate of mixing in phase space X. Several different mathematical setups can formalise this idea, such as selecting the Banach space $\mathcal{B}$ to be compatible with the dynamics T [1] or adding a small amount of diffusive noise to T and setting $\mathcal{B}$ to $L^1(X)$, for example. Either way, the transfer operator possesses a spectral gap between the leading eigenvalue 1 (with eigenfunction the invariant density of T) and retains a well-defined exponential rate of mixing, given by $|\lambda_2|$ (see Figure 2a). The eigenfunction corresponding to λ_2 encodes the almost-invariant sets [2] responsible for the mixing rate (see Figure 2b).

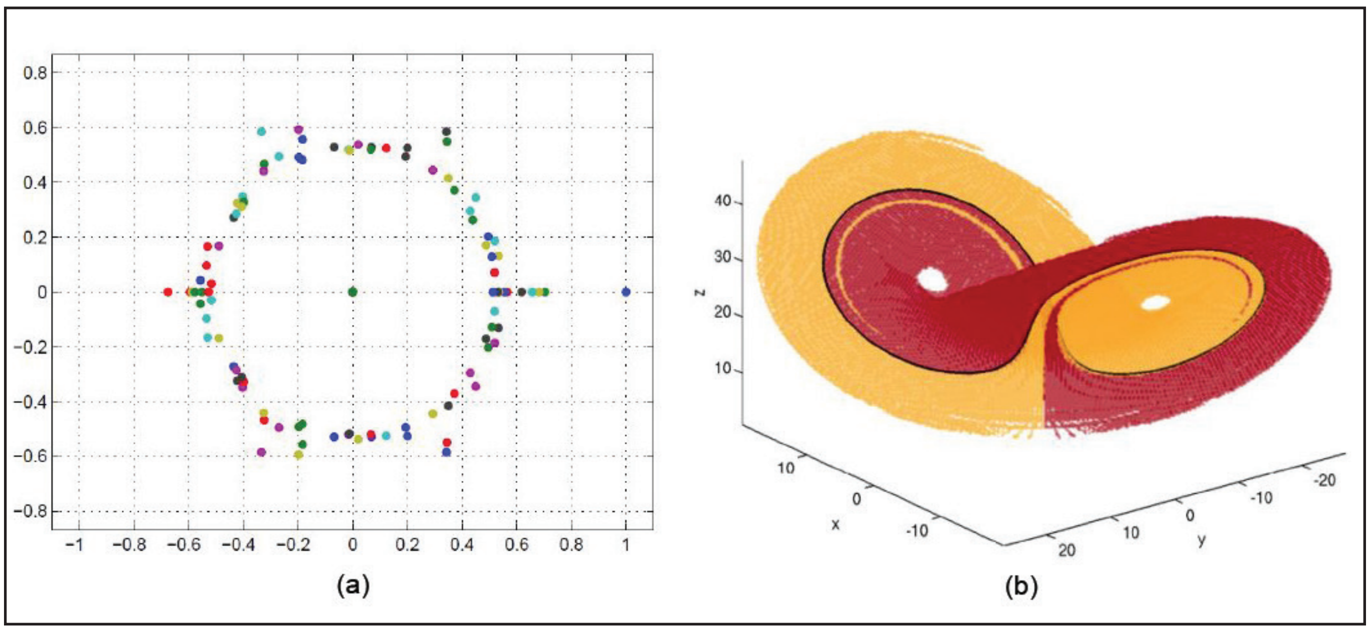


Figure 2. *Spectrum and almost-invariant sets.* **2a.** *Approximation of the largest (in magnitude) eigenvalues, plotted in the complex plane, of the transfer operator for the standard map. Image courtesy of Gary Froyland.* **2b.** *Computed dominant almost-invariant sets (shown in yellow and red) for the Lorenz system. The black curve identifies the lowest-period periodic orbit. Image courtesy of [5].*

Spectral Manipulation to Optimize Mixing

One can exploit the spectral picture in Figure 2 to optimally speed up or slow down the rate of mixing [6]. Figure 3 shows the result of manipulating the spectrum to make the second eigenvalue move away from the unit circle. This increases not only the size of the chaotic region in phase space (see Figures 3c and 3d), but also the rapidity of the spread of an initial parcel of dye in fluid (see Figures 3a and 3b).

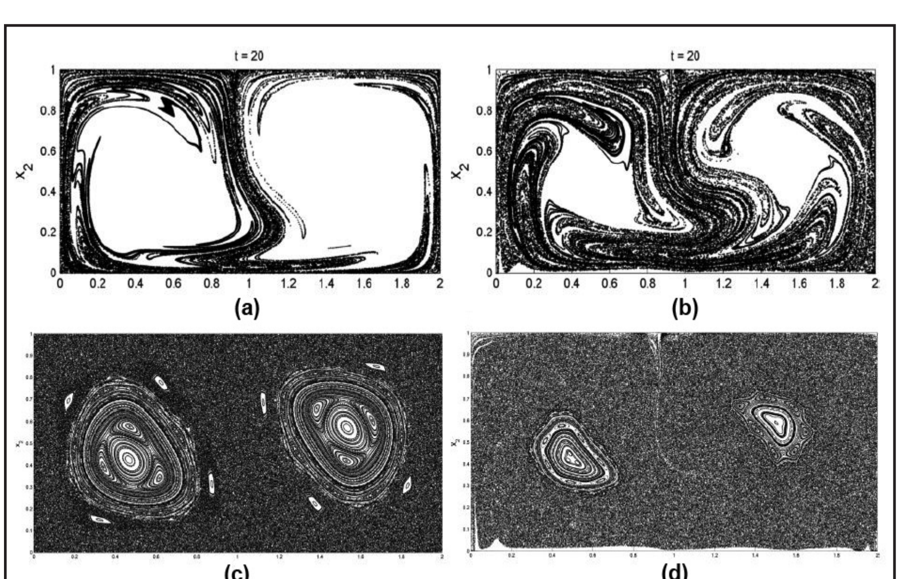


Figure 3. *Enhancing mixing in the double gyre flow.* **3a.** *Evolution of a small parcel of fluid for 20 periods of the double gyre flow [9].* **3b.** *Evolution of the same parcel of fluid after manipulation of the spectrum to increase mixing.* **3c.** *Poincaré map of the double gyre flow.* **3d.** *Poincaré map of the slightly perturbed flow. Images courtesy of [6].*

Nonstationary, Nonautonomous, and Time-dependent Dynamics

What can one do when the dynamics is nonstationary or nonautonomous, where the *governing dynamics changes over time* — as is the case in the atmosphere, where the wind field today may be very different from the wind field tomorrow? If a sequence of maps $T_1 : X \circlearrowleft$, $T_2 : X \circlearrowleft$, ..., $T_n : X \circlearrowleft$, ..., describes the nonstationary dynamics, one can study the phase space transport using the composition

$$\ldots \mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1}.$$

If we wish to study mixing for these *time-dependent* dynamics, we must adjust our approach. The notion of "second eigenvalue" does not make sense if the applied transfer operator varies from one time step to the next. The key property related to the second eigenvalue-eigenfunction pair (λ_2, f_2) when the governing dynamics is stationary is the existence of a $C < \infty$, such that $\|\mathcal{L}^n f_2\| \leq C\lambda_2^n \|f_2\|$ for all $n \geq 0$. This expression quantifies the exponential mixing rate of $|\lambda_2|$. We can mimic this property in the time-dependent setting by asking that

$$\|\mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1} f\| \leq C\lambda_2^n \|f\| \quad \text{for all } n \geq 0,$$

or taking logs, dividing by n and sending $n \to \infty$,

$$\lim_{n\to\infty} \frac{1}{n} \log \|\mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1} f\| \leq \log \lambda_2. \qquad (1)$$

Formally, $\log \lambda_2$ is a *Lyapunov exponent* of the cocycle of transfer operators $\ldots \mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1}$ and quantifies the rate of mixing [4]. We either select a Banach space $\mathcal{B}$ or add noise to the dynamics to ensure a (Lyapunov) spectral gap between $\log\lambda_1 = \log 1 = 0$ and $\log\lambda_2 < 1$. The subspace (which is one-dimensional if λ_2 is simple) spanned by f that produces equality in (1) encodes the *coherent set* at time 0 and is responsible for the mixing rate. Figure 4a shows two black sets, identified as coherent sets, and two nearby grey sets. As time progresses, the black sets remain largely coherent while the grey sets are quickly mixed into the phase space (see Figure 4b).

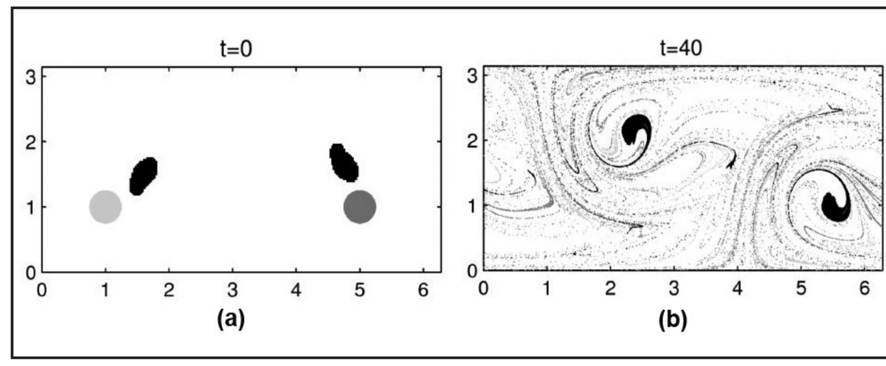


Figure 4. *A time-dependent flow on a cylinder.* **4a.** *Black sets are identified as coherent sets and grey sets are chosen arbitrarily.* **4b.** *After a lengthy evolution time, the black sets remain largely coherent while the grey sets have readily mixed with the rest of the phase space. Images courtesy of Gary Froyland and Naratip Santitissadeekorn.*

Finite-time Dynamics

In many situations, one is concerned with transport and mixing over a finite-time horizon. For example, physical, chemical, and biological systems often have natural timescales that are important for dynamical analyses. We take (1) and truncate time at step n, obtaining

$$\|\mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1} f\| \leq \lambda_2^n \|f\|. \qquad (2)$$

$\mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1}$ pushes the function f forward under n time steps of the time-dependent dynamics. We wish to find the largest $0 < \lambda_2 < 1$, which is again possible due to the existence of a spectral gap from $\lambda_1 = 1$. We accomplish this by selecting f as the *singular vector* corresponding to the second-largest singular value of the composition $\mathcal{L}_{T_n} \circ \ldots \circ \mathcal{L}_{T_2} \circ \mathcal{L}_{T_1}$ [3, 7]. The singular vector f describes the distribution with the slowest decay or mixing over the finite-time duration $t = 1, \ldots, n$, and encodes the *finite-time coherent set* responsible for this slow mixing (see Figure 5a and 5b).

