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SIAM Welcomes Suzanne Weekes as New Executive Director

By Lina Sorg

On January 1, 2021, Suzanne L. Weekes officially began her tenure as SIAM's third executive director. She succeeds James Crowley,[1] who served in this position for 25 years. Suzanne comes to SIAM from Worcester Polytechnic Institute (WPI), where she was Associate Dean of Undergraduate Studies and a professor of mathematical sciences. Last month, she sat down with *SIAM News* to discuss her passion for applied mathematics, prior involvement with SIAM, commitment to the SIAM membership community, and probable focal points as executive director.

***SIAM News*: How did you first develop an interest in mathematics?**

Suzanne Weekes: My interest began in elementary school with the same math that everyone else my age in Trinidad was doing. My teachers and family encouraged me to do well and pursue math and the sciences. I came to the United States for university and earned a B.S. in mathematics and a minor in computer science from Indiana University in Bloomington, and then a Ph.D. in mathematics and scientific computing from the University of Michigan. The latter was an interdisciplinary degree. I also took graduate classes in aerospace engineering, industrial engineering, and computer science, so it wasn't your traditional math degree.

SN: Why did you choose to pursue a career in applied mathematics?

SW: I've always liked to see connections to applications and understand how the mathematics is being used. As an undergraduate and graduate student, I spent summers working at companies where I utilized both my mathematics and computer training, which also fed my interests. I enjoy seeing how foundational research comes to market in terms of usability.

SN: You've spent your whole career in academia. Will it be strange to transition after all this time?

SW: I've been engaged with SIAM as a volunteer over the years and have worked with some members of the SIAM staff before. The executive director position is a wonderful new challenge and, going by history, the opportunity does not come up often at all. My interests and experience line up well with what is needed for this role.

SN: What type of experiences have you had with industry?

SW: I've been involved with industry and academia research partnerships for a while now. When I was in graduate school in the 1990s, I interned at IBM's Thomas J. Watson Research Center in Yorktown Heights, NY. After receiving my Ph.D., I was a visiting assistant professor in the Department of Mathematics and the Institute for Scientific Computation at Texas A&M University, where we worked with ExxonMobil on oil recovery simulation. I was integrally involved in WPI's Center for Industrial Mathematics and Statistics, which actively engages with industry. Among other things, the center runs the NSF-supported Research Experiences for Undergraduates in Industrial Mathematics and Statistics. I am also a founding co-director of the Preparation for Industrial Careers in Mathematical Sciences (PIC Math) program,[2] which is supported by the NSF and the National Security Agency.

Suzanne Weekes began her tenure as SIAM's third executive director on January 1, 2021. She was previously Associate Dean of Undergraduate Studies and a professor of mathematical sciences at Worcester Polytechnic Institute.

The SIAM Industry Committee has done a lot of work to develop plans and ideas that enhance SIAM's existing connection to industry, and I am excited to move things forward.

SN: How have you been involved with SIAM over the years?

SW: My first research article was published in the *SIAM Journal on Numerical Analysis*, and the first conference that I ever attended was the 1993 SIAM Annual Meeting in Philadelphia. My first time presenting at a conference was at the 1995 SIAM Annual Meeting in Charlotte, NC, right after I received my Ph.D. I am also the founding chapter advisor of the WPI Student Chapter of SIAM,[3] which is one of the oldest student chapters. The chapter began hosting events in 2003.

