Newsjournal of the Society for Industrial and Applied Mathematics

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siam news

Volume 55/ Issue 7
September 2022

SIAM Annual Meeting Issue

Check out prize photos and articles about invited presentations, panel discussions, and student experiences at the 2022 SIAM Annual Meeting.

Kristin Lauter of Meta AI Research delivered the I.E. Block Community Lecture at the 2022 SIAM Annual Meeting, which took place in Pittsburgh, Pa., this July. Her talk was entitled "Artificial Intelligence and Cryptography: Privacy and Security in the AI Era." The Block Community Lecture, which is meant to encourage public appreciation of the excitement and vitality of applied mathematics, was followed by a community reception for all attendees. SIAM photo.

A photo spread on page 8 recognizes major prize winners and SIAM Fellows from multiple classes who were honored at the 2022 SIAM Annual Meeting.

The Mathematical Machinery That Makes Cells Move

By Matthew R. Francis

A white blood cell slips through the gaps between other cells, stretching and bending as it goes. Though its movement strongly evokes that of a macroscopic creature—perhaps a rodent nosing its way through a maze—the cell is guided only by chemical signals and molecular forces. It has no need for a brain, not even the one in the human body that it shares.

Mathematical biologists have developed a number of models to understand self-organization both within and between cells. Leah Edelstein-Keshet of the University of British Columbia received SIAM's prestigious 2022 John von Neumann Prize[1] for her significant contributions to this field. Edelstein-Keshet has been a leader in mathematical biology research for several decades and also penned one of the earliest textbooks on the subject: *Mathematical Models in Biology* [1]. She delivered the associated prize lecture at the hybrid 2022 SIAM Annual Meeting[2] (AN22), which took place in Pittsburgh, Pa., this July.

[1] https://go.siam.org/Mjc1Nh
[2] https://www.siam.org/conferences/cm/conference/an22

"I started off by looking at the interesting patterns that cells make," Edelstein-Keshet said. "Fibroblasts try to align in parallel patterns, and the question was, how do they form these parallel arrays? We developed some mathematical language to deal with that. And it turns out that there are a lot of related problems of units that line up in parallel arrays."

Specifically, Edelstein-Keshet and her collaborators applied similar mathematical models to actin fibers within individual cells. Actin gives cells their structure and—in concert with the molecule myosin—helps control how they move and change shape. In other words, the key to cell motion and organization lies partly in the self-organization of such fibers.

Many cells do not have a distinct front or back when in a quiescent (inactive) state, but sometimes cells polarize and reorganize their actin fibers. As in the aforementioned white blood cell example, the "front" of the cell can switch places with the back or sides to let the cell find a path; therefore, the organization of actin for steering purposes depends on stimuli both inside and outside of the cell.

During her talk, Edelstein-Keshet recognized the work of forces that are similar

See **Mathematical Machinery** *on page 4*

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A Week of Information, Inspiration, and Books: AN22 From a Student's Perspective

By Jenny Power

One's first international conference can be a daunting experience. The usual conference worries about being over- or underdressed, making a good impression, or asking a stupid question are accompanied by additional concerns about cultural differences. What if my humor doesn't translate, people struggle to understand my accent, or I get lost in an unfamiliar city? These were some of the thoughts that plagued my mind in the months leading up to the 2022 SIAM Annual Meeting,[1] which took place in July in Pittsburgh, Pa., in conjunction with the SIAM Conference on Applied Mathematics Education[2] (ED22), SIAM Conference on the Life Sciences,[3] and SIAM Conference on Mathematics of Planet Earth.[4] I was attending as the student chapter representative for the University of Bath SIAM Student Chapter in the U.K.

[1] https://www.siam.org/conferences/cm/conference/an22
[2] https://www.siam.org/conferences/cm/conference/ed22
[3] https://www.siam.org/conferences/cm/conference/ls22
[4] https://www.siam.org/conferences/cm/conference/mpe22

Nevertheless, I felt nothing but excitement during the eight-hour plane ride from London to Pittsburgh. I perused the conference program, studied the abstracts of the different sessions, highlighted the ones that I found most interesting, and drew up my itinerary. As my bus pulled into downtown Pittsburgh, I was pleasantly surprised by the city's beauty. I was expecting a city of steel and was thus taken aback by the array of colors; with yellow bridges, painted streets, and the green of Mount Washington, the city was a rainbow.

The conference commenced on Sunday evening with an orientation for students—part of the "Student Days" activities for student attendees—and a general Welcome Reception. I nervously set off from my hotel towards the looming David L. Lawrence Convention Center. Upon arriving at the orientation event, I received a pair of SIAM sunglasses and was instructed to turn around as a sticky note was placed on my back. This was part of an icebreaker activity wherein we were all given different mathematical words and had to ask the other students "yes" or "no" questions to identify our own terms (I was a derivative). After the icebreaker, we formed groups and completed a SIAM quiz; the winners received SIAM t-shirts and socks, though unfortunately my team did not win a prize. The evening concluded with food and drinks at the Welcome Reception, where I spent the evening chatting with some lovely people. My nerves had settled and I was excited for the week ahead.

Monday brought some of my favorite sessions of the conference. I primarily attended the ED22 plenaries, which were several of the most engaging and inspiring talks that I've experienced in my professional career. Discussions ranged from the incorporation of math modeling in the classroom via project-based learning to student pathways for graduate programs and even the development of "STEM centers" for children. I walked away from these sessions with a reignited determination to increase my involvement in mathematics communication and outreach when I returned home.

Later that evening, an industry panel—entitled "Shedding Light on Opportunities for Mathematicians in Business, Industry, and Government Careers"—yielded interesting insights for anyone who might wish to pursue a career outside of academia.[5] The discussion featured six panelists: Sharon Arroyo (The Boeing Company), Marisabel Rodriguez Messan (U.S. Food and Drug Administration), Helen Moore (University of Florida), Ian Price (UPMC Health Plan), Juliana Richardson (MITRE Corporation), and Pablo Seleson (Oak Ridge National Laboratory). They shared their experiences in industry versus academia, explored some of the pros and cons of each direction, and offered very insightful advice to students who are considering their next steps — I even got to ask a question. The panel was followed by a Graduate Student Reception and Industry Reception, which allowed for further networking and socializing.

See **Student's Perspective** *on page 3*

[5] An article on page 7 outlines the key takeaways from this panel.

Attendees of the Student Chapter Breakfast at the 2022 SIAM Annual Meeting, which took place in July in Pittsburgh, Pa., gather for a group photo. SIAM student chapter representatives networked and shared ideas with each other as well as SIAM staff and leadership. SIAM photo.

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Mentoring the Missing Millions

By David Goldberg and Padmanabhan Seshaiyer

The National Science Board's (NSB) January 2022 biennial report[1] on "The State of U.S. Science and Engineering" identified the need to increase representation from the "missing millions"[2] in order to strengthen the nation's research enterprise [1, 2]. To do so, the NSB estimates that the science, technology, engineering, and mathematics (STEM) workforce must undergo the following necessary changes: the number of women must nearly double, Hispanic and Latino individuals must triple, Black and African American individuals must more than double, and individuals of Native American and Alaska Native descent must quadruple [3]. Here we argue that *mentorship* is the key to increasing diversity and reducing the significant talent gap in all STEM areas.

One of the main draws of the scientific enterprise is the opportunity to meaningfully contribute to the breadth of human knowledge within a given discipline. The fact that such a large portion of research occurs in academic settings indicates that the process of teaching and training new scientists is an important component of scientific advancement. Many of us seek to institutionalize our own contributions by guiding students through the process of becoming researchers and/or instructors. The importance of mentorship is widely recognized; for instance, award recipients nearly always acknowledge the valuable influence of several mentors.

When we mentor the next generation, we are often drawn to students who remind us of ourselves. However, we should also recognize that we are mentoring *all the time* — whether we know it or not. As such, we must be intentional about offering adequate advice and direction to everyone. To harness society's full potential, we need to purposefully reach out to students from backgrounds that are different than our own, offer encouragement, and expose them to the vast array of opportunities for graduate study and employment. When programs and faculty undertake such deliberate mentoring, they more effectively mentor *all* students, not just women and underrepresented minorities.

A good mentor supports students in their personal interests and passions. Doing so can be challenging for researchers who must then connect student enthusiasms to their own fields of expertise. Students often want to solve problems that impact their communities, so mentors should be prepared to help them navigate the connections between such real-world challenges and mathematical thinking[3] [5].

When the COVID-19 pandemic disrupted well-established structures around in-person mentoring, many individuals took advantage of virtual mentorship. Several research and internship programs pivoted online and successfully mentored students at all levels. For instance, the National Science Foundation (NSF) invited proposals for rapid response research grants to better understand COVID-19, which provided further opportunities for faculty to engage in mentored projects with students [4, 6].

Now we will discuss the Math Alliance:[4] a successful mentorship program that continues to serve as a national model. The Math Alliance evolved from an NSF-funded project called *The Alliance for the Production of African American Ph.D.s in the Mathematical Sciences*.[5] It comprises a community of student participants (known as Math Alliance Scholars) and faculty mentors[6] who believe that any student with the talent, desire, and ability to earn a doctorate in a mathematical, statistical, or quantitative science should have the chance to do so. The community has continued to grow organically since its inception in 2006 (see Figure 1).