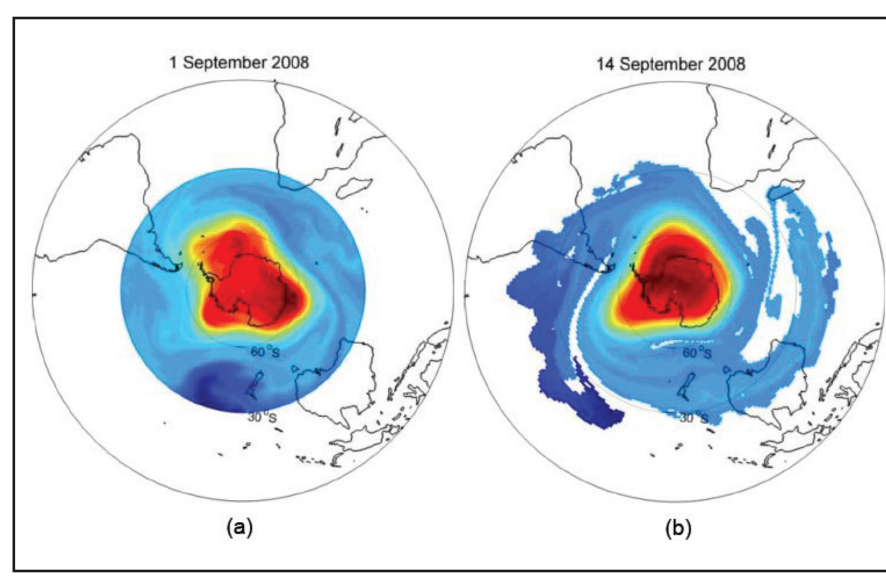


Figure 5. *Stratospheric flow over the South Pole. The Antarctic polar vortex is the most coherent set in the region over the polar cap and is identified as red in the second singular vector.* **5a.** *Left singular vector (on September 1, 2008).* **5b.** *Right singular vector (on September 14, 2008). Figure courtesy of [7].*

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Climate Science

Continued from page 1

sequence of size n, given by the harmonic series $\mathbb{E}(R) = 1 + 1/2 + 1/3 + \cdots + 1/n$. For large n, $\mathbb{E}(R) = \gamma + \log(n)$, where γ is the Euler constant.

If the theorem applies to temperature data, we expect to wait increasingly long intervals for each new record temperature value because the probability declines as $1/(t - t_0)$. Here the time t of each temperature observation takes the place of the statistical index n, and t_0 is the start of the particular temperature observations (we would also expect similar rates of record highs and lows if the probability distribution were symmetric).

Figure 1a (on page 1) compares the record highs and lows obtained from a synthetic random time series to the July temperatures measured at the Moscow station, from about 1880 to 2011. The highs and lows are similarly spaced in time for the random time series, but the Moscow temperature data shows many early lows and none after about 1910. By contrast, the record highs are more evenly spaced and continue through the observation period. The data suggests that the theorem is not fulfilled and the rate at which record highs or lows occur at time t does not follow $1/(t - t_0)$.

Figures 1b and 1c (on page 1) plot temperature data from 30 Northern Hemisphere locations, chosen at random but mostly concentrated in temperate zones. The time series are not of equal length, and some stations did not report every year. The annual mean temperatures shown in Figure 1b—which highlights seven arbitrarily-chosen temperature time series—indicate a long-term warming trend. But qualitatively at least, it is not obvious that a stationary temperature distribution is an unacceptable statistical model for mean temperatures. Figure 1c (on page 1) highlights the records associated with the seven data points. To facilitate comparison, we adjust these data sets by subtracting the first temperature data point in the set (leading to an adjusted temperature of zero for each time series). Adding more observations to the top or bottom set does not change the fact that one can expect more high than low records over time (the low records stop occurring). The record highs and lows tell a clearer story: they do not obey the $1/t$ dependence, establishing that they must not sample from a stationary process.

Incorporating Uncertainties in GHG Projections

Global estimates of GHG emissions are readily available [1] and have tightly-constrained uncertainties, since they are critical to the energy sector of the economy. Uncertainties are associated with changing policies regarding carbon emissions, including international treaties and carbon pricing and the potentially time-varying nature of natural carbon sinks and sources. However, we focus here on variability spanning several decades to hundreds of years and the largest of spatial scales. A simple balance is used to estimate the temporal evolution of the global temperature T.

We can explore the extent to which GHG uncertainties—derived from a statistical analysis of the historical temperature and forcing data—affect conclusions of future temperature projections. This allows us to compare natural and anthropogenic GHG forcings to determine whether the outcomes' sensitivity depends on the relative uncertainties in these two GHG components. We can also infer whether natural or anthropogenic forcings are dominant, both prior to and during the industrial era and in the future.

Black body radiation theory tells us that Earth's radiation is proportional to T^4. The surface energy balance, in terms of surface temperature T, is $C dT/dt = Q + \kappa\sigma T_{Atm}^4 - \sigma T^4$, where T_{Atm} is the atmospheric temperature, t is time, C is the effective heat capacity, and σ is the Stefan-Boltzmann constant. Q represents the effective incoming radiation. If $C_a dT_{Atm}/dt$ is small, where C_a is the effective atmospheric heat capacity, then $\kappa\sigma T^4 + 2\kappa\sigma T_{Atm}^4 \approx 0$ and $C dT/dt = Q - (1 - \frac{\kappa}{2})\sigma T^4$. Since the temperature range is not large, $(1 - \frac{\kappa}{2})\sigma T^4 \approx A + BT$, where A and B are constants. The energy balance is spectrally dependent. The high frequency component has one portion that mostly dissipates and another that reflects back to space via clouds and snow/ice. On the other hand, reflectivity and a complex layer of gas, dust, and droplets capable of trapping surface outgoing radiation affect the low frequency component. Let us assume that Q is a linear combination of the effective solar radiation and GHG-induced radiative forcing. Hence, $Q = \frac{1}{4}(1 - \alpha)S + F_{GHG}$, where the albedo $\alpha \approx 0.3$ and the global average solar radiation is presently $S/4 \approx 1370/4\,\mathrm{Wm}^{-2}$. The EBM we adopt[1] is thus

$$C dT = \frac{S}{4}(1 - \alpha)dt + F_{GHG}dt - (A + BT)dt + \nu(t)dt,$$

where T is the temperature of Earth's surface (approximated as a 70-meter-deep, mixed-layer ocean covering 70 percent of the surface area). $C = 2.08 \times 10^8\,\mathrm{J\,K^{-1}m^{-2}}$ is the effective heat capacity that accounts for the thermal inertia of the mixed-layer ocean; however, it does not allow for heat exchange with the deep ocean. The last term in the model is a stochastic forcing term, which represents inherent uncertainties and unresolved processes.

Figure 2 depicts a single realization of temperature predictions that accounts for natural and anthropogenic forcing and their variability (see Figure 3). The long-wave emissivity's upward trend still dominates any uncertainties due to natural and man-made forcings during the Industrial Revolution. Ultimately, the steadily-increasing carbon dioxide forcing overwhelms natural factors in temperature prediction during the industrial era and into the future, even when accounting for variability and uncertainty due to natural volcanic and solar forcing of climate.

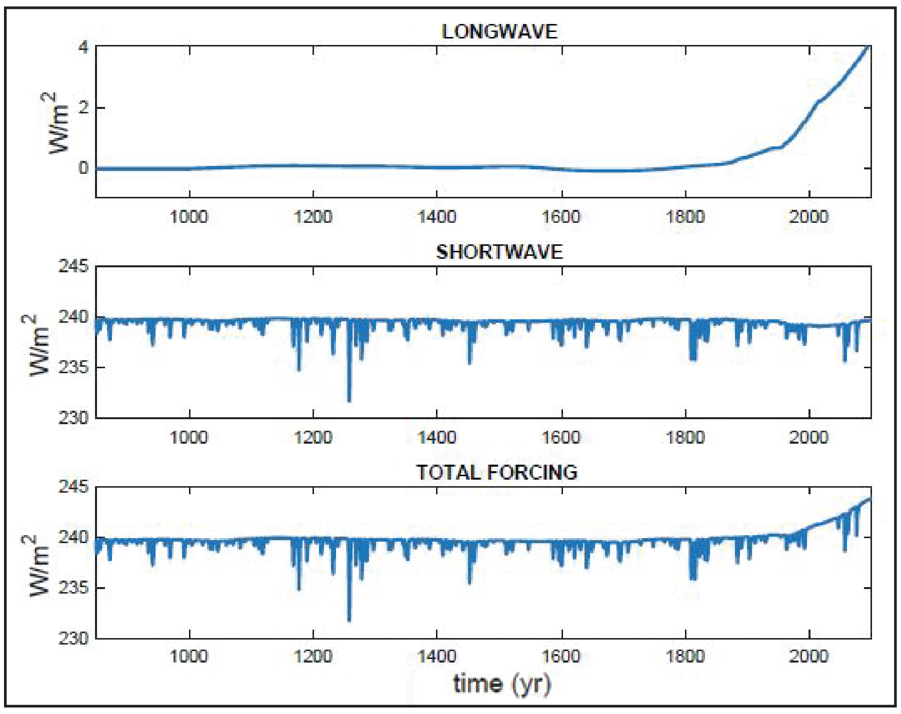

Figure 3. *Stochastic long-wave, short-wave forcing and composite total forcing, with uncertainties due to carbon dioxide emissions, volcanic activity, and solar forcing. A single stochastic realization is depicted. Figure courtesy of Juan Restrepo and Michael Mann.*

Summary

Using observational surface temperature data, we show that temperatures around the Northern Hemisphere do not exhibit a time-stationary distribution. To explore the causal factors behind the observed non-stationarity, we drive a simple zero-dimensional EBM with estimated natural and anthropogenic forcings. The key natural forcings are associated with volcanic emissions and insolation changes, while anthropogenic forcing is primarily due to the warming effect of GHG increases from fossil fuel burning, which is accompanied by a secondary offsetting cooling influence from sulphate pollutants. We explain the effect of inherent uncertainties on projections of future global temperature, constructing historically-informed statistical models for the variability of the forcings that account for factors in stochastic influences. One must invoke both natural and anthropogenic forcings for the model simulations to agree with instrumental temperature data.