See **Suzanne Weekes** *on page 2*

[1] https://sinews.siam.org/Details-Page/executive-director-jim-crowley-retires-after-25-years-of-siam-leadership

[2] https://math.siam.org/picmath

[3] https://wp.wpi.edu/siam

New Bridges Between Deep Learning and Partial Differential Equations

By Lars Ruthotto

Understanding the world through data and computation has always formed the core of scientific discovery. Amid many different approaches, two common paradigms have emerged. On the one hand, primarily data-driven approaches—such as deep neural networks (DNNs)—have proven extremely successful in recent years. Their success is based mainly on their ability to approximate complicated functions with generic models when trained using vast amounts of data and enormous computational resources. But despite their many triumphs, DNNs are difficult to analyze and thus remain mysterious. Most importantly, they lack the robustness, explainability, interpretability, and fairness required for high-stakes decision-making. On the other hand, increasingly realistic model-based approaches—typically derived from first principles and formulated as partial differential equations (PDEs)—are now available for various tasks. One can often calibrate these models—which enable detailed theoretical studies, analysis, and interpretation—with relatively few measurements, thus facilitating their accurate predictions of phenomena. However, computational methods for PDEs remains a vibrant research area whose open challenges include the efficient solution of highly nonlinear coupled systems and PDEs in high dimensions.

In recent years, exciting work at the interface of data-driven and model-based approaches has blended both paradigms. For instance, PDE techniques and models have yielded better insight into deep learning algorithms, more robust networks, and more efficient training algorithms. As another example, consider the solution of high-dimensional PDEs, wherein DNNs have provided new avenues for tackling the curse of dimensionality. One must understand that the exchange between deep learning and PDEs is bidirectional and benefits both communities. I hope to offer a glimpse into a few of these activities and make a case for the creation of new bridges between applied mathematics and data science.

Continuous Neural Networks Motivated by Ordinary and Partial Differential Equations

Researchers have traditionally constructed DNNs by concatenating a small, finite number of functions, each consisting of a trainable affine mapping and a pointwise nonlinearity[1] [9, 13]. Because the difficulty of initializing and training the network weights increases with the number of layers, the network's depth has been limited in practice. However, the arrival of the so-called residual neural networks (ResNet) in 2016—which outperformed traditional networks across a variety of tasks—dramatically changed this situation.

For a simple example of a ResNet in action, consider the training of a neural network that classifies points in $\mathbb{R}^2$ into two classes based on training data $\{(\mathbf{y}^{(1)}, c^{(1)}), (\mathbf{y}^{(2)}, c^{(2)}), \ldots\} \subset \mathbb{R}^2 \times \{0,1\}$. We have plotted an instance