One key to the Math Alliance's success is that every scholar must be nominated by a mentor. One former NSB member remarked that the Math Alliance has institutionalized, within itself, the scaffolding that moves students from where they are to where they can achieve their potential. We continue to build this scaffolding even as our Math Alliance Scholars climb it, and thus constantly try to stabilize the infrastructure. Figure 2 charts the increasing number of Math Alliance Predoctoral Scholars—participants who became part of our community before entering a doctoral program—that have earned Ph.D.s each year, and Figure 3 (on page 5) provides a breakdown of the positions that Predoctoral Scholars have obtained after completing their degrees. The program has led to more than 220 Ph.D.s to date, while 175 Math Alliance Predoctoral Scholars

See **Missing Millions** *on page 5*

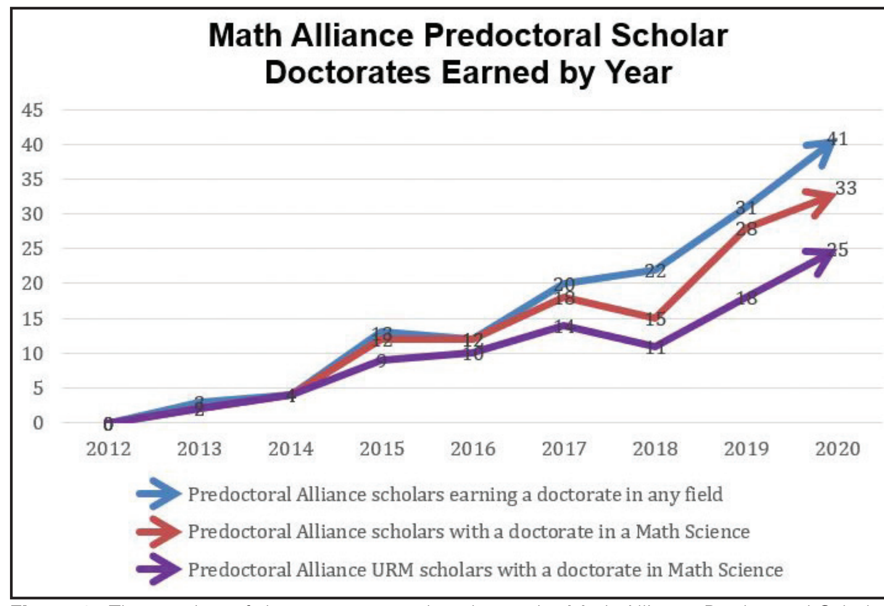

Figure 2. *The number of doctorates earned each year by Math Alliance Predoctoral Scholars. Figure courtesy of David Goldberg.*

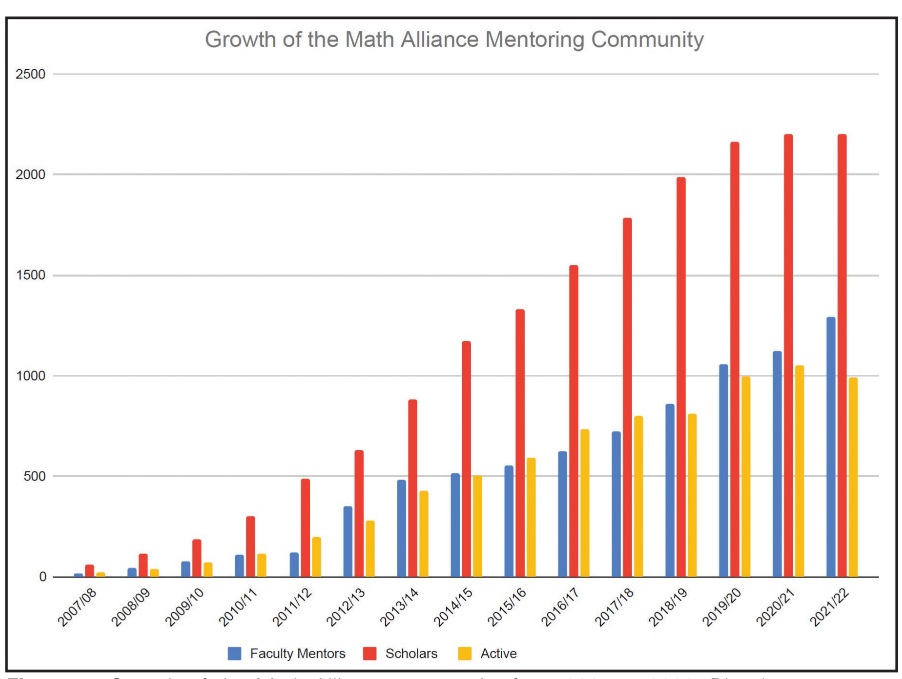

Figure 1. *Growth of the Math Alliance community from 2007 to 2022. Blue bars represent faculty members, red bars represent the cumulative total of Math Alliance Scholars, and yellow bars represent active participants. Figure courtesy of David Goldberg.*

1 https://ncses.nsf.gov/pubs/nsb20221
2 https://www.rti.org/publication/missing-millions/fulltext.pdf
3 https://sinews.siam.org/Details-Page/preparing-future-generations-to-address-global-pandemics-with-innovative-mathematical-thinking
4 https://mathalliance.org
5 https://www.nsf.gov/awardsearch/showAward?AWD_ID=0502354
6 https://mathalliance.org/become-an-alliance-predoctoral-mentor

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A Comprehensive Exploration of the Path to Modern Computing

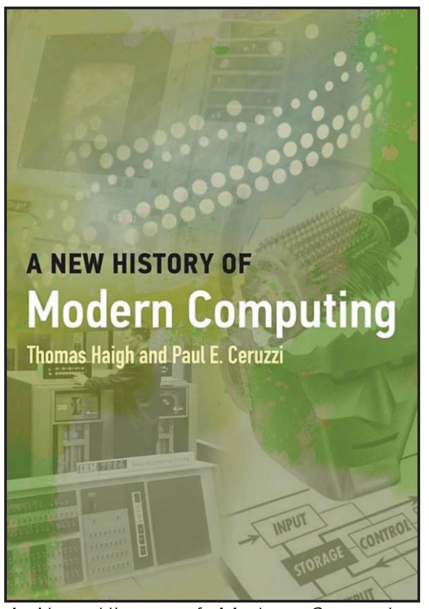
BOOK REVIEW
By Paul Messina

A New History of Modern Computing. *By Thomas Haigh and Paul E. Ceruzzi. MIT Press, Cambridge, MA, September 2021. 544 pages, $40.00.*

The 2021 major update to Paul Ceruzzi's *A History of Modern Computing*—originally published by MIT Press in 1998 and expanded upon in 2003—provides a comprehensive description of almost every facet of computing. In *A New History of Modern Computing*, Ceruzzi and Thomas Haigh use an approachable and engaging narrative style with in-line definitions of words and concepts in layman's terms. The book is a captivating and enjoyable read, though 41 pages of notes and a 28-page bibliography certainly make it a scholarly tome.

The account begins with the commencement of ENIAC's (Electronic Numerical Integrator and Computer) operation at the University of Pennsylvania in 1945, though there are occasional references to previous developments. The authors chose ENIAC as the starting point because it is typically considered the "first electronic, general purpose, programmable computer;" they base their definition of "computer" upon these three attributes. Although the text focuses on computing practices and technology rather than research, it does amply describe numerous research results.

One feature that stands out is Haigh and Ceruzzi's inclusion of the etymology for words like "subroutine," "assembler," "stored program," and "operating system." For instance, the term "memory" for a device that stores information originated from John von Neumann's use of biological language to describe computer systems. He broke the structure into "organs" and referred to switching circuits as "neurons." "Memory" is the only biological term that stuck. The authors take care to identify the origins of technologies, protocols, and products that were based on concepts or prototypes from previous decades. An extreme instance of a vision of future capabilities is Vannevar Bush's 1945 article in *The Atlantic* that predicted (to some extent) many technologies that were ultimately invented long after its publication, including hypertext, personal computers, the Internet, speech recognition, and online encyclopedias such as Wikipedia [1]. Bush's vision in the article is awe-inspiring.



A New History of Modern Computing. By Thomas Haigh and Paul E. Ceruzzi. Courtesy of MIT Press.

Given my background in the field of computing, I was pleasantly surprised to learn new facts when reading *A New History of Modern Computing*. For instance, I discovered that small- and medium-scale computers sold more than a thousand units in the 1950s; small-scale computers cost as little as $30,000, while large-scale units ranged from $500,000 to $1,000,000.

I was also fascinated to learn that France deployed an experimental packet-switched network called Cyclades in 1974 that routed packets through host computers — an approach that the Internet later adopted. In the early 1980s, France Télécom developed Minitel: one of the first implementations of an end-user information system. Cheap Minitel terminals—which had small monochrome screens and a keyboard—connected over telephone lines and were widely adopted, with nearly 6.5 million units in use by 1993. The text explains that "[d]uring the late 1980s, more French people were using online services for banking, shopping, news, and email than the rest of the world put together."

In the 1950s, the Semi-Automatic Ground Environment (SAGE) network for air defense against Soviet bomber aircraft emerged. It employed computers to process information from radar, ships, aircraft, telephone links, and radio. According to the authors, "SAGE introduced more fundamentally new features to computing than any other project of its era, including networking computers and sensors and the development of interactive computer graphics." In other words, it pioneered what is now called edge computing; ironically, a National Science Foundation-funded project about edge computing is also called SAGE: Cyberinfrastructure for AI at the Edge.[1]

Towards the beginning of the text, Haigh and Ceruzzi state that "[t]he history of computing is the story of repeated redefinitions of the nature of the computer itself, as it opened new markets, new applications, and new places in the social order." Since advances in technologies and applications often result from the evolution of several factors, the authors made the interesting and effective choice to present the book's 14 chapters based on topic rather than in global chronological order; every chapter then contains its own chronology according to types of computers and their uses. Consequently, each chapter's chronology overlaps with that of several others. The authors frequently note the dependence of new capabilities or computer uses on prior advances. For example, they expand upon the theme of graphical tools with references to video games and interactivity.

Chapter one, "Inventing the Computer," carefully dissects the features of the so-called von Neumann architecture (or stored program architecture) versus the ones created by J. Presper Eckert, John Mauchly, and the team that designed the ENIAC and EDVAC (Electronic Discrete Variable Automatic Computer). The text clearly

See **Modern Computing** *on page 6*

[1] https://sagecontinuum.org

Student's Perspective

Continued from page 1

On Tuesday morning, the student chapter representatives attended a breakfast meeting with SIAM staff and leadership. This event granted students the opportunity to network with each other and SIAM leadership through both general discussion and an icebreaker activity. Conversation then moved to more SIAM-specific topics. We talked about our respective student chapters, shared some examples of chapter activities from the past year, and brainstormed ideas for the future. As the incoming president of the University of Bath SIAM Student Chapter, I found this event incredibly helpful and came away with a variety of ideas that I hope to implement.

Jenny Power of the University of Bath poses with her books from the student book giveaway at the 2022 SIAM Annual Meeting, which took place in July in Pittsburgh, Pa. The event allowed student attendees the opportunity to select free textbooks on a multitude of topics. Photo courtesy of Jenny Power.

My table also held a very thought-provoking discussion about COVID-19's effect on student chapters. It was comforting to know that my chapter isn't the only one struggling with participant enthusiasm during the pandemic, and we brainstormed ways to improve engagement in the forthcoming academic year. After this breakfast, I felt extremely lucky to be part of such a wonderful community of students with a love for applied math. I hope that our interactions will eventually lead to increased collaboration between student chapters — perhaps even internationally.