Our calculations indicate that warming is a result of anthropogenic increases in GHG concentrations, a finding that is robust with respect to uncertainties in the forcings as represented by stochastic models. Moreover, since the effect of forcing variability is small compared to the upward trend of anthropogenic forcing, inherent variability cannot prevent further increases in global temperature without a slowdown in anthropogenic forcing, i.e., a cessation or decrease in GHG emissions. Scientists using more sophisticated state-of-the-art climate models reach the same conclusions,[2] and have been unable to find a plausible non-anthropogenic explanation for the observed warming and increase in warm extremes during the anthropogenic era [3]. We find no evidence that future natural radiative forcing contributions could substantially alter projected anthropogenic warming; the impact of their variability would contribute to "known unknowns" in temperature uncertainty. The model's longtime features agree well with historical data and thus do not require the introduction of epistemic variability ("unknown unknowns") in the model.

Shah's appraisal of the outcomes in the Fourth National Climate Assessment motivated us to demonstrate the ways in which simple, well-established, quantitative methods can address apparent challenges posed by uncertainties in climate assessments. Because key climate change attributes, such as ice sheet collapse and sea level rise, are occurring ahead of schedule [4], uncertainty has in many respects turned against us. Scientific uncertainty is not a reason for inaction. If anything, it should inspire more concerted efforts to limit carbon emissions.

Article partially adapted from "This is How 'Climate is Always Changing,'"[3] published in the American Physical Society Physics GPC Newsletter, Issue 9, February 2018.

Further details on records in time series and the stochastic parametrization of uncertainties can be found in an appendix available in the online version of this article.

Acknowledgements: We would like to thank Barbara Levi, who provided invaluable editorial assistance with this article.

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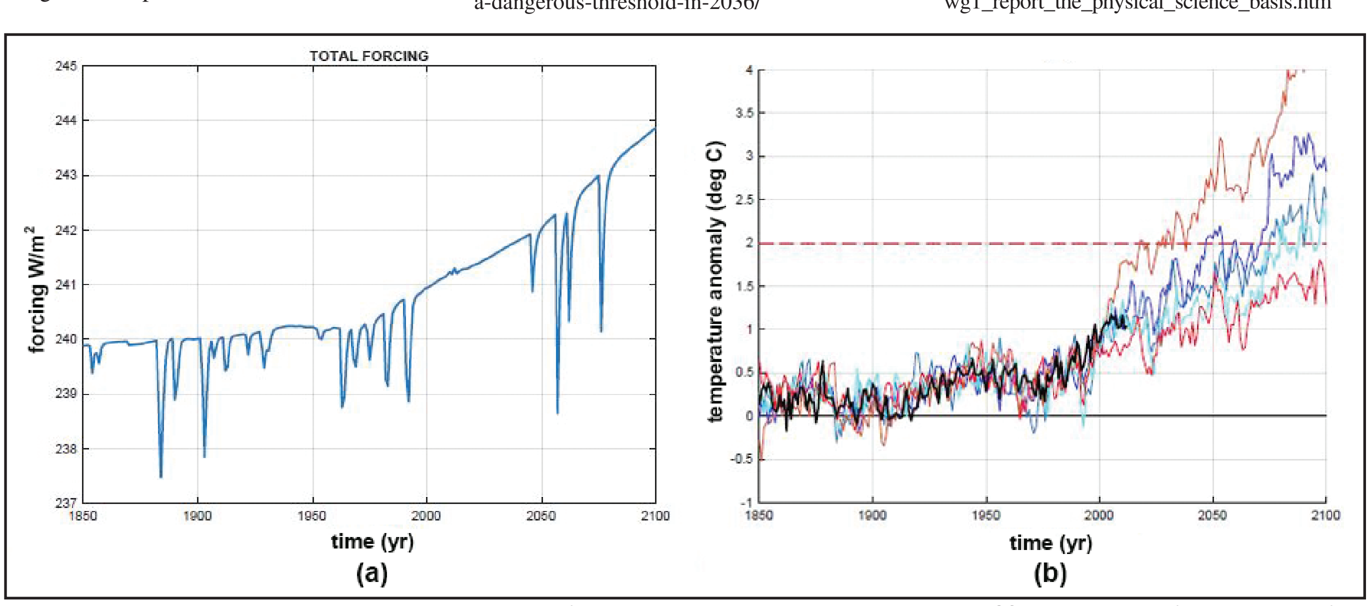

Figure 2. *Temperature predictions, including uncertainties, for various equilibrium climate sensitivities (ECS).* **2a.** *Highlight of the composite forcing (see Figure 3) corresponding to the period 1850-2100.* **2b.** *Temperature predictions as a function of ECS, taking into account uncertainties due to carbon dioxide emissions, volcanic activity, and solar forcing. Stochastic variability due to temperature uncertainties is included. Historical temperature variability data informs the stochastic model of temperature fluctuations. From left to right, equilibrium climate sensitivity equals 4.5, 3, 2.5, 2, 1.5. Figure courtesy of Juan Restrepo and Michael Mann.*

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How to Make Friends and Influence People at Conferences

By Nilima Nigam

After reading many, many newsletters of distinguished mathematical societies, I have come to one conclusion: most mathematicians are excellent at meeting new people at conferences. Countless photographs show happy people making eye contact and seemingly immersed in deep, meaningful conversations. Participants are quoted, cheerily and eloquently describing the valuable new networks and lifelong friendships they have formed. Career panels communicate the importance of making connections at conferences, and attendees nod their heads in vigorous agreement.

I have a confession: conferences fill me with terror. The process of introducing myself to someone I do not know comes fraught with anxiety for me; many years and N (a large number) conferences have neither dulled the pain nor rendered the experience any easier. Meeting someone for the second or third time is only a slightly less awful prospect. There is a high probability that he/she has forgotten who I am, and my subtle attempts to unobtrusively raise my conference badge to eye level never really work. So I have to reintroduce myself to someone whom I had already done the arduous work of introducing myself to before, and who appears to have blocked out the memory. It seems better all around if I just avoid contact with other attendees.

I look at conference photographs in *SIAM News* and miserably wonder how I can join the broader fraternity of conference-adept mathematicians. Am I the sole misfit in this community of people who can happily meet and greet each other sans awkwardness? Everyone featured in articles that recap meetings seems chipper, sociable, and smart. No one appears to suffer from jetlag. No one visibly yearns for a quiet evening huddled with a notepad.

I have consulted many articles and blogs to glean wisdom on this issue, seeking help from various oracles. Some recommend having someone you know introduce you to other people. This assumes many things. Let us begin by defining, for a given conference attendee c, the set of acquaintances

$$\mathcal{A}_c := \{p \mid p \text{ is a person at this conference already known to } c.\} \subset \mathcal{U} := \{\text{all conference attendees}\}.$$

The first and most important assumption is that that you already have a nonzero initial state of acquaintances at the conference (i.e., $\mathcal{A}_{you} \neq \varnothing$). The next assumption is that $\exists p \in \mathcal{A}_{you}$, so that $\mathcal{A}_p \setminus \mathcal{A}_{you} \neq \varnothing$; that is, at least one of your acquaintances knows people beyond your acquaintance-space. Even conditioning on these two facts, you must assume that your acquaintances are willing to perturb their acquaintance-state by introducing you to someone else in it. As we all know, injecting a longer-range interaction term in an inherently localized system is a recipe for weirdness. We are, in fact, looking for person $q \in \mathcal{U}$, so that

$$q \in \mathcal{A}_{you} \cap \{p \in \mathcal{U} \mid \mathcal{A}_p \setminus \mathcal{A}_{you}\} \cap \{w \mid w \text{ is willing to risk an awkward three-way conversation}\}.$$

The cardinality of the set on the right is small indeed.

Photos from conferences typically depict happy attendees partaking in purposeful conversation and making lasting connections. SIAM photo.

Some experts recommend approaching a speaker after his/her talk and asking a mathematical question. This strategy assumes that the question you carefully crafted during the first half of the speaker's talk was not inconveniently and comprehensively answered on the penultimate slide, rendering your opening gambit useless and leaving you no time to formulate a backup question. "What about 3D?" only works so often.

Certain websites suggest trying to have a meal with someone you do not know. I have not yet found a polite way to say "Hello, I don't know you, but will you have dinner with me?" It sounds about as easy as taking up another suggestion: arbitrarily contacting people on the participant list ahead of time and inviting them to a board or bridge game. I think that could be a lot of fun, but have yet to hit "send" on any such emails I have drafted.

At a meeting a few years ago, I deployed a foolproof strategy. I had read that hanging out near coffee tables or posters was a good icebreaker, and seeing posters arrayed near the coffee-break tables gave me hope. Surely two hours in the simultaneous vicinity of posters and coffee would help me meet people? Well, after one hour of diligent lingering and reading, I knew a lot about a mathematical model of some little bacterium. Then the poster presenter appeared. Over the next hour, the presenter and I very carefully read said poster. Each of us was very respectful of the other's space and did not interrupt our careful reading to say a word. There is an art to reading a four-by-eight poster side-by-side while carefully avoiding any conversation, and I'm happy to report that I achieved complete mastery of this art. I am also now rather proficient in the ways of this bacterium, or at least as much as can be said on a giant sheet of paper.