See **Deep Learning** *on page 3*

[1] https://sinews.siam.org/Details-Page/the-functions-of-deep-learning

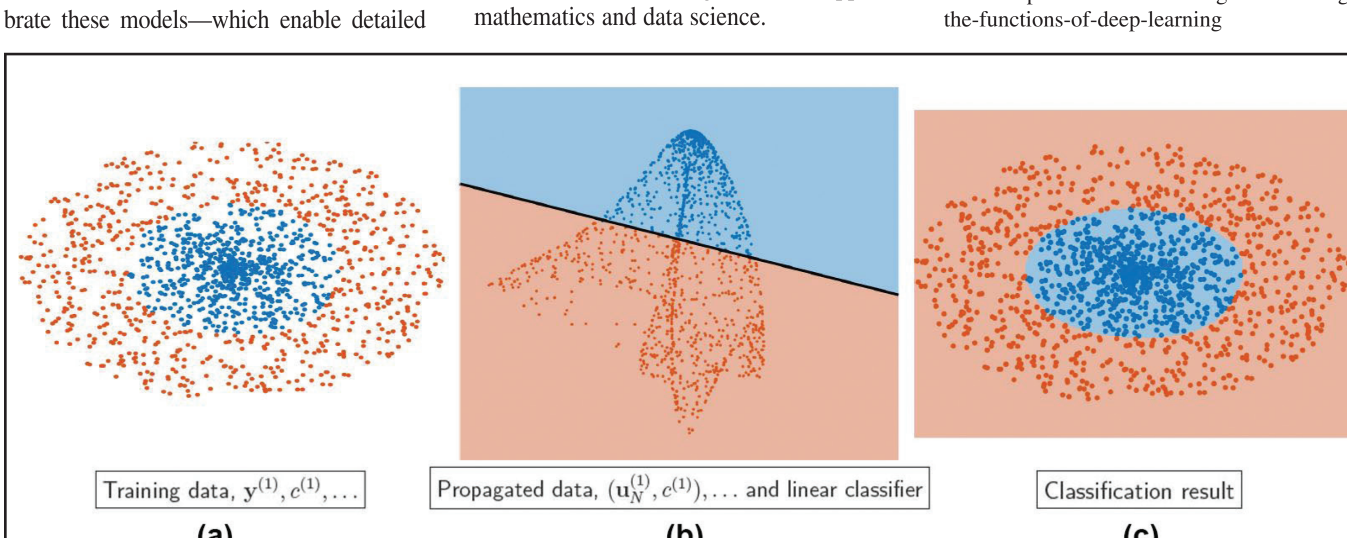

Figure 1. *Binary classification via a deep residual neural network.* **1a.** *A synthetic dataset consisting of concentric ellipsoids in two dimensions that are labeled into two classes, which are visualized as blue and red points.* **1b.** *The propagated input features for the trained neural network. When trained successfully, the propagated features can be classified with a linear model. We visualize the decision boundary with a black line and the model's prediction with a background that is colored according to the predicted class.* **1c.** *The classifier's prediction in the original data space. Figure courtesy of Lars Ruthotto.*

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4 **Cryptocurrencies, Mining, and Mean Field Games**
Understanding and modeling the interactions of Bitcoin miners and the consequent evolution of wealth inequality among participants is a fascinating problem. A. Max Reppen and Ronnie Sircar use numerical analysis and novel mean field games of intensity control to explore this idea.

5 **How Intelligent is Artificial Intelligence?**
Oana Marin reviews *Rebooting AI: Building Artificial Intelligence We Can Trust* by Gary Marcus and Ernest Davis. The authors pose several questions about the future and expectations of artificial intelligence (AI), ultimately offering both a scientific assessment of AI's status in a data-heavy world and a popular science view that appeals to readers from a wide variety of research fields.

7 **The Task Force Report on Future Research Directions for NSF in the Era of COVID-19**
Last year, SIAM established a task force to help inform the National Science Foundation's response to present needs associated with the ongoing COVID-19 pandemic. Executive director Suzanne Weekes explores the resulting report's themes, which lay the groundwork for a more robust disaster response regime and future economic security.

8 **xSDK: Building an Ecosystem of Highly Efficient Math Libraries for Exascale**
Developers of scientific applications embrace various software ecosystems, such as the Extreme-scale Scientific Software Development Kit (xSDK), as they build increasingly powerful computer architectures and strive for productivity, sustainability, and portability. Ulrike Meier Yang and Lois Curfman McInnes detail the specifics of xSDK.

9 **Writing an Interactive Textbook**
The static images in traditional mathematics textbooks are not always well-suited for illustrating dynamic phenomena. David Ketcheson, Randall LeVeque, and Mauricio del Razo, authors of *Riemann Problems and Jupyter Solutions*, describe the process of writing an interactive text comprised entirely of Jupyter notebooks.

Suzanne Weekes

Continued from page 1

In 2013, I flew to D.C. to have a conversation about developing a program that would help train faculty and students to better understand mathematics' use in industry. That's when I first met Jim Crowley — when we were brainstorming at the office of the Mathematical Association of America. The PIC Math program was born from this discussion.

I became chair of the SIAM Education Committee[4] in 2016. We revamped and relaunched the SIAM Visiting Lecture Program,[5] organized minisymposia and panels at the Joint Mathematics Meetings and the SIAM Annual Meetings, and supported SIAM student chapters,[6] among other things. I am also a member of the SIAM Committee on Science Policy[7] and will continue on this committee, ex officio.

SN: Your first SIAM conference experience was in graduate school. Why is it important for students and early-career mathematicians to attend conferences?