Thursday brought one of my favorite moments of the week: the student book giveaway. Rumors of what this session could possibly entail had been circling amongst the students during lunch, with the general consensus being some type of raffle. 15 minutes before the event, I observed SIAM staff members set up two large tables in the center of the foyer and place brand-new textbooks all over the tables, resulting in a chaotic collage of books. A large group of students watched as the mountain of textbooks grew increasingly larger; representatives from Springer and the American Mathematical Society even contributed to the pile.

Once setup was complete, we formed two single-file lines facing the table and received our instructions. The rules were simple: we were to approach the table two by two, at which point we would have 30 seconds to choose a book before returning to the back of the line. This process would continue until all of the books were gone. I quickly started doing some mental math; with approximately 30 participating students and over 200 textbooks, we were each going to walk away with a significant haul.

My first round was somewhat disastrous and perhaps the fastest 30 seconds I have ever experienced. I frantically walked around the tables, attempting to spot topics that I recognized and found compelling. With two seconds left, I picked up a random book and went to the back of the line. The text in my hand was about Bayesian analysis — an important topic, but well outside the scope of my research and interests. I realized that I had to be more strategic in subsequent rounds; if I found a book that I liked, I needed to stick with it.

The next few rounds went quite well for me, and I picked up some titles that piqued my interest (and even managed to swap the Bayesian analysis book with another student). Our time decreased to only 15 seconds as the rounds continued, which led to even more gleeful panic. In the last free-for-all round, we were allowed to approach the table and *calmly* take whatever we liked until everything was gone. Ultimately, I walked away with a whopping nine textbooks on topics like finite elements, optimization, and partial differential equations.

Overall, my first international conference—and second-ever SIAM conference—was a resounding success and an invaluable experience. I met many wonderful people with whom I look forward to connecting at future SIAM conferences. I truly believe that some of the connections I made with other Ph.D. students throughout the week will lead to fruitful collaborations, both in research and SIAM-based activities.

I would strongly encourage all students to broaden their horizons by attending conferences, SIAM and otherwise. Several other Ph.D. students at AN22 were surprised that I was going to meetings so early in my academic career (I'm a first-year Ph.D. candidate), noting that they did not do so until much later. To this I say, why wait? In Pittsburgh, I realized that conferences offer so much more than opportunities to present one's own work. They provide the space for students to meet individuals in their fields, experience cutting-edge research firsthand, and learn from other participants' presentations — not only from a content perspective, but also in terms of *how* people display and communicate their research. One can also visualize the types of presentation styles that work (and don't work), and adapt their own performances accordingly. But even if students feel that their research isn't ready to be shared, I would still recommend that they attend these events. Who knows — you might just learn about a new method that is the key to solving your problem.

After an unforgettable week, I returned to the U.K. full of inspiration and ideas — and with a suitcase that was nine textbooks heavier than before.

Jenny Power received funding to attend AN22 as the student chapter representative for the University of Bath. Every student chapter is eligible for funding to send a chapter representative to the SIAM Annual Meeting. Please contact Maggie Hohenadel, the SIAM Student Chapter and Fellows Coordinator, at ***hohenadel@siam.org*** *with any questions about student chapters, including the prospect of starting one at your own university.*

SIAM also offers Student Travel Awards to offset the cost of attending and presenting at a SIAM conference. To learn more about Student Travel Awards and submit an application, visit the online page.[6]

Jenny Power is a first-year Ph.D. student at the University of Bath in the U.K. She received her Bachelor of Science in mathematics and physics from the University of Limerick in Ireland. Power's work focuses on radiotherapy modeling via partial differential equation constrained optimization, and she is passionate about applied mathematics and science communication. You can find her on Instagram at @thejennypowerhour, where she posts mathematics content and chronicles her experiences as a Ph.D. student.

[6] https://www.siam.org/conferences/conference-support/siam-student-travel-awards

Mathematical Machinery

Continued from page 1

to those that govern pattern formation on larger scales — a concept that was first described mathematically by Alan Turing. "But it has a certain twist to it," she said. "These proteins can interact with each other. And they can diffuse both *along* the membrane of the cell and *inside* the fluid part of the cell. It turned out [to be] a very intriguing new phenomenon."

Edelstein-Keshet and her collaborators called this phenomenon "wave-pinning," as the one-dimensional (1D) mathematical solutions describe a wave that is confined to a single part of the cell, rather than one that propagates across the entire cell. The model offers a simple explanation of the way in which certain influences could cause high molecular activity at one end of the cell—leading to movement in that direction, for example—and little to no activity at the other end.

To Be a Cell in Motion, All You Need is Some PDEs

The reaction-diffusion equations, which might look familiar from other applications in biochemistry, form the basis for the 1D wave-pinning model [2]. To describe polarization in a single protein type, the concentrations of active u and inactive v proteins are each assigned their own reaction-diffusion equation

$$\epsilon\frac{\partial u}{\partial t}=\epsilon^2\frac{\partial^2 u}{\partial x^2}+f(u,v)$$

$$\epsilon\frac{\partial v}{\partial t}=D\frac{\partial^2 v}{\partial x^2}-f(u,v)$$

in dimensionless form, where

$$\epsilon^2=\frac{D_u}{\eta L^2},\quad D=\frac{D_v}{\eta L^2}.$$

Here, D_u and D_v are the respective rates of diffusion for the active and inactive proteins, η is the reaction rate, and L is the cell diameter. The nonlinear coupling term $f(u,v)$ is the difference between the activation and inactivation rates

$$f(u,v)=\left(\delta+\frac{\gamma u^2}{1+u^2}\right)v-u,$$

with positive constants δ and γ.

For simplicity, Edelstein-Keshet and her colleagues set Neumann boundary conditions with the cell membrane and the cytosol occupying all of the points in $0<x<1$. The lack of flux of the protein into or out of the cell conserves the total amount K:

$$\int_0^1 (u+v)\,dx=K=\text{constant}.$$

Finally, the group made the reasonable assumption that the diffusion rate for the membrane-bound active protein is much lower than that of the inactive one: $D_u \ll D_v$.

Despite its simplicity, the mathematical model also describes a mechanism—governed by parameter ϵ—through which cells can switch polarization on and off. This parameter depends on the small diffusion rate of the active protein and is inversely proportional to the cell diameter, meaning that ϵ itself is a small number. By examining the model's behavior over a range of total protein concentrations and ϵ values, the researchers generated a bifurcation diagram in which a certain range of values leads to polarization and wave-pinning. Beyond those values—i.e., at a very large diffusion rate, small cell size, or protein concentrations that are too large or small—the cell never polarizes (see Figure 1). "These are actual biological or physical properties of cells that affect whether or not they can polarize," Edelstein-Keshet said. "And that's in the *simplest* caricature of polarization."

To move beyond that caricature, Edelstein-Keshet and her collaborators examined far more complex models. They considered a wide range of generalizations for the minimal model by allowing for the influence of other components, including multiple interacting protein species; permitting the cell to dynamically change shape; and creating two-dimensional models with and without these additional factors. Many of these generalizations were too complicated for even an indirect analytical approach and necessitated purely computational treatment [3].

"We simulated the model over and over again and extracted a summary of what we saw," Edelstein-Keshet said. Yet clear bifurcations still emerged, even in this instance. "When you tweak certain parameters in the system, you get cells that either polarize, do nothing, exhibit some kind of oscillatory behavior, have a wave that travels through them, and so forth" (see Figure 2).

Multiscale Mathematics

These models are certainly fascinating from a mathematical standpoint, but Edelstein-Keshet also collaborates with experimental biologists to test specific predictions and assumptions. One of the biggest challenges in biological self-organization is understanding wound healing. "The details in one case were worked out experimentally," she said. "You've got a cell sheet that grows and seals this open gap."

A theoretical treatment, however, requires examining not just individual cells' movements—for example, the means through which white blood cells find their way to the right spots—but also collective cell organizational efforts to seal the wound. Such a model must consider several scales at once, which might involve different mathematical toolkits. "We could code that into a multiscale simulation that showed under what conditions you get pieces to fragment or form fingers [to close wounds]," Edelstein-Keshet said.

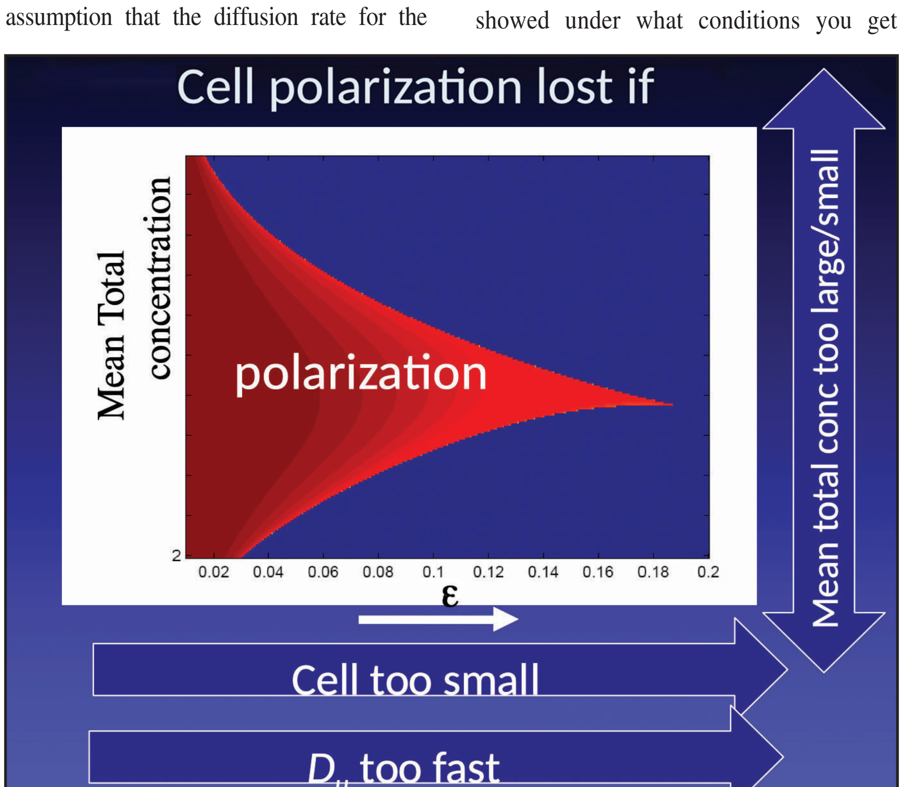


Figure 1. *A bifurcation diagram for the one-dimensional cell model that shows the effects of varying total protein concentration K and parameter ϵ, the latter of which depends on cell size and diffusion rate of the active protein. Active protein polarization turns "on" or "off" depending on these factors. Figure courtesy of Alexandra Jilkine and Leah Edelstein-Keshet.*