A colleague once assured me that the situation would improve with more years in the profession, and there is certainly truth to this. You often see the same faces at conferences, and after a few years you might say "hello" and finally develop a collaboration. However, sometimes I like to learn new things and explore new mathematical areas *before* working up the courage to actually talk to someone about these topics. This means that I attend conferences where I know the names of authors but not the faces of actual people (online headshots are not helpful). The key reason to frequent such conferences is precisely to meet these experts...which is an excruciatingly difficult task.

Still life: plants and posters. Image credit: David J. Muraki.

By this juncture, the diligent reader may expect anagnorisis — that moment in a story where the protagonist makes a crucial discovery. Unfortunately, dear reader, prepare for disappointment. Conferences remain terrifying to me, and I fear that I am alone in this sentiment. I am utterly grateful to spot someone (anyone?!) I already know, and remain at the complete mercy of friends to introduce me to new people. The best advice that I can offer fellow sufferers—based on my decades of diligent conference-going—is to find a large potted plant (every conference has one). Learn to comfortably read behind it, leaning against the foliage. You'll be doing this a lot.

Readers, do you have similar experiences at conferences? Or do you happen to be among the proficient few who have mastered the art of socializing and collaborating at meetings? Share your misgivings, experiences, and insights via comments on the online version of this article!

Nilima Nigam is a professor of applied mathematics at Simon Fraser University. She has acquired vast expertise on the indoor potted plants favoured by conference venues.

Upcoming Career Fair at AN18

If you plan to attend the 2018 SIAM Annual Meeting in Portland, Ore., from July 9-13, you may be interested in the Career Fair sessions on July 9. The Career Fair will showcase employers from both industry and government, with whom attendees can discuss opportunities for internships and postdoctoral and full-time appointments.

Morning and afternoon sessions will be held from 8:30 to 11 a.m. and 3:30 to 5:30 p.m., respectively. A Graduate Student and Industry Reception will follow from 7:15 to 9:15 p.m. that evening. This will serve as an excellent opportunity for students and early-career professionals to meet government and industry representatives, learn what they look for in candidates, and hear what each employer has to offer. If you are searching for employment or would like to learn more about potential careers, do not miss the chance to network and speak with knowledgeable individuals from a range of organizations.

Representatives from 20 to 30 employers are expected to discuss current and future opportunities in their organizations and industries. The list of participating employers currently includes the following: 3M Company; American Family Insurance; Argonne National Laboratory; Battelle; Nokia Bell Labs; BlackRock; Boeing; Dyndrite Corp.; ExxonMobil; Ford; Google; Lawrence Berkeley National Laboratory; Lawrence Livermore National Laboratory; MathWorks; MITRE Corporation; NASA's Langley Research Center, High Performance Computing Incubator; Pacific Northwest National Laboratory; Sandia National Laboratories; and Schlumberger.

If you are attending the Career Fair as a student or professional, do not forget to submit your resume! Submission instructions are available on the Career Fair website.[1] As the event nears, SIAM will make submitted resumes available to organization representatives.

Interested employers are also encouraged to participate. With over 1,000 attendees, more than 200 of whom are students, the SIAM Annual Meeting is a perfect opportunity to recruit individuals with mathematical talent and training. Many of these students and professionals have advanced mathematical backgrounds and are highly skilled in computational methods. The Career Fair is an exceptional chance to not only hire employees, but to advertise a company's mission to a broad and diverse audience.

For further information about the Career Fair at the 2018 SIAM Annual Meeting—including helpful hints for navigating the event and employer participation instructions—please refer to the Career Fair website. See you in Portland!

— *Maxwell Hayes, SIAM*

1 http://www.siam.org/meetings/an18/career.php

Möbius Map in Hinges, Bikes, Fluids, and Ellipses

MATHEMATICAL CURIOSITIES
By Mark Levi

The Möbius map

$$z \mapsto w = e^{i\alpha}\frac{z-c}{1-\bar{c}z}, \qquad (1)$$

the linear fractional transformation leaving the unit circle $|z|=1$ invariant, is present in every course on complex analysis. Interestingly, this same map arises in other contexts, four of which I describe here.

1. A "Locomotive" Map

Consider a parallelogram whose sides are rods of lengths 1 and $a>1$ (see Figure 1). Fold the parallelogram along the dotted diagonal to obtain a "butterfly" figure in the plane (see Figure 2). Imagine that each vertex is a hinge; fixing the segment AB and rotating AD will cause BC to rotate

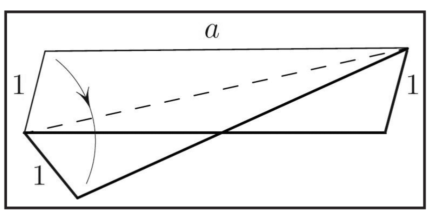

Figure 1. *Folding a parallelogram into a "butterfly."*

(in the opposite direction), vaguely reminiscent of a locomotive. D's position on the circle uniquely determines C's position on its own circle. We thus have the map of a circle to itself (identifying the two circles). Remarkably, this map is a Möbius map — up to a reflection. More precisely, if we treat $AD=z$ and $BC=w$ as complex numbers on the unit circle with AB along the x-axis, then

$$w=\overline{\left(\frac{z-a}{1-az}\right)},$$

a special case of (1), up to the conjugation. A short proof of this is available in [1].

2. The "Bicycle"

The bicycle in Figure 3 is a segment of fixed length moving in the plane in such a way that the velocity of the "rear"

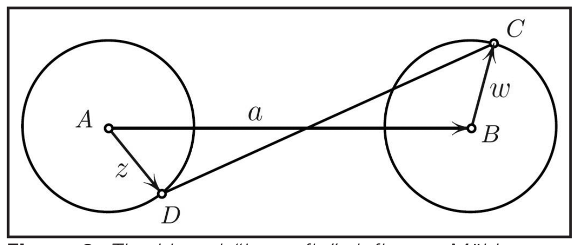

Figure 2. *The hinged "butterfly" defines a Möbius map from z to w.*

endpoint constrains to the segment's line (there is no sideslip), while the "front" endpoint moves along a *prescribed* path Γ. Fixing Γ once and for all, the starting orientation determines the final orientation; that is, we have a circle map (see Figure 3). Robert Foote observed that it is actually a Möbius map [2], i.e., it is given by (1). The constants α and $c=a+ib$ depend on the front path Γ but not on the bike's initial orientation.

3. The Fluid

Imagine a cylinder guided through ideal fluid (i.e., one with vanishing curl and divergence) in an arbitrarily-prescribed path; Figure 4 shows a snapshot of the fluid velocity field in the cylinder's reference frame. Particles on the boundary of the cylinder slide on the surface (the ideal fluid does not stick to walls). We thus have a map from the particle's initial position on the circle to its ending position. This map also turns out to be of the Möbius form (1), with α and c dependent upon the cylinder's path through the fluid. Incidentally, Figure 4 illustrates the zero circulation case, but the statement remains true for nonzero circulation as well.

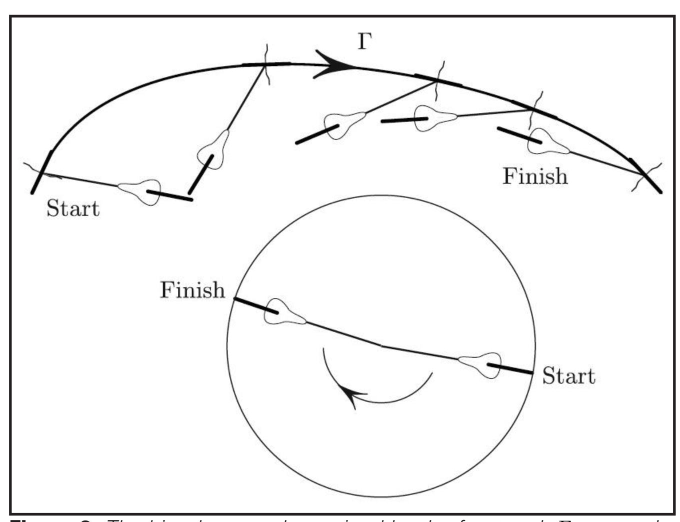

Figure 3. *The bicycle map, determined by the front path Γ, maps the bike's original orientation to its final orientation.*

4. An Ellipse

The unit vectors z and w (treated as complex numbers) in Figure 5 are related by the Möbius transformation (1), where $\alpha=0$ and

$$c=\sqrt{1-\frac{b^2}{a^2}};$$

here a and b are the minor and major semiaxes of the ellipse. This fact occurred to me as I was writing the article, although I am sure it has been observed before.

5. A Note on the Explanation

Facts 2, 3, and 4 follow from the observation on the circle's simplest nontrivial flow, given by

$$\dot{\theta}=\sin\theta.$$

Namely, the time advance map of this flow acts on points $e^{i\theta}$ as a Möbius map. This can be shown by a quick geometrical argument or short calculation (both omitted). The "Möbiusness" of the time advance map survives the addition of rotation and time-dependence

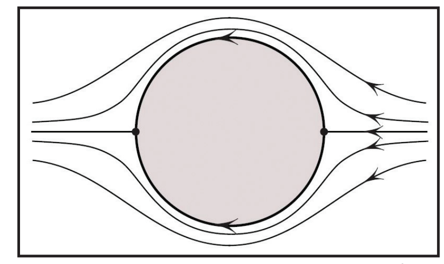

Figure 4. *An instantaneous snapshot of the ideal fluid in the cylinder's reference frame (shown with zero circulation).*

$$\dot{\theta}=p(t)+q(t)\sin\theta,$$

for any continuous p,q. One can deduce this latter fact from the preceding remark and the fact that Möbius transformations form a group under composition.