SW: Conferences are valuable for researchers at all levels, but especially for early-career mathematicians who are looking to establish themselves in the community. They provide spaces where attendees can get acquainted, share ideas, network with one another, and expand their understanding of the fields. Conferences become more fun once you get to know people, so I'm glad that SIAM hosts "Student Days" at our meetings. We need to continue making the SIAM conference environment very welcoming and inclusive. It can certainly be overwhelming or lonely to go to a strange city and strange hotel and not know anyone. But as you come more often, you begin seeing friends and look forward to meetings.

I have always encouraged my students at WPI to attend SIAM conferences. Three or four undergraduates attended the 2018 SIAM Annual Meeting in Portland, Ore., and it was wonderful for me to see them happily racing down the hallways on their way to some exciting talk or event.

Now that I'm a senior person and can afford to do so, I take my students or junior colleagues out to lunch or dinner, introduce them to other people, and just have a good and special time. I think that this is valuable for everybody, as is making introductions and sparking conversations. That's what we mean by networking. We do have to look out for each other, especially for our junior people.

SN: You have mentioned that in addition to "Industry," the "I" in SIAM can also stand for "Innovation." Tell us more about that.

SW: Research itself feeds innovation, of course, and we are in great shape if it adds real value and can improve our lives, communities, and businesses. Work by SIAM members is often connected to applications, and I hope that the SIAM network allows us to explore and increase the impact of our creative thinking and discoveries, and even bring our ideas to market.

Moving forward with research and innovation requires support from federal agencies, foundations, corporations, individuals, etc. Therefore, we must be able to effectively communicate what we do and bring to light the value of our work. We have to initiate these conversations and gain the support and understanding of policymakers, decision-makers, and the general public.

SN: Which of SIAM's recent programs or initiatives are you particularly excited about?

SW: So many wonderful ideas came from the highly engaged members of the Task Force on Future Research Directions for NSF in the Era of COVID-19.[8] We sent out a survey to SIAM membership and received a good number of responses. People really took time to answer our questions, so that was very helpful. This feedback is available via a link in the resulting report.

Other exciting developments are taking place in the field of data science, and I am glad to see the SIAM Activity Group on Data Science[9] working well. With the recent launch of SIAM Engage,[10] we will experience a lot of activity in that community and all of our others. It has also been great to witness modeling and computation addressing social sciences problems, and I look forward to seeing more of that work.

SN: What steps should SIAM take to further foster a diverse and inclusive environment?

SW: We want to elevate our work. There may be initiatives that we're pursuing in little silos or pockets, and having a new Vice President for Equity, Diversity, and Inclusion[11] who works with the Diversity Advisory Committee[12] will broaden these initiatives.

We need to continue examining our community climate and make sure that we provide a range of people with the agency and opportunity to serve in positions of influence and take part in our conference lineups. It is important that we continue to be mindful of maintaining a wider view and refrain from making assessments or conclusions based on how things run at one particular institution or in one geographical region. Broadening our perspective requires that we broaden participation. We need all voices at the table and all hands on deck. We want to recognize that we may exist in a system that might not have been set up for all peoples, and use that awareness to change things so that more people are welcome and want to be with us.

SN: How can SIAM continue to grow in the coming years?

SW: We have wonderful conferences and our publications are among the best in the world. We regularly receive exciting new articles, our journal editors and publishing staff do an excellent job, and we will do what we need to ensure that SIAM publications flourish. Mathematics and computational science have applications in a variety of fields. We will continue to develop partnerships and engage our broader community. I look forward to working with incoming president Susanne Brenner, all of the SIAM officers, members of the Board of Trustees and Council, and our esteemed volunteers to uphold and advance SIAM's mission and grow our reputation and influence.

Lina Sorg is the managing editor of SIAM News.

Suzanne Weekes (far right) served on the organizing committee of the 2007 SIAM Conference on Mathematics for Industry, which took place in Philadelphia. Here she poses at the meeting with students and faculty from the Worcester Polytechnic Institute (WPI) Center for Industrial Mathematics and Statistics and the WPI SIAM Student Chapter, all of whom presented their work at the conference. This photo initially appeared in the June 2008 issue of SIAM News.