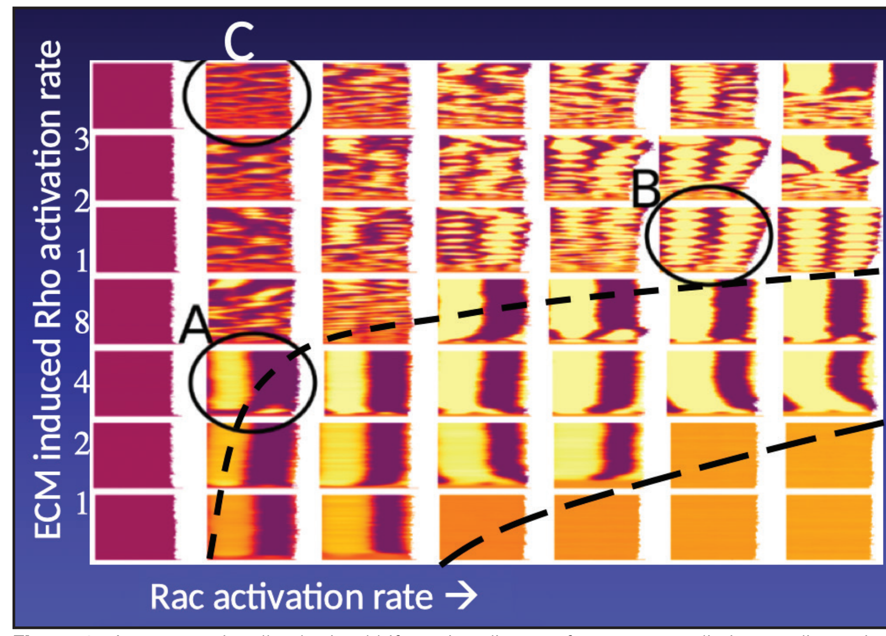


Figure 2. *A computationally obtained bifurcation diagram for a more realistic two-dimensional system wherein the parameters are two protein activation rates. The computer model identified two bifurcation curves that separate regions where the cell exhibits spiral waves, oscillations, and other behaviors. Figure courtesy of Elisabeth Rens and Leah Edelstein-Keshet.*

Multiscale simulations are still relatively new and have only come into their own within the last decade or so. Yet despite their novelty, they have already found a range of important applications. Along with wound healing, multiscale simulations have the potential to effectively model cancers and other disorders that involve chemical signals, individual cells, tissues, and entire organs. During her AN22 lecture, Edelstein-Keshet presented state-of-the-art models that allow researchers to identify emergent behaviors from smaller-scale phenomena.

Since cellular self-organization was Edelstein-Keshet's initial entry into this field of study, it seems fitting that she return to the topic now that computers are finally powerful enough to advance her research. "I've had a lot of fun working on all of these problems," she said. "In particular, I've had a great deal of good fortune in having wonderful people to work with. This area has many fascinating opportunities for applied mathematicians to do things that are both interesting and hopefully scientifically useful."

References

[1] Edelstein-Keshet, L. (2005). *Mathematical models in biology*. In *Classics in applied mathematics*. Philadelphia, PA: Society for Industrial and Applied Mathematics.

[2] Mori, Y., Jilkine, A., & Edelstein-Keshet, L. (2011). Asymptotic and bifurcation analysis of wave-pinning in a reaction-diffusion model for cell polarization. *SIAM J. Applied Math., 71*(4), 1401-1427.

[3] Rens, E.G., & Edelstein-Keshet, L. (2021). Cellular tango: How extracellular matrix adhesion choreographs Rac-Rho signaling and cell movement. *Phys. Biol., 18*(6), 066005.

Matthew R. Francis is a physicist, science writer, public speaker, educator, and frequent wearer of jaunty hats. His website is BowlerHatScience.org.

Missing Millions

Continued from page 2

and 59 "doctoral only" scholars have earned doctorates — the overwhelming majority of which were in the quantitative sciences.

Several key Math Alliance programs evolved as our community steadily grew. The **Facilitated Graduate Applications Process**[7] **(F-GAP)** provides undergraduate seniors and terminal master's students with the advice and assistance to successfully apply to and thrive in graduate programs. William Vélez (University of Arizona)—who was on Math Alliance's Executive Council until 2020 and continues to serve as the Associate Director for Undergraduate Programs—spearheaded this initiative. A year and a half before receiving their undergraduate or master's degrees, students are paired with Math Alliance Doctoral Mentors who help them select the disciplines they wish to pursue in graduate school, assist with their application materials, and discuss the programs to which they should apply. Math Alliance staff then track these applications and ensure that Math Alliance Mentors at the programs/institutions in question are aware of them.

The annual **Field of Dreams Conference**[8] unites roughly 200 Math Alliance Predoctoral Scholars in the quantitative sciences; approximately 80 to 90 percent of these scholars are members of minority groups that are traditionally underrepresented in STEM fields. About half of these students are participants in the F-GAP program. Other conference attendees include doctoral students; Math Alliance Mentors; Math Alliance staff; faculty members who are not (yet) mentors; and representatives of funding agencies, NSF-funded Mathematical Sciences Institutes,[9] professional organizations, industry, and government. In 2020 and 2021, the conferences convened virtually due to the COVID-19 pandemic. The virtual format allowed for many more participants than in previous years, with over 500 people attending each event. The Field of Dreams Conference will return to an in-person format in 2022 and is scheduled to take place from November 4-6 in Minneapolis, Minn.

Graduate Program Groups[10] **(GPGs)** consist of a significant assembly of faculty in a quantitative sciences graduate program who have agreed to provide a welcoming and nurturing environment for students. The Math Alliance certifies these groups based on proposals that include explicit mentoring plans. There are currently 42 Doctoral Program Groups and 12 Master's Program Groups, the latter of which comprise terminal master's programs with a demonstrated, successful track to a doctorate. GPGs provide Math Alliance Scholars with consistent mentoring throughout their pursuit of graduate degrees.

Initially, we thought that Math Alliance programs would essentially conclude when participating students earned their doctorates. However, we are learning that Math Alliance Scholars can benefit from our community's continued support throughout their careers. We must ensure that scholars who pursue academic professions receive adequate mentoring in regard to research funding, grants and fellowships, tenure and promotion processes, and other cultural aspects. We have discussed the formation of a program to provide this type of support and expect that it will include several F-GAP features, as we aim to ensure that upcoming doctoral graduates are paired with mentors who will complement the advice of their thesis advisors. Students who are interested in nonacademic positions will connect with mentors in industry who can help them chart a career path.

Serving as a mentor is a rewarding experience that is pivotal for the success of every student's academic journey and intellectual growth. Through effective mentorship, we can build a living and learning community of student scholars in STEM and create a systemic change to reach the missing millions.

[7] https://mathalliance.org/fgap-information-for-students
[8] https://mathalliance.org/field-of-dreams-conference
[9] https://mathinstitutes.org
[10] https://mathalliance.org/math-alliance-mentors/alliance-doctoral-mentors/alliance-departmental-graduate-program-groups-gpg

References

[1] Blatecky, A., Clarke, D., Cutcher-Gershenfeld, J., Dent, D., Hipp, R., Hunsinger, A., … Michael, L. (2021). *The missing millions: Democratizing computation and data to bridge digital divides and increase access to science for under-represented communities*. Alexandria, VA: National Science Foundation.

[2] Burke, A., Okrent, A., & Hale, K. (2022). *The state of U.S. science and engineering 2022*. Alexandria, VA: National Science Board.

[3] National Science Board. (2022). *The U.S. is a keystone of global science and engineering* (Report #: NSB-2022-2). Alexandria, VA: National Science Board.

[4] Ohajunwa, C., Kumar, K., & Seshaiyer, P. (2020). Mathematical modeling, analysis, and simulation of the COVID-19 pandemic with explicit and implicit behavioral changes. *Comput. Math. Biophys.*, *8*(1), 216-232.

[5] Seshaiyer, P. (2022, March 1). Preparing future generations to address global pandemics with innovative mathematical thinking. *SIAM News*, *55*(2), p. 2.

[6] Wang, W., & Seshaiyer, P. (2021). Engaging students in applied mathematics education and research for global problem solving. In R. Buckmire & J.M. Libertini (Eds.), *Improving applied mathematics education* (pp. 27-49). Cham, Switzerland: Springer.

David Goldberg is a professor of mathematics at Purdue University and has served as executive director of the Math Alliance since 2016. He works in the broad area of the Langlands program and focuses on the confluence of number theory and representations of p-adic groups. Padmanabhan Seshaiyer is a professor of mathematical sciences at George Mason University and chair of the SIAM Diversity Advisory Committee. He works in the broad area of computational mathematics, data science, biomechanics, design and systems thinking, and STEM education. Seshaiyer also serves as vice chair of the U.S. National Academies Commission on Mathematics Instruction and as Associate Director for Applied Mathematics of the Math Alliance.

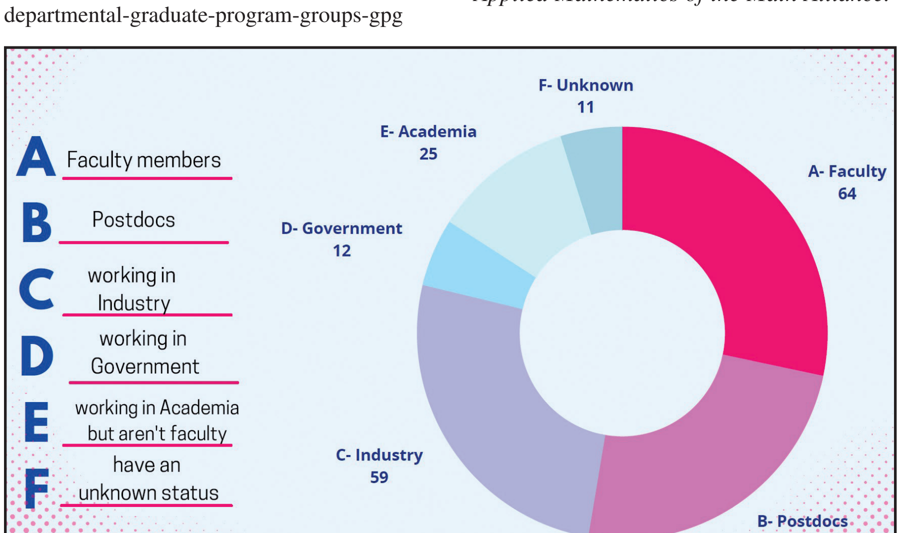


Figure 3. *Outcomes of the Math Alliance mentoring program as of March 2022, in terms of the employment breakdown of Math Alliance Predoctoral Scholars who earned their Ph.D.s. Figure courtesy of David Goldberg.*

Modern Computing

Continued from page 3

documents the impact of the EDVAC and the IAS family of computers. I was previously unaware that the IAS family included 18 hand-built computers and 29 production line models from the U.S., Sweden, Israel, Australia, Japan, and Denmark [2].