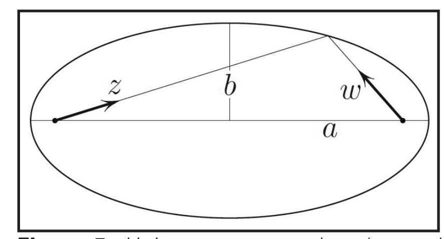

Figure 5. *Unit vectors z and w (treated as complex numbers) emanate from the ellipse's foci. $z\mapsto w$ is a Möbius transformation.*

Facts 1 and 4 are shown by calculation. To end on a sad note, I am not aware of their geometrical proof.

The figures in this article were provided by the author.

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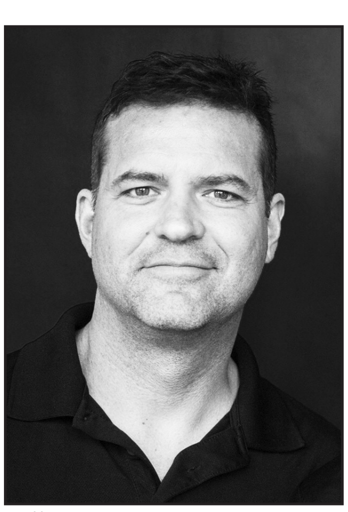
Applied and Computational Mathematics: A New Curriculum for 21st Century Discovery and Innovation

The following is a short introduction to an invited lecture to be presented at the upcoming 2018 SIAM Annual Meeting (AN18) in Portland, Ore., from July 9-13.

In recent years, we have seen an unprecedented surge in discovery and innovation — led largely by advances in science and engineering. A central and unifying theme of these breakthroughs is the role of applied and computational mathematics. Our ability to use mathematical abstraction to cast real-world problems into quantitative investigations has led to many crowning achievements.



Jeffrey Humphreys, Brigham Young University.

As the frontier of discovery and innovation continues to progress, our curricula must stay in sync so that students are well-prepared to engage the workforce, thrive in postgraduate research, and compete in a fast-moving global economy. This means that the applied mathematics curriculum must remain aligned with the demands of industry and the broader STEM community.

Brigham Young University's new and completely redesigned undergraduate Applied and Computational Math Emphasis (ACME)[1] program provides students with a rigorous foundation in mathematics, statistics, and computation. It runs as a two-year, upper-division lockstep curriculum consisting of 32 credit hours distributed evenly over four semesters. In addition, students select an area of specialization from over 25 topics in the pure and applied sciences and take additional coursework, apart from the core curriculum, to fulfill a concentration requirement.

The program's first year devotes meticulous study to the design, analysis, and optimization of algorithms, and offers students a substantial arsenal of mathematical and statistical tools to make definitive and rigorous statements about the performance, complexity, and accuracy of algorithms. The second year focuses on the art and science of mathematical modeling, which gives students the ability to connect the real world with abstract mathematics and numerical simulation.

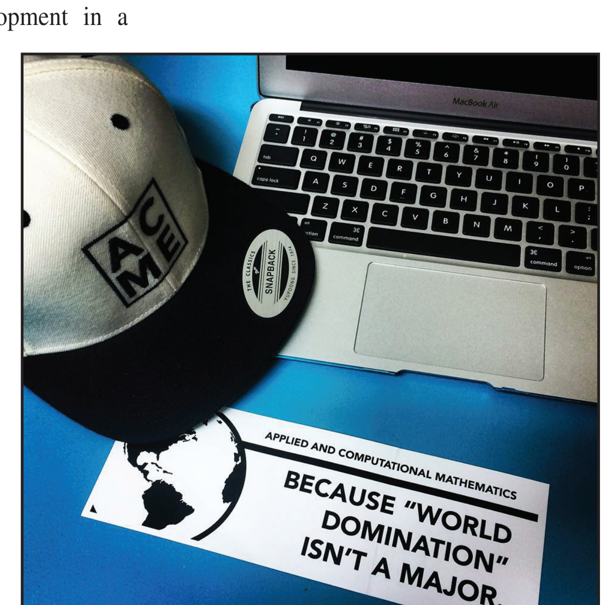
In terms of technical education, students become well-versed in numerical analysis, scientific computing, data processing, relational databases, advanced programming concepts, software development, and scientific visualization. These skills are important for today's scientific workforce, and are sure to be crucial for that of the coming generation. The curriculum also immerses students in several big data and high-performance computing frameworks and technologies.

Although Python is the program's primary computing platform, students focus on the basic principles of scientific computing and algorithm development in a way that transcends specific languages and technologies. Through computation, they explore many applications of mathematics and statistics and gain a broad collection of interdisciplinary experiences to provide context and stimulate diverse interests.

In addition to a robust mathematical foundation, exposure to applications, and a strong technical education, the ACME program also fosters personal development through close collaboration, coaching, and a soft-skills seminar. These efforts help shape students' careers by teaching them how to thrive in group settings.

The program's ultimate goal is to produce a solid and vibrant pipeline of young scholars in the mathematical and computational sciences well-equipped to meet the challenges of a globally competitive scientific workforce. During the 2018 SIAM Annual Meeting, I will present an overview of this program and the content, technical development, outcomes, and insights learned in the five years since its commencement.

— Jeffrey Humphreys, Brigham Young University



Brigham Young University's new, redesigned undergraduate Applied and Computational Math Emphasis (ACME) program offers students a rigorous foundation in mathematics, statistics, and computation.

[1] http://www.acme.byu.edu/

The Impact of Computerized Social Services on the Underprivileged

BOOK REVIEW
By Ernest Davis

Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor. *By Virginia Eubanks. St. Martin's Press, New York, NY, January 2018. 272 pages, $26.99.*

How does the computerization of governmental social services impact the poor? In *Automating Inequality*, Virginia Eubanks delivers a harsh verdict: throughout American history, government policy towards the poor has often amounted to criminalizing poverty; computer technology makes these policies more inescapable, more implacable, and more brutal. Eubank's book is deeply researched, well-written, passionate, and extremely troubling.

The core of *Automating Inequality* consists of three case studies: welfare eligibility determination in Indiana, housing eligibility in Los Angeles, and child welfare in Pennsylvania's Allegheny County.

In 2006, the state government of Indiana hired IBM and Affiliated Computer Services (ACS) to develop a new, more efficient system to determine eligibility for welfare programs such as Medicaid and food stamps. Office centralization was the new plan's main feature. In the old system, applicants and beneficiaries visited local offices that held their documentation; each family was assigned a fixed case worker. The new system moved services and documents to a centralized call center. Workers at the call center handled issues on a task-by-task basis; each time a beneficiary called, he or she would talk to a new person.

The results were catastrophic. Under the previous system, the positive error rate (benefits incorrectly awarded) was estimated at 4.4 percent and the negative error rate (benefits incorrectly denied) at 1.5 percent. Between 2006 and 2008, the combined error rate more than tripled, rising from 5.9 to 19.4 percent, mostly in incorrect denials. 283,000 personal documents faxed to the center were lost — and any single missing document could deny an applicant benefits.

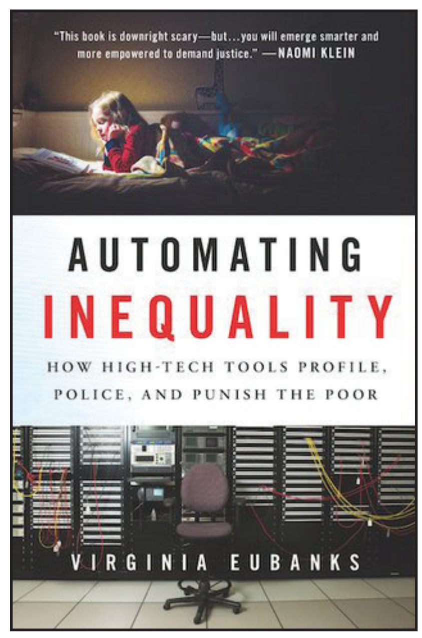
Interacting with the system was often a nightmare. Applicants were told to expect a phone call within a certain time window; they would take leave from work to be home at that time, only to wait for a call that never came. Inability to reschedule the call was sufficient reason for denial of benefits. Applicants received letters from the office refusing coverage, with the justification "FAILURE TO COOPERATE IN ESTABLISHING ELIGIBILITY" without further explanation. After weeks of work, they often discovered that one required signature was missing or a document had been lost.

The whole incident became a major scandal, with multiple lawsuits. Fundamentally, however, IBM and ACS had given the state what it had asked. Eubanks writes:

> The goals of the project were consistent throughout the automation experiment: maximize efficiency and eliminate fraud by shifting to a task-based system and severing caseworker-to-client bonds. They were clearly reflected in contract metrics: response time in the call centers was a key performance indicator; determination accuracy was not. Efficiency and savings were built into the contract; transparency and due process were not.

In 2013, Los Angeles County introduced a "coordinated entry" system to match homeless people with available public housing. Its guiding principle is to give priority to the most vulnerable homeless people, as long as they are deemed responsible enough to be safe neighbors. To evaluate vulnerability, a program called the Vulnerability Index-Service Prioritization Decision Assistance Tool uses applicant information to compute a score between one (low risk) and 17 (very vulnerable).

Eubanks concedes that the entry system fairs better than the chaos that existed under the previous process. However, two large issues persist. Computerization cannot solve the first problem: public housing resources are simply incapable of matching need. Under such circumstances, the system is merely a source of bitter disappointment for many applicants, who complete applications but get no results (Los Angeles recently passed two major ballot initiatives funding housing and other services for the homeless, which will hopefully alleviate this fundamental dilemma).



Automating Inequality: How High-Tech Tools Profile, Police, and Punish the Poor. By Virginia Eubanks. Courtesy of St. Martin's Press.

The second issue pertains to the collected data. To apply through the coordinated system, one must provide a large amount of personal information. Applicants have no way of knowing where this information might go or how it may be used. Few people will sacrifice an opportunity for housing by refusing to provide the requisite details. As a result, while information is collected from large numbers of people, only a handful benefit by actually receiving housing.