4 https://www.siam.org/about-siam/committees/education-committee
5 https://www.siam.org/students-education/programs-initiatives/siam-visiting-lecturer-program
6 https://www.siam.org/students-education/student-chapters
7 https://www.siam.org/about-siam/committees/committee-on-science-policy-csp
8 See page 7 for an article by Suzanne Weekes about the task force report.
9 https://www.siam.org/membership/activity-groups/detail/data-science
10 https://engage.siam.org
11 https://sinews.siam.org/Details-Page/siam-welcomes-first-vice-president-for-equity-diversity-and-inclusion
12 https://www.siam.org/about-siam/committees/diversity-advisory-committee

SIAM Welcomes First Vice President for Equity, Diversity, and Inclusion

Ron Buckmire, Associate Dean for Curricular Affairs and a professor of mathematics at Occidental College, began his tenure as SIAM's first Vice President for Equity, Diversity, and Inclusion (EDI) on January 1. The primary focus of the VP for EDI is to expand SIAM membership across all demographics and establish an ethos of equity and inclusion throughout all SIAM programs and activities, ultimately ensuring that SIAM is serving its entire diverse community.

The VP for EDI will be a voting member of the SIAM Council and work with SIAM leadership and the VPs for Industry, Education, Publications, Science Policy, and Programs, as well as members of the Diversity Advisory Committee and Membership Committee.

Ron has previously served on both the SIAM Education Committee and the Diversity Advisory Committee; he is also currently chair of the Membership Committee. He will act as VP for EDI until December 31, 2022.

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Supporting the SIAM Community During Challenging Times

By Richard Moore

SIAM membership means different things to different people. To some, it is a chance to receive discounted access to SIAM's numerous books, journals, and conferences. Others value the opportunities that SIAM provides for career advancement and recognition. Many feel that their continued membership expresses a fundamental commitment to SIAM's mission to advance industrial and applied mathematics, and we all enjoy the sense of community with like-minded friends and colleagues. I had all of these rewards in mind when I first joined SIAM as a student over 20 years ago. Now they continue to inform our work at SIAM headquarters as we confront the many challenges that our community is currently facing during the COVID-19 pandemic.

To ensure that the SIAM community retained journal access even when unexpectedly working from home, we granted all members free access to LoPack—which includes SIAM's entire journal archive—during the spring and early summer of 2020. To build a greater sense of connectedness amidst our physical separation, we offered all members the opportunity to join an additional SIAM Activity Group (SIAG)[1]—a growing number of which have now launched webinar series to promote the open exchange of research and ideas—free of charge. SIAM has also deepened and widened its connection to applied mathematicians within the U.S. and abroad by forging new reciprocal agreements with domestic and international societies, and increasing the number of student chapters[2] to 200 across 27 different countries. Our two "new" SIAGs, the SIAG on Applied and Computational Discrete Algorithms[3] and the SIAG on Data Science[4] (a rescoped version of the former SIAG on Data Mining[5]), are rapidly expanding in membership. And as always, SIAM members will get discounted rates for all 2021 conferences. We look forward to gathering together again, virtually or in person.

2020 exposed the ways in which a lack of equity and opportunity permeates all aspects of society. SIAM is taking steps to understand the demographics of our members and community, and actively working to bolster programs that will address the underrepresentation of Black, Latino, and Native American researchers in applied mathematics and computational science. I am grateful to the large number of you who responded to our recent anonymous survey on race and ethnicity, and to those who completed their membership profiles with our updated demographic categories. SIAM's recent appointment of Ron Buckmire (Occidental College) as the first Vice President for Equity, Diversity, and Inclusion[6] will enable organization-wide coordination of our efforts to bring all voices to the shared pursuit of advancing applied math. SIAM continues to be an exemplar among mathematical societies in its recruitment and appointment of women to positions of honor and authority, and we are seeing persistent growth in their numbers as a proportion of overall SIAM membership.