Chapter one also notes that Eckert and Mauchly's UNIVAC (Universal Automatic Computer) turned a scientific instrument into a commercial business tool that quickly saw many non-scientific applications, such as linear programming, prediction of the 1952 election results, payroll, and logistics. General Electric (GE) purchased the first UNIVAC model in 1954 for tasks that were previously handled by punch card machines and stated that speed of computing was only of tertiary importance. This sentiment was unsurprising given that input/output was a bottleneck for the UNIVAC, which initially printed output via a 10-character-per-second typewriter. But even in the 1950s, GE sought to use computers for advanced tasks like long-range planning, logistics for inventory management and shipping, and market forecasting based on demographic data. Product design applications soon followed.

Despite chapter two's title of "The Computer Becomes a Scientific Supertool," it only covers supercomputer systems through the Cray-1 — which was superseded by the Cray X-MP in 1982. The end of the chapter abandons the topic of supercomputers with the sentiment that "[b]y then, scientific computer users were switching to interactive operating systems and the new modes of computing." As a result, *A New History of Modern Computing* merely addresses the first three decades of scientific supercomputing. I found this constraint disappointing as a reader and would have liked to have seen as detailed a history of supercomputing as there is of computer gaming.

On a positive note, the authors frequently credit supercomputers with being the first machines to develop or require architectural advances that were eventually incorporated into mainframes, minicomputers, and even smartphones. Yet there is almost no coverage of parallel computer architectures and programming issues, even though all high-performance computing (HPC) systems have such architectures and several large parallel computers existed as early as the 1970s and 80s. Chapter 13—"The Computer Becomes a Network"—does mention Oak Ridge National Laboratory's Titan and Summit systems, their highly parallel architectures, and their IBM PowerPC processors and NVIDIA graphics processing units (which themselves have high parallelism). However, the book neglects to acknowledge the challenges of utilizing such systems or producing relevant algorithms and software.

Moving on, chapter 10—"The PC Becomes a Minicomputer"—includes a fascinating history about the effect of personal computer (PC) case standard and software availability on the evolution of processors and motherboards. It also discusses the use of scientific computer architecture features in microprocessors. The digital camera section in chapter 11, "The Computer Becomes a Universal Media Device," offers a nice overview of hardware for images and architectural tradeoffs. Equally interesting are the descriptions of digital media, storage technologies, and the transition to digital music. This chapter also features ample detail on games, game hardware, and game development companies.

Chapter 12, "The Computer Becomes a Publishing Platform," includes insightful explanations of the successes and failures of certain technologies or products. For example, Tim Berners-Lee and Robert Cailliau developed three unassuming yet effective standards that defined the web: the URL, HTTP, and HTML. All three standards were based on existing technologies and provide a compelling example of the value of design simplicity. Finally, the closing sentence of chapter 13 neatly summarizes the section's title: "The Computer Becomes a Network." By 2020, the advent of online applications and cloud storage meant that "[t]he PC has become a network computer and the network has finally become the computer."

Two topics that I believe would have added value to *A New History of Modern Computing* are computational science and the international competition at the high end of supercomputing. The text appropriately contains many references to Turing Award winners, but it would have been nice to see several acknowledgments of Nobel Prizes that were largely based on computing — e.g., Max Ferdinand Perutz and John Cowdery Kendrew's 1962 Nobel Prize in Chemistry, which required the University of Cambridge's EDSAC (Electronic Delay Storage Automatic Calculator) to determine the structure of myoglobin. A history of HPC's perceived importance to nations around the world would also have been an interesting addition. This idea was widely publicized when Japan's Earth Simulator supercomputer became operational and was ranked #1 in the June 2002 Top500 list[2] — it was five times faster than the #2 computer: ASCI White at Lawrence Livermore National Laboratory. Though this was not the first time that a computer from outside the U.S. had placed first, the Earth Simulator's ranking spurred U.S. Congressional hearings and led to the enactment of the High-End Computing Revitalization Act of 2004,[3] which authorized the Secretary of Energy to carry out a research and development program to advance high-end computing.

Despite that Act, Japanese and Chinese computers were ranked first at various points in the following years. These rankings motivated the 2015 U.S. executive order for a National Strategic Computing Initiative,[4] which established a whole-of-government effort to create a cohesive, multi-agency strategic vision and federal investment strategy to maximize HPC's benefits in the U.S. The European Commission has also funded numerous projects on various aspects of computing to ultimately create a state-of-the-art European chip ecosystem and unify the European Union's world-class research, design, and testing capacities.

A New History of Modern Computing closes with a somewhat brooding epilogue—"A Tesla in the Valley"—which is not surprising given that it was published in 2021: a year that was fraught with the COVID-19 pandemic and revelations of the detriments of social media and its role in the so-called *post-truth society*. In summary, this text is well worth reading in its entirety. Interested researchers will find that its detailed index provides a handy reference for almost any topic in computing.

[2] https://www.top500.org/lists/top500/2002/06

[3] https://www.congress.gov/bill/108th-congress/senate-bill/2176

[4] https://www.nitrd.gov/nsci

References

[1] Bush, V. (1945, July). As we may think. *The Atlantic*. Retrieved from https://www.theatlantic.com/magazine/archive/1945/07/as-we-may-think/303881.

[2] Deane, J. (2003). The IAS Computer Family Scrapbook. *Australian Computer Museum Society Inc*. Retrieved from http://archive.computerhistory.org/resources/access/text/2017/11/102693640-05-01-acc.pdf.

Paul Messina is a computational scientist who is retired from the California Institute of Technology and Argonne National Laboratory.

AN22 Panelists Discuss Career Opportunities in Business, Industry, and Government

By Lina Sorg

The rapidly changing nature of research and development continues to introduce a wide variety of new career opportunities beyond the realm of academia for applied mathematicians and computational scientists. During a hybrid session[1] at the 2022 SIAM Annual Meeting,[2] which took place in Pittsburgh, Pa., this July, six panelists shared their real-world experiences in business, industry, and government (BIG) with a rapt audience of students and early-career professionals. Sharon Arroyo (The Boeing Company), Marisabel Rodriguez Messan (U.S. Food and Drug Administration), Helen Moore (University of Florida), Ian Price (UPMC Health Plan), Juliana Richardson (MITRE Corporation), and Pablo Seleson (Oak Ridge National Laboratory) offered personal anecdotes and advice for embarking on a successful career in BIG. Kevin Bongiovanni (Raytheon Technologies) and Nessy Tania (Pfizer Inc.) moderated the hour-long panel.

CAREERS IN MATHEMATICAL SCIENCES

Arroyo opened the session by admitting that she did not even consider a career in industry while pursuing her Ph.D. in operations research. Upon earning her degree, she secured an assistant professor role at Iowa State University that involved collaboration with industry groups. Arroyo quickly realized that she thoroughly enjoyed the interdisciplinary nature of these problems. "I really liked seeing what the math did, how it impacted industry, and the value that it had for the company," she said. After three years, she left Iowa and joined the Applied Mathematics Group at Boeing;[3] Arroyo has remained with Boeing for 26 years and is now a Senior Technical Fellow.

Like Arroyo, Moore never initially intended to pursue employment in industry. Yet after collaborating with a medical group on leukemia research that corresponded with her academic work, she applied for a position at a biotechnology company called Genentech.[4] Moore quickly received an offer and subsequently spent the next 15 years at various companies, including Bristol Myers Squibb and AstraZeneca. "Not only is the mathematics incredibly beautiful, but it can also help people who are very sick," Moore said. "That really drives me." She currently runs a mathematics research group within the Laboratory for Systems Medicine at the University of Florida; similar research groups exist at the University of North Carolina, University of Texas, Houston Methodist, and Moffitt Cancer Center. Moore reminded attendees that such programs—which employ mathematicians but are located outside of academic math departments—present rich opportunities for partnerships with scientists who are working on data-driven projects that have mathematical components.

After earning her Ph.D., Rodriguez Messan spent several years in academia before accepting a job with the U.S. Food and Drug Administration[5] (FDA). She was impressed by the agency's research efforts, which include applications to cancer and immunotherapy, and liked that the position allowed her to utilize many of the skills that she acquired in graduate school. Rodriguez Messan has now been with the FDA for nearly three years and enjoys her team's analytical focus. "So far it's been a really nice experience," she said. "I've started learning more about different subjects, the problems are challenging, and I find myself learning new mathematical skills and new ways to apply those skills to modeling."

Unlike his counterparts, Price never considered a career in academia and instead went straight into industry. "I really wanted to make an impact, get my hands dirty, get involved, and see a little more immediacy to my work," he said. "One of the things I've enjoyed about industry is being a bit of a universal hex wrench." As a lead data scientist at UPMC Health Plan,[6] Price aims to provide stakeholders and customers with what they need, rather than a hypothetical version of what they *think* they might need. Yet despite his title, he still considers himself a mathematician; in fact, Price believes that his mathematics background makes him an even better data scientist. For example, the concepts from his graduate-level numerical methods classes help him see things like the impact of convergence in ways that his colleagues might not.

As a research scientist in Oak Ridge National Laboratory's (ORNL) Computer Science and Mathematics Division,[7] Seleson encouraged attendees to pursue internships outside of academia and explore places like the national laboratories. "It's very exciting to be in an environment that leads in several areas," he said, noting ORNL's focus on supercomputing and operation of Frontier[8] — the world's first exascale supercomputer. "Over the years, I've been engaging with the applied mathematical community on one side and the computational science community on the other side."

Next, the moderators migrated the discussion to the types of skills that are necessary for success in industry-based professions. Moore emphasized the importance of persuasive communication—both written and verbal—in non-academic settings, as industry employees often report to people who are not experts in their particular areas of specialization. She noted that teaching can be an effective means of preparation for this broader style of communication.