Additionally, one's criminal record inevitably becomes part of the application. However, conflicts with the law can be unavoidable for the chronically homeless. Consequently, the collection and storage of data often leads to criminalization of the poor. Eubanks writes:

> [T]he pattern of increased data collection, sharing, and surveillance reinforces the criminalization of the unhoused, if only because so many of the basic conditions of being homeless—having nowhere to sleep, nowhere to put your stuff, and nowhere to go to the bathroom—are also officially crimes. If sleeping in a public park, leaving your possessions on the sidewalk, or urinating in a stairwell are met with a ticket, the great majority of the unhoused have no way to pay resulting fines. The tickets turn into warrants, and then law enforcement has further reason to search the databases to find "fugitives."

The Allegheny Family Screening Tool (AFST) is an automated system designed to identify children at risk of abuse or neglect. It was launched in Allegheny County, Penn., which includes Pittsburgh and its environs, in August 2016. The system's design was hands-on and transparent, its usage is measured, and its goals are modest.

The output of the program is merely advisory, and final decisions are always left to the judgment of a human being. Marc Cherna and Erin Dalton, administrators of the department utilizing the program, have much experience and are respected and trusted by the community.

Nonetheless, there are reasons for concern. The predictive model is trained on decades of records, but both the input and outcome variables are problematic. The program aims to predict abuse and neglect, but neither is easy to accurately measure from the data. Instead, the system uses two proxies for outcome variables: "community re-referrals," i.e., multiple calls to the hotline, and placement of children in foster care. But hotline calls seem to be racially biased and are sometimes simply malicious. As calls are anonymous, screening out vicious callers is impossible.

The input variables are also questionable. Distinguishing indicators of neglect—lack of food, inadequate housing, unlicensed childcare, unreliable transportation, utility shutoffs, homelessness, lack of health care—from the natural effects of poverty is very challenging.

The Office of Children, Youth, and Families (CYF) offers a variety of services and support to indigent families. Necessarily, it is also tasked with reporting problematic family situations. This results in conflicted parents: in asking for aid, they risk the CYF taking their children away.

A determination of neglect or abuse can have lifelong consequences; offenders are permanently barred from any jobs involving interactions with children. Children suffer as well. Since growing up in a troubled family is predictive of being an inadequate parent, they start life with an elevated AFST score. As Eubanks indicates, a high AFST score can easily become a self-fulfilling prophecy:

> A family scored as high risk by the AFST will undergo more scrutiny than other families . . . A parent is now more likely to be re-referred to a hotline because the neighbors saw child protective services at her door last week. Thanks in part to the higher risk score, the parent is targeted for more punitive treatment, must fulfill more agency expectations, and faces a tougher judge. If she loses her children, the risk model can claim another successful prediction.

Based on these case studies, I do not think a decisive argument can be made that computerization has hurt the poor in material respects and deprived them of services, housing, or goods. The Indiana case was an enormous fiasco, but the major failing seems to have been almost entirely organizational. The digitization was simply a web-based interface and standard database for record-keeping.

Computerization plays a much larger role in the Los Angeles coordinated entry program—a decision support system—and the AFST, a decision support system based on big data analysis. But in these instances, it is not clear whether the computerized system is performing worse than any other system; the coordinated entry program certainly seems better than the preceding method.

However, if we ask instead whether these computerized tools bring benefits that outweigh costs to the poor in increased risk of arrest, potential loss of their children, compromise of privacy, dehumanization, anger, and alienation, then Eubanks' studies show that we have no reason for confidence and many grounds for skepticism. These systems look very different to their targets than to their designers. No computerized system, however thorough its data or clever its algorithm, can single-handedly make a major change to the state of the poor; such change will require a large and serious commitment from American society. At present, there is not much sign of that.

Ernest Davis is a professor of computer science at the Courant Institute of Mathematical Sciences, New York University.

2018 SIAM FELLOWS

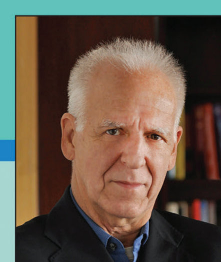
SIAM is pleased to announce the newly selected Class of SIAM Fellows—a group of distinguished members of SIAM who were nominated by their peers for exceptional contributions to the fields of applied mathematics and computational science. Please join us in congratulating these 28 members of our community.

SIAM Fellow


Todd Arbogast
The University of Texas at Austin


Liliana Borcea
University of Michigan


Luis Caffarelli
The University of Texas at Austin


Ronald DeVore
Texas A&M University


Stanley Eisenstat
Yale University

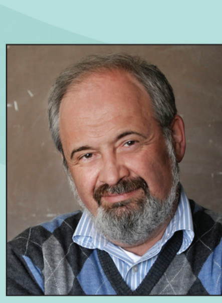

Michael Elad
Technion – Israel Institute of Technology


David Field
General Motors Corporation


Margot Gerritsen
Stanford University


Michael Giles
University of Oxford


Alain Goriely
University of Oxford

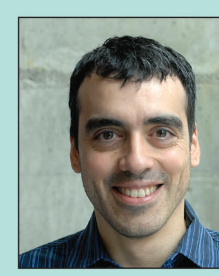

Peter Kuchment
Texas A&M University


Madhav Marathe
Virginia Tech


Alison Marsden
Stanford University


Bojan Mohar
Simon Fraser University and IMFM

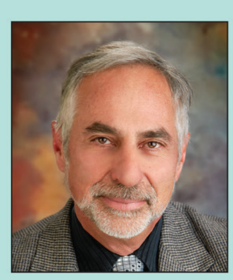

Helen Moore
AstraZeneca

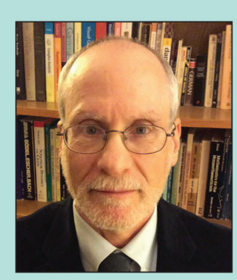

Pablo Parrilo
Massachusetts Institute of Technology

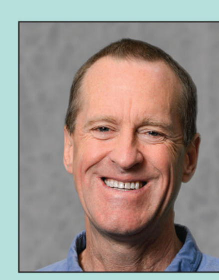

Alex Pothen
Purdue University


Helmut Pottmann
Technische Universitaet Wien


Juan Restrepo
Oregon State University


John Shadid
Sandia National Labs and University of New Mexico


Arthur Sherman
National Institutes of Health

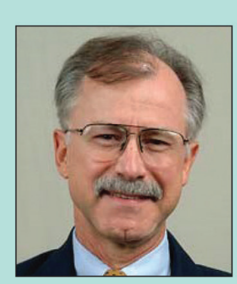

Ralph Smith
North Carolina State University


Tamas Terlaky
Lehigh University


Robin Thomas
Georgia Institute of Technology


Kim-Chuan Toh
National University of Singapore


Panayot Vassilevski
Portland State University and Lawrence Livermore National Laboratory


Homer Walker
Worcester Polytechnic Institute


Karen Willcox
Massachusetts Institute of Technology

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Nominate a colleague for the 2019 Class of Fellows.

SIAM Launches New Journal on the Mathematics of Data Science

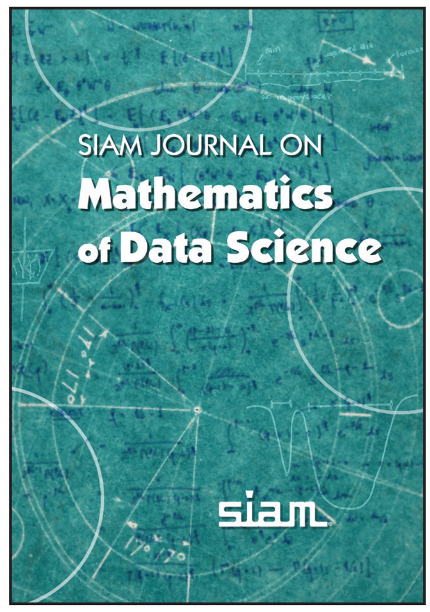
As advances in data collection lead to unprecedented analysis challenges, data science is becoming increasingly important in science, engineering, and business. While there is no single, agreed-upon definition of "data science," one view puts it at the intersection of computational and inferential thinking.

Regardless of its interpretation, data science is undoubtedly a hot topic within the SIAM community. Themes at recent SIAM annual meetings have included machine learning and statistics; big data, data science, and privacy; integration of models and data; data-enabled modeling and simulation; data assimilation and mining; data science in image reconstruction, processing, and visualization; computational neuroscience; and mathematics of dynamic networks. The SIAM International Conference on Data Mining[1] has continued to attract top papers in the field for over a decade. The SIAM Workshop on Network Science[2] arose organically in 2013 and has attracted more attendees every year. More and more SIAM members, many of them students, are entering the field. The SIAM Activity Group on Data Mining and Analytics[3] has nearly 1,000 members — a fourth of whom represent industry. It is the fourth-largest activity group overall and second-highest in student members.

Data science is also gaining prominence in the field of applied mathematics at large. The National Science Foundation (NSF) report on its 2016 "Theoretical Foundations of Data Science: Algorithmic, Mathematical, and Statistical" workshop[4] discusses many areas of interest to SIAM, including computational statistics, randomized linear algebra, signal processing, graphs analysis, nonconvex optimization, and multimodal data. The workshop led to the recently-launched NSF program called Transdisciplinary Research in Principles of Data Science (TRIPODS). Various applied math institutions—including the Institute for Mathematics and Its Applications (IMA) at the University of Minnesota, the Institute for Computational and Experimental Research in Mathematics (ICERM) at Brown University, the Statistical and Applied Mathematical Sciences Institute (SAMSI), and the Alan Turing Institute in London—have hosted data science workshops focused on the development of tools and resources to aid research and collaboration.

Recognizing the expanding role of applied mathematics in data science, SIAM has launched the *SIAM Journal on Mathematics of Data Science* (*SIMODS*).[5] The National Academies' 2013 *Frontiers in Massive Data Analysis*[6] states that, "The research and development necessary for the analysis of massive data goes well beyond the province of a single discipline, and one of the main conclusions of this report is the need for a thoroughgoing interdisciplinarity in approaching problems of massive data." *SIMODS* creates a unique opportunity to strengthen the mathematical constituency's role in the ascent of data science while positively reinforcing the field's connections to complementary communities in statistics, computer science, network science, and signal processing.