As the COVID-19 vaccines suggest some light at the end of the pandemic tunnel, SIAM looks to emerge as a stronger society with a revitalized membership that is ready to make the world a better place through the power of mathematics. Some of you, whether due to difficult circumstances or the fact that SIAM's pivoted 2020 conferences were offered free of charge, have yet to renew your membership. You have received (or will soon receive) appeals from SIAM luminaries, whom you will recognize from your favorite textbooks, webinars, and plenary talks. They have graciously agreed to share, in their own words, why they value SIAM membership. Please heed their call to renew if you are able, and consider SIAM's discounted rate for unemployed/disabled members if applicable. As always, if you have suggestions for how SIAM can better serve you as a member, feel free to contact me at **moore@siam.org**. I and SIAM's amazing Membership team would love to hear from you.

Richard Moore is the Director of Programs and Services at SIAM.

1 https://www.siam.org/membership/activity-groups
2 https://www.siam.org/students-education/student-chapters
3 https://www.siam.org/membership/activity-groups/detail/applied-and-computational-discrete-algorithms
4 https://www.siam.org/membership/activity-groups/detail/data-science
5 https://sinews.siam.org/Details-Page/new-siam-activity-group-on-data-science
6 https://sinews.siam.org/Details-Page/siam-welcomes-first-vice-president-for-equity-diversity-and-inclusion

Deep Learning

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of this scenario in Figure 1a (on page 1). The deep learning approach to this problem consists of two stages. We first transform the feature space (possibly increasing its dimension) via a neural network. Next, we employ a simple classification model, such as linear multinomial regression. By utilizing a ResNet with N layers for the first step, we transform the data point $\mathbf{y}$ into $\mathbf{u}_N$ as follows:

$$\mathbf{u}_0 = \mathbf{K}_{\text{in}}\mathbf{y}$$

$$\mathbf{u}_1 = \mathbf{u}_0 + h\,\sigma(\mathbf{K}_0\mathbf{u}_0 + \mathbf{b}_0)$$

$$\vdots = \vdots$$

$$\mathbf{u}_N = \mathbf{u}_{N-1} + h\,\sigma(\mathbf{K}_{N-1}\mathbf{u}_{N-1} + \mathbf{b}_{N-1}).$$

Here, $\sigma(x) = \tanh(x)$ serves as an activation function that is applied element-wise, $h > 0$ is a fixed step size, and $\mathbf{K}_{\text{in}} \in \mathbb{R}^{3\times 2}$, $\mathbf{K}_0, \ldots, \mathbf{K}_{N-1} \in \mathbb{R}^{3\times 3}$, and $\mathbf{b}_0, \ldots, \mathbf{b}_{N-1} \in \mathbb{R}^3$ are the trainable weights. Figure 1b (on page 1) depicts the ResNet's action for the learned weights, which we determined through optimization. Based on the projections of the transformed points $\mathbf{u}_N$ onto their first two dimensions, it is apparent that solving the classification problem with a linear model has become trivial. Figure 1c (on page 1) displays the trained classifier in the original data space.

One can also interpret the transformed feature $\mathbf{u}_N$ as the forward Euler approximation of $\mathbf{u}(T)$ that satisfies the initial value problem

$$\partial_t \mathbf{u}(t) = \sigma(\mathbf{K}(t)\mathbf{u}(t) + \mathbf{b}(t)),$$

$$t \in (0, T], \quad \mathbf{u}(0) = \mathbf{K}_{\text{in}}\mathbf{y}.$$

Here, $T > 0$ is an artificial final time that is loosely related to the network's depth [4, 8].

This continuous viewpoint has been popularized in the machine learning community under the term "neural ordinary differential equations" (ODEs) [3]; however, similar ideas are already published [6]. Scientists have recently been applying ODE techniques to create faster, better-understood algorithms for neural networks. For instance, we have proposed new architectures that lead to more stable ODE dynamics [8]. Furthermore, since one might view training as a (stochastic) optimal control problem, efficient solvers for the learning problem (as well as insight into this problem) have resulted from adapted computational science and engineering methods [5, 7].