Rodriguez Messan seconded the benefit of strong communication, then confessed that she wished she had become more acquainted with data analysis while in graduate school. Given the growing prevalence of big data, she advised students to take on a data-based project or enroll in a class that involves significant data use. Moore echoed these comments, adding that knowledge

See **Career Opportunities** *on page 9*

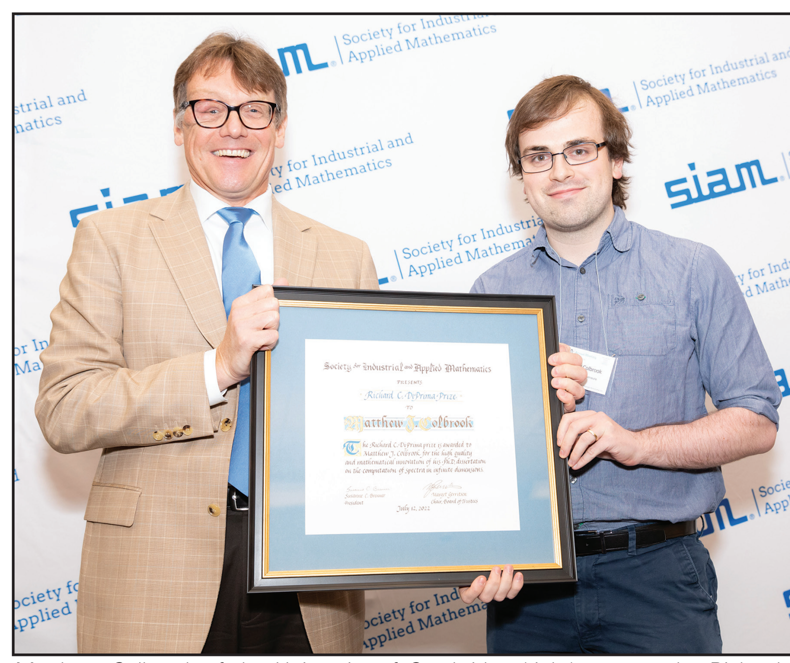
[1] https://meetings.siam.org/sess/dsp_programsess.cfm?SESSIONCODE=75151
[2] https://www.siam.org/conferences/cm/conference/an22
[3] https://www.boeing.com
[4] https://www.gene.com
[5] https://www.fda.gov
[6] https://www.upmchealthplan.com
[7] https://www.ornl.gov/division/csmd
[8] https://www.olcf.ornl.gov/frontier

Photos from the 2022 SIAM Annual Meeting

SIAM President-elect Sven Leyffer (right) and Association for Women in Mathematics (AWM) President Kathryn Leonard (left) congratulate Anne Greenbaum of the University of Washington for her receipt of the AWM-SIAM Sonia Kovalevsky Lecture. As one of the original developers of the LAPACK software, Greenbaum was recognized for her long-lasting and significant impacts on many aspects of numerical linear algebra during the Prizes and Awards Luncheon at the 2022 SIAM Annual Meeting, which took place this July in Pittsburgh, Pa. The previous day, she delivered a lecture entitled "Two of My Favorite Problems." SIAM photo.

SIAM President-elect Sven Leyffer (left) presents James Crowley, the former executive director of SIAM, with the SIAM Prize for Distinguished Service to the Profession at the Prizes and Awards Luncheon during the 2022 SIAM Annual Meeting, which took place in Pittsburgh, Pa., this July. Crowley, who retired from SIAM in 2020 after 25 years of service, received a standing ovation from SIAM staff, leadership, and conference attendees as he took the stage to accept the award. SIAM photo.

During the Prizes and Awards Luncheon at the 2022 SIAM Annual Meeting, which took place this July in Pittsburgh, Pa., SIAM President-elect Sven Leyffer honored Barbara Mahler of KTH Royal Institute of Technology (left) and William Anderson of North Carolina State University (right) with the SIAM Student Paper Prize. Mahler's paper, "Analysis of Contagion Maps on a Class of Networks that are Spatially Embedded in a Torus," appeared in the SIAM Journal on Applied Mathematics in 2021, and Anderson's paper, "Evolution of Nonlinear Reduced-order Solutions for PDEs with Conserved Quantities," published in the SIAM Journal on Scientific Computing in 2022. Both students presented their work during a "Student Days" minisymposium session. SIAM photo.



Matthew Colbrook of the University of Cambridge (right) accepts the Richard C. DiPrima Prize from SIAM President-elect Sven Leyffer during the Prizes and Awards Luncheon at the 2022 SIAM Annual Meeting, which was held in Pittsburgh, Pa., this July. Colbrook was honored for the high quality and mathematical innovation of his Ph.D. dissertation on the computation of spectra in infinite dimensions. SIAM photo.

Members of the SIAM Fellows classes of 2020, 2021, and 2022 were recognized during the Fellows Reception at the 2022 SIAM Annual Meeting, which took place this July in Pittsburgh, Pa. First row (from left): Edmond Chow (Georgia Institute of Technology), Sharon Arroyo (The Boeing Company), SIAM President-elect Sven Leyffer, Kristin Lauter (Meta AI Research), Abba Gumel (Arizona State University), and Rachel Levy (North Carolina State University). Second row (from left): Jonathan Rubin (University of Pittsburgh), James Crowley (former executive director of SIAM), Peter Monk (University of Delaware), Chen Greif (University of British Columbia), Amit Singer (Princeton University), Raymond Tuminaro (Sandia National Laboratories), Jie Shen (Purdue University), and Anna Mazzucato (Pennsylvania State University). SIAM photo.

Enrique Zuazua of Friedrich-Alexander-Universität Erlangen-Nürnberg (right) accepts the W.T. and Idalia Reid Prize in Mathematics from SIAM President-elect Sven Leyffer during the Prizes and Awards Luncheon at the 2022 SIAM Annual Meeting, which was held in Pittsburgh, Pa., this July. Zuazua was honored for fundamental theoretical and computational contributions to the control, numerics, and analysis of nonlinear partial differential equations and multi-physical systems with impactful scientific and industrial applications. He gave a corresponding talk during the meeting about "Control and Machine Learning." SIAM photo.

View information on all 2022 major SIAM prize recipients at *https://www.siam.org/Prizes-Recognition/Major-Prizes-Lectures*

A full list of all 2020, 2021, and 2022 Fellows is available at *https://www.siam.org/prizes-recognition/fellows-program/all-siam-fellows*

Career Opportunities

Continued from page 7

of statistics, uncertainty quantification, and sensitivity analysis is also valuable. Furthermore, it is important to keep up with the latest developments in one's research area — especially in fields like biology or medicine that often progress quickly and in real time. "I get my domain knowledge as needed but am always working to improve my mathematics," Moore said.

When the moderators opened the floor to questions, an attendee asked about the level of collaboration that occurs outside of academia. In response, Seleson commented on the cooperative nature of national laboratories. "National labs are environments where collaboration is extremely encouraged," he said. "It's not always necessary, but it's very helpful." Though Price clarified that that the level of collaboration within organizations depends on company culture, he urged all young professionals to develop good networking skills and be present around their colleagues.

Richardson then spoke about her own experiences as a data scientist at MITRE.[9] "I collaborate with people all the time," she said. "I couldn't do my job without other people." Richardson works on several problems simultaneously and thus routinely partners with computer scientists, aerospace engineers, mathematicians, physicists, and other professionals. Because multiple employees often contribute to different parts of a project's pipeline, they must all communicate throughout the process and understand each other's roles.

Another attendee inquired about the transition from academia to industry and vice versa. Moore remarked that if she had known she would eventually migrate to industry, she would have made a concerted effort to publish in industry journals, attend industry-based conferences, and otherwise get involved in some capacity. She added that a successful transition depends in part on publishing in applicable journals, encountering the right people, attending and presenting at the appropriate conferences, and networking whenever possible.

In addition, Moore encouraged industry employees to maintain some type of tie to academia, perhaps by giving talks or presenting posters at meetings. "If you at least present a poster, that gives you something from an industry job that you can present during an interview or list on a resume," she said. Arroyo expanded upon Moore's comments and urged students who are considering BIG careers to complete an internship with a company so that future employers have tangible evidence of their experience and enthusiasm. In contrast, individuals in academia with an interest in industry might consider consulting as a side business.

Conversation then turned to the nuances of the interview process. One student asked about the types of skills that researchers can bring to mathematics-based industry roles, especially if they have a degree in engineering or another tangential field. Moore advised interviewees to emphasize undertakings with a clear impact. Because industry employers focus heavily on impact, discussing one's involvement in the application and success of a specific project is thus particularly valuable. For example, candidates can explain their data analysis efforts, the application of a code that they wrote, or their role in the implementation of a new system.

Moreover, Richardson acknowledged the importance of interviewing with the right people. "Try to target your job search to places where you'll interact with other Ph.D.s — people with backgrounds in electrical engineering or computer science," she said. "They'll understand that [your experience] is relevant and you won't have to convince them."

Seleson noted that national labs offer many exciting internship opportunities. "Look into labs, try to find people who work on projects that you may be interested in, and attempt to contact those people," he said. He also recommended the U.S. National Science Foundation's Mathematical Sciences Graduate Internship Program:[10] a 10-week session that provides hands-on experience for mathematical sciences graduate students at federal national laboratories and research facilities. In addition, many job and internship openings are advertised on SIAM's Career Center[11] and sites like LinkedIn, Twitter, and Indeed.

As the session concluded and attendees prepared for the post-panel networking reception, Arroyo shared a few final thoughts about internships. She specifically mentioned that companies post a lot of internships in the fall, which is a good time to start looking for openings for the following summer. "Don't only search for 'math,'" she said. "The math could be hidden in other areas. Look under 'data science' and 'data analytics' as well."

*SIAM is always interested in hearing more about the needs of our members who work in industry, or who might be considering a future career path in industry. Send your suggestions and questions to **membership@siam.org**.*

Lina Sorg is the managing editor of SIAM News.

From left to right: Sharon Arroyo (The Boeing Company), Helen Moore (University of Florida), and Ian Price (UPMC Health Plan) relay their own experiences outside of academia and offer career advice during a hybrid industry panel at the 2022 SIAM Annual Meeting, which took place in Pittsburgh, Pa., this July. SIAM photo.

During the 2022 SIAM Annual Meeting, which took place this July in Pittsburgh, Pa., a hybrid panel explored the nuances of careers in business, industry, and government. Panelists Sharon Arroyo (The Boeing Company), Helen Moore (University of Florida), and Ian Price (UPMC Health Plan) were present on site, while Marisabel Rodriguez Messan (U.S. Food and Drug Administration), Juliana Richardson (MITRE Corporation), and Pablo Seleson (Oak Ridge National Laboratory) participated virtually. SIAM photo.

[9] https://www.mitre.org
[10] https://orise.orau.gov/nsf-msgi
[11] https://jobs.siam.org

What Can You See with Computed Tomography?