In alignment with SIAM's traditional strengths, the journal will focus on topics such as numerical algorithms, optimization and control, functional analysis, and theoretical computer science. It will also include additional areas of relevance like machine learning, signal processing and information theory, applied probability, network science, and statistical inference. As with many other SIAM journals, accepted papers may include some combination of algorithm development, scalable computational methods and implementations, and theoretical analysis. Because of SIAM's strong focus on applications, *SIMODS* will also feature papers on applications of mathematical methods in data and information processing to science and engineering problems. Interdisciplinary papers are highly encouraged.



The new SIAM Journal on Mathematics of Data Science is currently taking submissions.

Publishing mathematical data science research in one journal, rather than dispersing it across many different journals, will help researchers keep track of the field's latest developments. *SIMODS* will provide a natural home for data-focused papers, such as those on mathematical data analysis in the life sciences, relational graph mining in the social sciences, compression of scientific data, data imputation for climate observations, theoretical analysis of machine learning methods, and so on. The journal will thus help SIAM stay relevant to the growing number of current and future members conducting research in this area.

Editor-in-chief Tamara G. Kolda (Sandia National Laboratories) and section editors Alfred Hero (University of Michigan), Michael Jordan (University of California, Berkeley), Robert D. Nowak (University of Wisconsin-Madison), and Joel A. Tropp (California Institute of Technology) have assembled a distinguished team of associate editors[7] with a wealth of experience in applied mathematics, computer science, statistics, signal processing, and network science. They include longtime SIAM members and new colleagues from related fields.

SIMODS is now open for submissions — submit[8] to the journal today!

[1] http://www.siam.org/meetings/sdm18/
[2] https://www.siam.org/meetings/ns18/
[3] https://www.siam.org/activity/dma/
[4] http://www.cs.rpi.edu/TFoDS/TFoDS_v5.pdf
[5] http://www.siam.org/journals/simods.php
[6] https://www.nap.edu/catalog/18374/frontiers-in-massive-data-analysis

[7] http://www.siam.org/journals/simods/board.php
[8] http://www.siam.org/journals/simods/authors.php

Venturing Outside the Silo

By Hans G. Kaper and Hans Engler

Pushing the boundaries of our discipline ensures that mathematics has an impact across various fields. As mathematical scientists, we continue to make significant advances and expose new areas of application. But how proficient are we at communicating the results of our efforts outside our silo? Some scientists are well aware of the contributions we can offer their discipline; however, too many are not, and consequently invent their own mathematical approaches. Decision-makers rarely recognize mathematics' important contributions to the "real world." Even well-educated members of the general public believe that most—if not all—mathematical problems were solved a long time ago. Our profession clearly has a communication problem.

We organized a scientific session on the "Mathematics of Planet Earth" (MPE) at the 2018 Annual Meeting of the American Association for the Advancement of Science (AAAS), held in Austin, Texas, this February. Entitled "MPE: Superbugs, Storm Surges, and Ecosystem Change," our session featured three talks on applications of mathematics: "Unseen Enemies: Surveilling, Predicting, and Controlling Epidemic Outbreaks" (Glenn Webb, Vanderbilt University), "Spatial Self-Organization and Its Implications for Ecosystem Robustness" (Corina Tarnita, Princeton University), and "Resilient and Sustainable Coasts: How Mathematics and Simulation Play a Role" (Clint Dawson, University of Texas). The meeting allowed us to experience firsthand how other scientists view mathematics and how we can communicate science.

The AAAS is the world's largest general scientific society. It fulfills its dual mission to "advance science and serve society" through many initiatives in science policy, education, and science communication. Thousands of scientists attend AAAS annual meetings, which feature prominent non-scientist speakers, such as this year's keynote presentation by former vice president Joe Biden. Many science journalists and writers from around the world frequent the meetings, which leads to wide media coverage.

"Mathematics" is Section A among a total of 24 AAAS sections — recognition of its integral and enabling role in the larger scientific enterprise. Despite this status, very few mathematicians regularly attend the meetings, and mathematics rarely features prominently in the program lineup.

We left Austin with the impression that mathematicians had missed another opportunity to engage with other scientists and the general public. We also witnessed other scientists' increased proficiency in communicating the importance and relevance of their research. Not interacting sufficiently with our peers and failing to regularly and skillfully share our work with a broader audience can only hurt our profession in the long run.

Why does our community not engage more actively with the world beyond our silo? Some of the reasons are apparent. We often find it difficult to determine the questions that drive projects in other disciplines, or see little opportunity for interesting mathematics in these projects, so we tend to stay within the comfort zone of our own discipline and its reward system. Our training compels us to emphasize correctness and generality over accessibility and illustrative examples. Additionally, mathematicians tend to use their own jargon. Many of us believe that our work is too complicated to explain in terms that might resonate with a general audience. Too often we communicate to address a few dozen peers, when in fact we could be reaching thousands. And unfortunately, those more extensive audiences almost expect such idiosyncrasies.

Effective communication should not be left to professional societies, and we as mathematicians can change our habits. The 2018 AAAS Annual Meeting featured many engaging presentations on a variety of topics, including "What Citizens Think About Science: Survey Data and Implications for Communicators," "Science for All: Using Social Media to Take Your Research Around the World," and "Advancing Artificial Intelligence: From the Lab to the Street." See the accompanying inset for additional examples.

Persuasive science communication is a major challenge, especially for our discipline, and requires a shift in our collective thinking. We must recognize that it is not enough to be heard by a gathering of peers; there are broader audiences worth reaching.

To get started, consider the following questions. Can you summarize the impact of your work in 200 words, or even a few tweets? Could you explain your in a 30-second elevator pitch to a dean or provost? Would you be able to get a three-minute video about your work produced and published? By venturing outside our silo, we learn how to strengthen our discipline's communication efforts and spread awareness of mathematics' relevance and value.

Noteworthy Sessions from the 2018 AAAS Annual Meeting

– In a session titled "Exploring Universal and Industrial Quantum Computing," speakers from Google, IBM Research, and Delft University of Technology presented different strategies to increase quantum computation's error resistance and broad availability, and develop new hardware approaches for this task.

– In a flash talk discussion session titled "Developing Robotics to Assist Humans," speakers employed videos and animations to generate a lively discussion about the technical and societal challenges that result from robotic advancement.

– In a plenary lecture titled "When Facts are Not Enough," Katharine Hayhoe, an atmospheric scientist at Texas Tech University, offered suggestions for connecting with climate skeptics, including bonding over a shared love of gardening or concern for national security.

Acknowledgments: The authors thank the American Mathematical Society and Section A (Mathematics) of the AAAS for supporting their participation in the 2018 AAAS Annual Meeting.

Hans Kaper, founding chair of the SIAM Activity Group on Mathematics of Planet Earth (SIAG/MPE) and editor-in-chief of SIAM News, is an adjunct professor of mathematics at Georgetown University. Hans Engler is a professor of mathematics at Georgetown University. He currently chairs SIAG/MPE.

Françoise Tisseur to Deliver Olga Taussky-Todd Lecture at ICIAM 2019

The International Council for Industrial and Applied Mathematics has selected Françoise Marie Louise Tisseur (University of Manchester) to deliver the Olga Taussky-Todd Lecture at the 2019 International Congress on Industrial and Applied Mathematics (ICIAM), to be held next summer in Valencia, Spain. The most important international event in applied and industrial mathematics, ICIAM is held once every four years under the sponsorship of the International Council for Industrial and Applied Mathematics.

Françoise Marie Louise Tisseur, University of Manchester.

Françoise is a numerical analyst specializing in numerical linear algebra. She has contributed real-world applications to the fields of theoretical analysis, perturbation theory, and numerical methods and software development.

Françoise is at the forefront of research on the theory and numerical solution of nonlinear eigenvalue problems, particularly polynomial eigenvalue problems. She has made major advancements in the analysis, perturbation theory, and numerical solution of these problems. Polynomial eigenvalue problems arise in a wide variety of science and engineering applications, such as dynamic analysis of mechanical systems, linear stability of flows in mechanics, and electronic band structure calculations for photonic crystals.

Françoise's work shows for the first time that from the point of view of numerical stability, the usual approach to solve these problems is very often not the best. She has made major contributions to a fundamental open problem in the field — the derivation of a method that works directly on polynomial eigenvalue problems. As an important step towards their solution, she developed a new class of transformations allowing one to treat the problems directly with numerical techniques.

Pervading much of Françoise's research is the theme of exploiting structure in matrix problems. She has devoted significant time to the creation of tools for analyzing structured problems, derivation of new or improved algorithms that exploit structure, and execution of error analysis to reveal the numerical properties of structure-exploiting algorithms for comparison and improvement.

Françoise recently adopted tropical algebras, a tool from pure mathematics. When combined with a valuation map in the tropical setting, roots of polynomials, eigenvalues and singular values of matrices, and matrix factorizations offer order-of-magnitude approximations to the corresponding objects in the usual algebra. Tropical algebra becomes a useful tool for numerical linear algebra because tropical analogues are usually cheaper to compute than those in conventional algebra. One can then use them in the design of preprocessing steps to improve the numerical behavior of algorithms, such as convergence and stability.

Françoise studied at the University of St.-Étienne in France, completing her Ph.D. in numerical analysis in 1997. Following a postdoctoral position at the University of Tennessee, she moved to the University of Manchester, where she is now a professor of numerical analysis and director of the Manchester Institute for Mathematical Sciences.

Françoise's work has garnered her many honors, including the 2010 Whitehead Prize of the London Mathematical Society, the 2012 Adams Prize of the University of Cambridge, and a Royal Society Wolfson Research Merit Award. She is also a SIAM Fellow.