By Per Christian Hansen, Jakob Sauer Jørgensen, William R.B. Lionheart, and Eric Todd Quinto

Computed Tomography: Algorithms, Insight, and Just Enough Theory[1]*—edited by Per Christian Hansen, Jakob Sauer Jørgensen, and William R.B. Lionheart, with contributions from Martin S. Andersen, K. Joost Batenburg, Yiqiu Dong, Eric Todd Quinto, and Jan Sijbers—was published by SIAM in 2021. The book, which is part of the Fundamentals of Algorithms series, illustrates how theoretical insight and numerical computation go hand in hand in the analysis of algorithms for computed tomography (CT).*

The following text focuses on CT problems with limited data and highlights a central theme in inverse problems: What can we reliably expect to recover from specific measurements? The text is based on excerpts from chapters 5, 8, and 10 (where more illustrations can be found) and has been modified slightly for clarity.

We begin by introducing a few basic elements of CT. Without loss of generality, we assume that we are scanning an object that is contained in a unit disk of radius 1. The object's attenuation coefficient is characterized by the nonnegative function $f(x_1,x_2)$. Let $L_{\theta,s}$ denote a line at angle θ and a distance s from the origin. We define the *projection* that expresses all line integrals along $L_{\theta,s}$ at fixed angle θ as

$$g_\theta(s) = \int_{L_{\theta,s}} f(x_1,x_2)\,d\ell \quad \text{for} \quad s \in [-1,1]. \tag{1}$$

The restriction of s to [-1,1] is possible because all lines for s that fall outside of this interval do not intersect with the object, meaning that their line integrals are simply equal to 0. We then define the *Radon transform* of f as the projections at all angles, i.e.,

$$\mathcal{R}[f](\theta,s) = g_\theta(s) \quad \text{for} \quad \theta \in [0^\circ, 360^\circ[\tag{2}$$

and $s \in [-1,1]$. The output of the Radon transform is also known as the *sinogram* due to distinct sinusoidal bands that appear when one views it as an image.

FROM THE SIAM BOOKSHELF

Complete data are taken over lines for all angles $\theta \in [0^\circ, 360^\circ[$ and displacements $s \in [-1,1]$, while limited data are taken over smaller sets of lines. Here we mention three common types of limited data:

- **Limited-angle data** arise when the angles θ are restricted. For example, limited-angle data would ensue if θ was restricted to $[90^\circ,180^\circ] \cup [270^\circ,360^\circ]$ but all values of $s \in [-1,1]$ were allowed.
- **Region-of-interest data** arise when lines only pass through a specific region of interest. For instance, if the region of interest is a ball of radius $1/2$ at the origin, then the corresponding region-of-interest data would be over lines for $\theta \in [0^\circ, 360^\circ[$ and $s \in [-1/2, 1/2]$.
- **Exterior data** arise when we limit the data to *avoid* a specific region. If the excluded region is the ball of radius $1/2$ that is centered at the origin, for example, then the exterior data would exist over all lines that do not meet this ball, i.e., lines for $\theta \in [0^\circ, 360^\circ[$ and $s \in [-1,-1/2] \cup [1/2, 1]$.

Example 1

Now we illustrate a simple limited-angle reconstruction. Figure 1 depicts a disk of radius $1/2$ that is centered at the origin, a limited-angle sinogram for $\theta \in [90^\circ,180^\circ] \cup [270^\circ,360^\circ]$, and a limited-angle reconstruction of the disk, computed as described in chapter 6 of *Computed Tomography*. Here, the limited-angle data domain solely consists of lines for $\theta \in [90^\circ,180^\circ] \cup [270^\circ,360^\circ]$ and $s \in [-1,1]$. The sinogram in Figure 1b is black in the missing range and only shows the data values in the limited data domain. The magenta vertical lines at $\theta = 90^\circ$, $\theta = 180^\circ$, $\theta = 270^\circ$, and $\theta = 360^\circ$ represent the data domain's outer boundaries.

The reconstruction in Figure 1c *should* look like the disk in Figure 1a, but it appears markedly different. The reconstruction does correctly contain circle boundaries with positive slopes in the second and fourth quadrants. The lines for θ between 90° and 180° have positive slopes, so the well-reconstructed object boundaries are tangent to lines in the data domain; these are the visible boundaries. However, the negatively sloped boundaries in the first and third quadrants are not evident in the reconstruction. Because of their negative slopes, these boundaries are tangent to *no* lines in the data domain and are thus invisible.

For $s = \pm 1/2$, we see vertical artifacts along the lines with $\theta = 0^\circ$ and horizontal artifacts along the lines with $\theta = 90^\circ$. Recall that the data's outer boundary consists of lines with $\theta = 90^\circ$, 180°, 270°, and 360° (see Figure 1b). Therefore, the artifact lines are tangent to the object and exist in the outer boundary of the data domain. ■

Using the discretization methods from chapter 9 of *Computed Tomography*, we obtain a linear algebra formulation of the CT reconstruction problem that takes the form $\boldsymbol{A}\boldsymbol{x} = \boldsymbol{b}$. In this form, vectors $\boldsymbol{x}$ and $\boldsymbol{b}$ respectively represent the image and sinogram. Let matrix $\boldsymbol{A}$ have dimensions $m \times n$ and assume that $m \geq n$ for the sake of simplicity. The *singular value decomposition* (SVD) then takes the form

$$\boldsymbol{A} = \sum_{i=1}^{n} \boldsymbol{u}_i \sigma_i \boldsymbol{v}_i^T, \tag{3}$$

where σ_i are the singular values and $\boldsymbol{u}_i$ and $\boldsymbol{v}_i$ are the corresponding left and right

See **Computed Tomography** *on page 11*

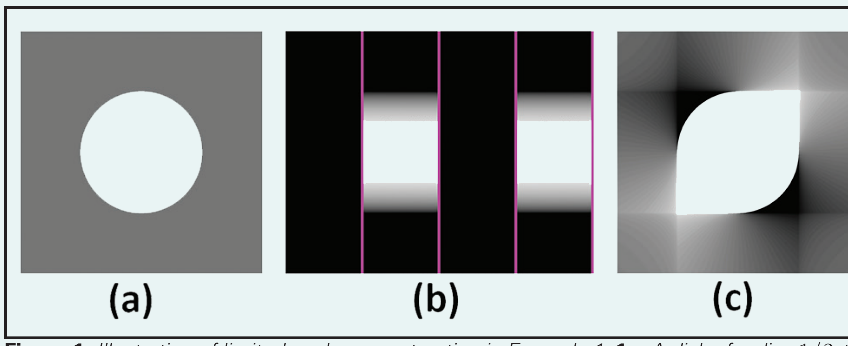


Figure 1. *Illustration of limited-angle reconstruction in Example 1.* **1a.** *A disk of radius 1/2 that is centered at the origin.* **1b.** *A limited-angle sinogram.* **1c.** *The corresponding reconstruction.*

[1] https://bookstore.siam.org/fa18

Computed Tomography

Continued from page 10

singular vectors. Further details about the SVD are available in chapter 10.

Example 2

Now we have computed the leading singular values and vectors of matrix $\boldsymbol{A}$ from Example 1. Figure 2 illustrates some of the right singular vectors $\boldsymbol{v}_i$, which have distinctive features that are characteristic of this specific limited-angle problem. In particular, all of the reshaped vectors are dominated by features that are elongated at a 45° angle with respect to the horizontal (the features for the complete-data problem have no dominating direction).

At this point, we know from the analysis in chapter 8 of *Computed Tomography* that we can only expect to recover structures and edges along the projection angles; other features are much harder to reconstruct without *a priori* information. Our singular vectors are completely in accordance with this fact. Since the reconstruction is a weighted sum over the right singular vectors $\boldsymbol{v}_i$, it will inherit the dominating features of these vectors — in this case, features and structures at roughly 45° angles. ■

Due to ill conditioning of $\boldsymbol{A}$, high-frequency components that relate to the smallest singular values tend to contaminate naïve CT reconstructions. A simple approach that reduces this noise's influence involves merely discarding the SVD coefficients that correspond to the small singular values. Doing so leads to the *truncated SVD* (TSVD) solution

$$x_k = \sum_{i=1}^{k} \frac{\boldsymbol{u}_i^T \boldsymbol{b}}{\sigma_i} \boldsymbol{v}_i, \quad k < n. \tag{4}$$

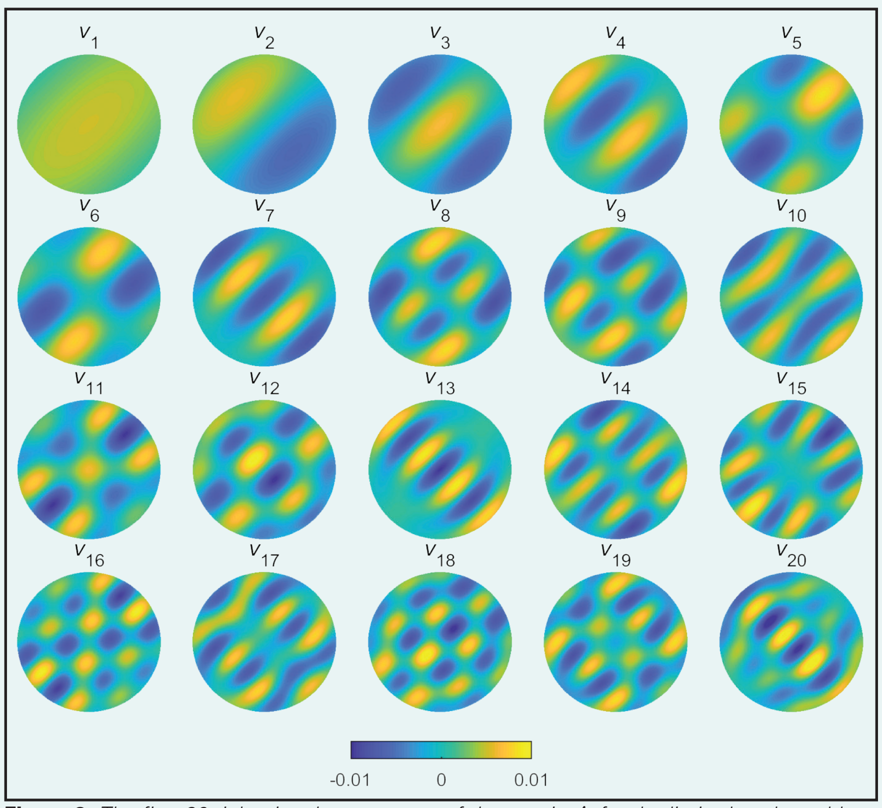


Figure 2. *The first 20 right singular vectors* $\boldsymbol{v}_i$ *of the matrix* $\boldsymbol{A}$ *for the limited-angle problem.*

Example 3

We finish by computing TSVD solutions to the limited-angle problem from Example 2 (see Figure 3). As k increases, contributions from higher-frequency singular vectors $\boldsymbol{v}_i$ are included, producing an increasingly sharper image. As Figure 2 shows, certain features dominate the right singular vectors $\boldsymbol{v}_i$; as a result, the reconstructions will also account for these features. We can thus indeed reconstruct the features and edges of the exact image at angles that are around 45°. On the other hand, features and edges at approximately -45° angles are almost completely absent from the reconstructions. ■

While there is no straightforward way to improve TSVD, more advanced reconstruction methods come to the rescue. These methods include algebraic iterative reconstruction methods (in chapter 11) and regularization techniques to incorporate prior information that compensates for incomplete data (in chapter 12). The latter rely on efficient optimization methods that are described in chapter 13 of *Computed Tomography*.

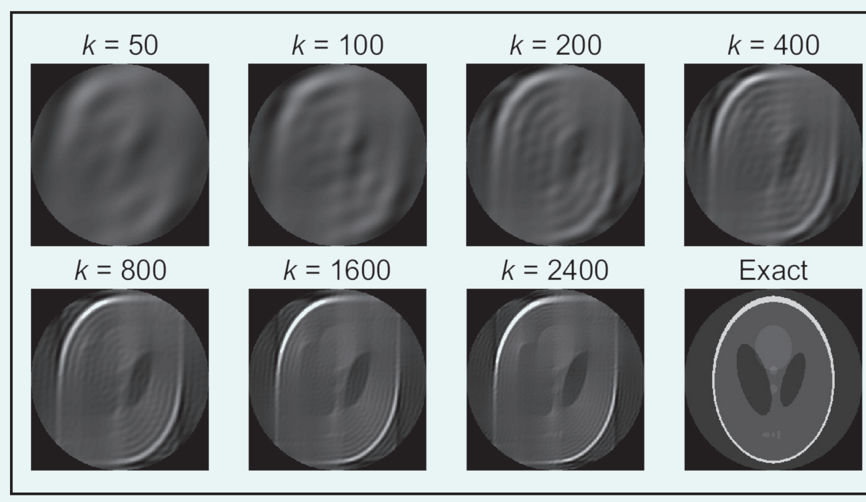


Figure 3. *Truncated singular value decomposition (TSVD) solutions to the limited-angle problem for select values of the truncation parameter* k*, as well as the exact solution.*

Enjoy this passage? Visit the SIAM Bookstore[2] *to learn more about Computed Tomography: Algorithms, Insight, and Just Enough Theory*[3] *and browse other SIAM titles.*

Per Christian Hansen is a professor of scientific computing at the Technical University of Denmark (DTU) and a SIAM Fellow with a research track in numerical methods for inverse problems. Jakob Sauer Jørgensen is a senior researcher at DTU and a Presidential Fellow at the University of Manchester. His work focuses on algorithms and software for computed tomography and uncertainty quantification. William R.B. Lionheart is a professor of applied mathematics at the University of Manchester who specializes in applied and theoretical inverse imaging problems in medicine, materials science, security, and radar. Eric Todd Quinto is the Robinson Professor of Mathematics at Tufts University. He uses microlocal analysis to understand strengths and weaknesses that are inherent to limited data problems in a range of tomographic modalities.

[2] https://my.siam.org/Store
[3] https://bookstore.siam.org/fa18

Introducing TPSE Math in the Context of Leadership and Equity, Diversity, and Inclusion

By Michael Dorff and Scott A. Wolpert

2012 saw an uproar over collegiate-level mathematics. The President's Council of Advisors on Science and Technology[1] (PCAST) reported to then-President Barack Obama[2] that "introductory mathematics courses often leave students with the impression that all science, technology, engineering, and mathematics (STEM) fields are dull and unimaginative, which has particularly harmful effects for students who later become K-12 teachers" [1]. They also advocated for "college mathematics teaching and curricula developed and taught by faculty from mathematics-intensive disciplines other than mathematics, including physics, engineering, and computer science" [1]. Multiple groups within the mathematical science community responded to this controversial PCAST report. For example, SIAM affirmed[3] that "Collaboration, rather than removing mathematicians from the education equation, will ensure that students have access to relevant and exciting learning experiences with appropriate breadth and depth" [2].

Unsurprisingly, the situation provoked numerous discussions among both pure and applied mathematicians. Concerns over the demand for stronger quantitative skills in the workforce inspired a small gathering of individuals from the mathematics community, higher education more broadly, and beyond. This meeting took place at the Carnegie Corporation of New York (CCNY) and led directly to the formation of Transforming Post-Secondary Education in Mathematics[4] (TPSE Math), which received initial funding from CCNY and the Alfred P. Sloan Foundation. Members of the initial action team included Phillip Griffiths (Institute for Advanced Study), Mark Green (University of California, Los Angeles), Uri Treisman (University of Texas at Austin), and Eric Friedlander (University of Southern California).

The TPSE vision is a postsecondary mathematics education that will enable all students—regardless of their identities, backgrounds, or chosen programs of study—to develop the modern mathematical knowledge and skills to productively engage in society and the workplace. TPSE Math aims to foster a mathematically rich and relevant education for every student, and to work with mathematicians, faculty, administrations, and professional organizations like SIAM to facilitate an inclusive movement that strengthens postsecondary education in mathematics. The current Board of Directors consists of Griffiths, Green, Friedlander, William Kirwan (University of Maryland), Sylvester James Gates, Jr. (Brown University and University of Maryland), Tara Holm (Cornell University), Karen Saxe (American Mathematical Society), Uri Treisman, and Suzanne Weekes (executive director of SIAM).

TPSE Math hosts a multitude of activities and programs. Here we highlight two such initiatives: the Leadership Institute[5] and Creating Opportunities in Mathematics through Equity and INclusion[6] (COME-IN).

The Leadership Institute

In school, mathematicians learn how to solve mathematics problems and conduct research. However, few receive formal training on leading a team, department, or organization — even when they are promoted to leadership positions. To address this disparity, TPSE created the Leadership Institute: a year-long program to help mathematicians learn leadership skills and develop their ability to act as leaders at their respective institutions, professional organizations, and federal agencies. The Institute encourages participation from underrepresented groups and recognizes that the mathematics community can benefit from the experience and insight of leaders from diverse backgrounds. Each Fellow in the Leadership Institute (i) receives leadership training via a two-day, in-person summer workshop and bimonthly virtual group meetings, (ii) works on a self-selected leadership project during the year, and (iii) is matched with a mentor who is an experienced leader.

One interesting component of the Leadership Institute is that all Fellows design their own projects to gain further leadership experience. For instance, Nathan Alexander (Morehouse College) is developing a community data hub that examines, communicates, and advocates for more justice-oriented data practices, while Dandrielle Lewis (High Point University) is creating a summer program that focuses on mentoring and mathematically training Black, Hispanic, and Indigenous students.

Mentors provide leadership advice and answer questions about the Fellows' year-long projects and potential future leadership opportunities. For example, Green—who cofounded the Institute for Pure and Applied Mathematics—serves as a mentor to Jayadev Athreya (University of Washington), who is the director of the Pacific Institute for the Mathematical Sciences (PIMS) in Canada. Athreya spoke highly of Green, noting that he "has been a valuable source of advice and a great sounding board as I've worked on diversifying PIMS' funding base and establishing a culture of diversity, equity, and inclusion in everything PIMS does."

[1] https://www.whitehouse.gov/pcast
[2] https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
[3] https://archive.siam.org/news/news.php?id=1995
[4] https://www.tpsemath.org

[5] https://www.tpsemath.org/leadership
[6] https://www.tpsemath.org/comein


Erika Tatiana Camacho (Arizona State University and National Science Foundation)—a member of the Creating Opportunities in Mathematics through Equity and INclusion (COME-IN) working group—chats with Roberto Alvarez (middle) and Danielle Brager (right), then-students at Arizona State University. Photo courtesy of the authors.

Creating Opportunities in Mathematics through Equity and INclusion

Many departments and organizations within the mathematical sciences community want to improve their equity, diversity, and inclusion (EDI) efforts. However, resources that support such efforts are scarce — especially ones that are specifically tailored to mathematics and statistics. To address this deficit, TPSE Math convened a diverse working group of 16 mathematicians to create resources that can guide a mathematical and statistical sciences department in assessing and enhancing its EDI endeavors. The working group adapted core criteria from the American Association for the Advancement of Science's STEMM Equity Achievement (SEA) Change[7] initiative to the specific needs of the mathematical and statistical sciences, ultimately resulting in the resources that comprise COME-IN. We are now actively promoting and distributing COME-IN to departments and organizations in the mathematics and statistics communities.

The COME-IN tools consist of a set of reflective questions about recruitment, evaluation, and mentoring that relate to students, faculty, and staff. They include considerations and issues of which leaders might be unaware as they work to assess and improve their EDI efforts. The tools are also self-guided; department leaders identify their priorities, collect data, and develop action plans to address the problems at hand. Some sample questions are as follows:

- What supports are available to ensure that students who start with entry-level courses can be successful in mathematics and statistics majors or other STEM majors?
- Are advisors trained to respond to cultural differences?
- How do the demographics of students who take advantage of certain opportunities compare with the overall undergraduate population?
- Does the department offer programs that prepare students for success in the workforce or graduate studies?
- How does the department assess the effectiveness of student placement in required courses and ensure continuous improvement?

[7] https://seachange.aaas.org

TPSE Math is supported by CCNY and National Science Foundation grants from the Division of Undergraduate Education and Division of Mathematical Sciences. Read more about TPSE and its various programs online.[8]

References

[1] President's Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics* (Report to the President). Washington, D.C.: Executive Office of the President.

[2] SIAM responds to PCAST report. (2012, July 17). *SIAM News*, *45*(6), p. 6.

Michael Dorff is a professor of mathematics at Brigham Young University and the Director of Strategy and Implementation at TPSE Math. Scott A. Wolpert is a professor emeritus of mathematics at the University of Maryland and a Senior Consultant at TPSE Math.

[8] https://www.tpsemath.org

Nan Sattler (Terra Community College) leads a virtual discussion about conflict management during a meeting of the Leadership Institute Fellows.