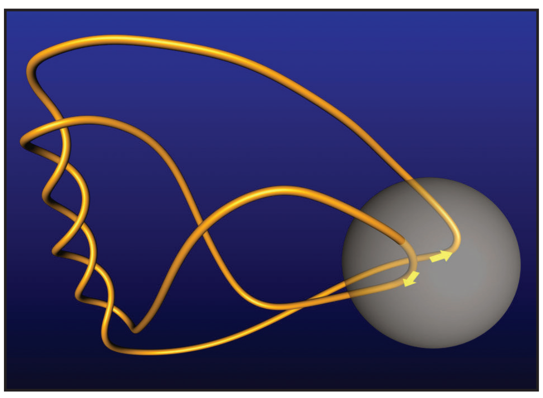
Inaugurated in 2007, the Olga Taussky-Todd Lecture is an invited lecture at ICIAM. This honor is conferred on a "woman who has made outstanding contributions in applied mathematics and/or scientific computation." The lecture is named for Olga Taussky-Todd, whose scientific legacy is in both theoretical and applied mathematics, and whose work exemplifies the aforementioned qualities.

Lecturers are selected by a committee established by the ICIAM President, with input from the Association for Women in Mathematics and European Women in Mathematics. Nominations are solicited from the mathematical sciences community. The Committee for the 2019 Lecture consisted of the following members: Barbara Lee Keyfitz (Chair, Ohio State University); Raymond Chan (Chinese University of Hong Kong); Sofia C. Ohlede (University College London, U.K.); Ruben D. Spies (Instituto de Matemática Aplicada del Litoral, Argentina); and Anna Karin Tornberg (KTH Royal Institute of Technology, Sweden).

Connections and Reconnections: A Link Between Mathematics, Physics, and DNA

The following is a short introduction to an invited lecture to be presented at the upcoming 2018 SIAM Annual Meeting (AN18) in Portland, Ore., from July 9-13.

Knots have appeared in art and architecture for centuries. Like many other areas of mathematics, the field of knot theory is rooted in questions related to the physical world. In 1833, Carl Friedrich Gauss reported on the magnitude of a magnetic field produced by a current traveling through a circular wire. He formulated the Gauss linking number while computing the magnetic field induced in a second loop interlinked with the first one but not carrying current. In the 1860s, Lord Kelvin postulated that matter is composed of "vortex atoms," some of which are knotted. This idea led Peter Guthrie Tait to first tabulate knots in 1867. Though Lord Kelvin's table of elements was incorrect, interest in knots continued — albeit with reduced enthusiasm. At the turn of the 20th century, notable mathematicians—including Max Dehn, Kurt Reidemeister, and James Waddell Alexander II—began a rigorous mathematical study of knots. For many decades, knot theory and low-dimensional topology epitomized the beauty and power of pure mathematics.

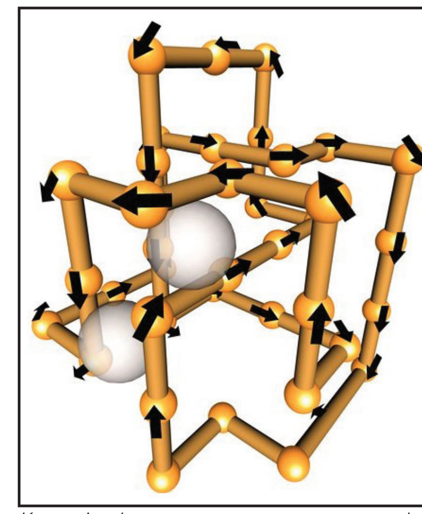


Mathematical representation of a DNA link using the tangle method of De Witt Sumners and Claus Ernst. We characterize the shortest unlinking pathways by local reconnection. Figure generated by Rob Scharein using KnotPlot software.

Mariel Vazquez, University of California, Davis.

Applications reemerged as the tools to study knots and their related spaces became more powerful, especially in regards to polynomial invariants by Vaughan F.R. Jones, Louis Kauffman, W.B. Raymond Lickorish, Kenneth Millett, Józef Przytycki, John Horton Conway, and others. Flexible circular chains often appear in nature, from microscopic DNA plasmids to macroscopic loops in solar corona. Such chains entrap rich geometrical and topological complexity that can offer insight into the processes underlying their formation or modification.

In the 1970s, molecular biologists encountered circular DNA molecules that adopted interesting geometrical and topological forms. Budding collaborations among mathematicians, physicists, chemists, and molecular biologists shaped DNA topology as an interdisciplinary field, with tools from mathematical and computational knot theory at its center. Although DNA knots and links are considered undesirable in the cellular environment, nontrivial topologies occur frequently. Enzymes use local cleavage and strand passage or local reconnection to simplify DNA topology. Examples include the action of type II topoisomerases and DNA recombinases. Physicists have observed local reconnection events of knotted vortices in fluid flow; their study reveals similar patterns of topology simplification as those observed after DNA recombination.



Knots in the computer are represented as polygons. We utilize Monte Carlo sampling in the cubic lattice to generate ensembles of conformations to be used as reconnection input. Figure generated by Reuben Brasher using KnotPlot software.

At the 2018 SIAM Annual Meeting, I will show how mathematicians use techniques from knot theory and low-dimensional topology—aided by computational tools—to identify minimal pathways of unlinking newly-replicated DNA molecules. Our results and numerical methods are not restricted to the biological example, and are applicable to any local reconnection process.

— Mariel Vazquez, University of California, Davis

SIAM at the 2018 USA Science & Engineering Festival

By Padmanabhan Seshaiyer

With a mission to promote awareness of mathematics and its applications, SIAM participated in the nation's largest celebration of science, technology, engineering, and mathematics at the USA Science & Engineering Festival,[1] held April 6-8 at the Walter E. Washington Convention Center in Washington, D.C. 29 volunteers from five SIAM student chapters came together to inspire thousands of students, teachers, and parents by presenting compelling and exciting educational activities that demonstrated the importance of mathematics and its real-world significance.

I had the pleasure of coordinating the event with officers from the George Mason University (GMU) Chapter of SIAM and other participating chapters, including North Carolina State University (NC State), University of North Carolina, University of Delaware, and George Washington University, with help from SIAM staff. During the course of the festival, SIAM booth attendees played a game of Shape Sudoku; tested their algebraic thinking skills with a balancing act activity; engaged in the paper-folding mathematics of origami; and learned about 3D-printed platonic solids, Archimedean duals, polyhedron building, and much more.

GMU student Ratna Khatri, student chair of the SIAM Festivals Working Group (FWG), reflected on the event. "As a female in STEM, I found the experience of working on the festival empowering," she said. "Seeing students from various SIAM chapters come together to run the booth under one umbrella was also powerful. The energy they brought made the booth a great success." Joey Hart of NC State—also a member of the FWG—spoke positively of his involvement as well. "Co-organizing the SIAM booth cultivated professional and organizational skills far beyond other experiences I have had organizing events as a graduate student," he said. "The greatest delight of the festival is seeing someone's facial expression during the "aha" moment when they connect the exhibit in front of them with the underlying mathematics."

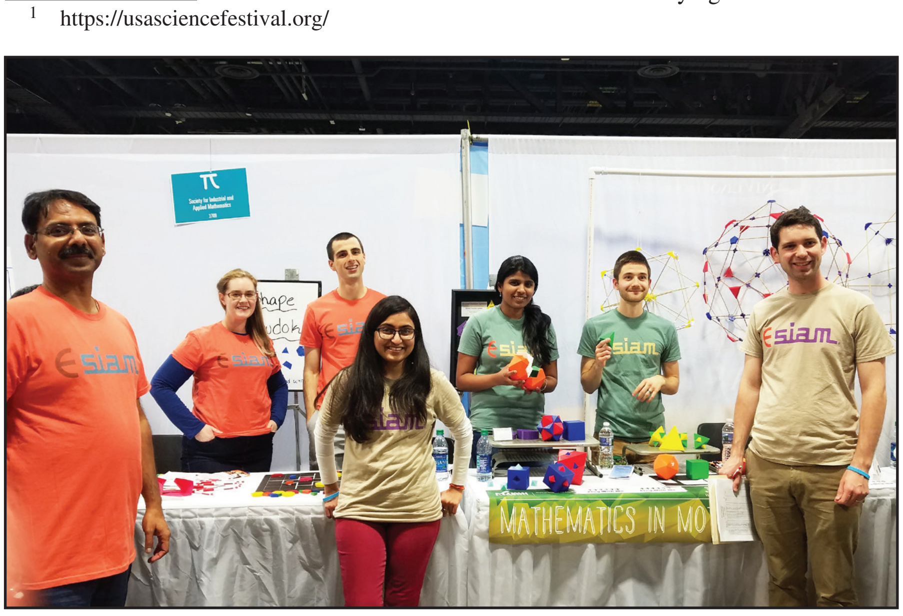
Always packed with excitement and energy, the SIAM booth attracted about a hundred attendees every hour through the entirety of the event. It served as a medium to celebrate the "M in STEM" through fun educational activities for a diverse audience of all ages, backgrounds, and mathematical expertise.

Padmanabhan Seshaiyer is a professor of mathematical sciences and the associate dean for the College of Science at George Mason University. He also serves as one of the USA Science and Engineering Festival's Nifty Fifty Speakers.[2] He is chair of the SIAM Diversity Advisory Committee.

[1] https://usasciencefestival.org/

[2] https://usasciencefestival.org/people/dr-padhu-seshaiyer/

At the USA Science & Engineering Festival, held in Washington, D.C., from April 6-8, children visiting the SIAM booth engage in various mathematical activities. Photo credit: Ratna Khatri.



Volunteers engaged attendees with a myriad of hands-on activities at the SIAM booth during the USA Science & Engineering Festival in Washington, D.C. From left to right: Padmanabhan Seshaiyer, Amy Tucker, Samuel Cogar, Ratna Khatri, Cigole Thomas, Nicholas Russell, and Joey Hart. Photo used with permission.

Attendees of the USA Science & Engineering Festival in Washington, D.C., play Shape Sudoku at the SIAM booth to learn about mathematics and its applications. Photo credit: Ratna Khatri.