Analysis of high-dimensional datasets like speech, image, and video data has been a significant focal point for the deep learning community. In fact, deep learning's breakthroughs in speech and image recognition roughly a decade ago are partly responsible for renewed interest in the subject. Nevertheless, some challenges remain difficult or beyond reach. These ongoing problems include controlling a self-driving car based on predictions made from high-resolution images of street scenes, and reliably computing the volume fraction of COVID-19-affected lung tissue in three-dimensional computed tomography images[2] [10].

While such theoretical and computational challenges may seem insurmountable, we can turn to the field of PDE-based imaging for inspiration. In the last several decades, researchers have created many celebrated algorithms by interpreting image data as discretized functions that can be processed via PDE or integral operators. One can also apply this viewpoint to deep learning with convolutional neural networks whose operators are linear combinations of PDE operators [6].

We have used this observation to extend the neural ODE framework to PDEs and create new types of networks. Specifically, we adapted residual neural networks to form unique models that inherit the stability of parabolic PDEs or—upon suitable discretization—lead to reversible hyperbolic networks [11]. The latter can help overcome memory limitations of current computing hardware. For instance, we trained a hyperbolic network with more than 1,200 layers to classify images on a single graphics processing unit [2].

Deep Learning for the Solution of High-Dimensional PDEs

With few exceptions, the numerical solution of high-dimensional PDEs is challenging due to the curse of dimensionality. As a simple example, consider a finite difference method for the solution of Poisson's problem on a rectangular grid with n cells in each dimension. This approach quickly becomes prohibitive as d grows, since the mesh consists of n^d cells. The exponential growth of computational costs prohibits the application of the finite difference method—and other methods that rely on grids—to high-dimensional problems that arise in areas like statistics, finance, and economics. To avoid this, one can utilize a neural network to parameterize the PDE solution and rely on the network's universal approximation properties. While the concept itself is not especially novel, deep learning advances—particularly new architectures, improved theoretical results, optimization algorithms, and easy-to-use software packages—have enabled several impressive outcomes.

One such example is the application of neural networks to high-dimensional mean field games [12]. Mean field games arise in multiple applications[3] [1]. Their solution is characterized by the value function that satisfies a PDE system, which couples the continuity equation and the Hamilton-Jacobi-Bellman (HJB) equation. Computing the value function is extremely challenging due to the forward-backward structure, the HJB equation's nonlinearity, and the high dimensionality. Our approach employs a neural network that is specifically designed to allow a mesh-free solution of the continuity equation via a Lagrangian method. Although more analysis is needed to fully understand the stochastic non-convex optimization problem that trains the network, our initial results indicate that neural networks can compete with well-understood, mesh-based methods in two dimensions while also being scalable to 100 dimensions.

Outlook

Here I intend to provide a glimpse into the exciting activities and opportunities at the interface of deep learning and applied mathematics. To demonstrate that this is not a one-way street, I discuss the promises of deep learning for difficult and almost impossible problems in applied math, particularly the numerical solution of high-dimensional PDEs.

The coming years will almost certainly see SIAM and its members drive advances in these areas. Given the widespread use of deep learning in real-world applications, one can perhaps expect the biggest impact to stem from mathematical theory—including numerical analysis—that aims to obtain reliable, interpretable, fair, and efficient machine learning models. These models would also enable deep learning in scientific applications where current results suggest significant potential yet open issues, such as convergence guarantees and uncertainty quantification. Finally, fusing data-driven and model-based approaches is a promising means of compensating the lack of first-principle-based models with data in the form of measurements, observations, and simulations.

This article is based on Lars Ruthotto's invited talk at the 2020 SIAM Annual Meeting,[4] which took place virtually last July. Ruthotto's presentation is available on SIAM's YouTube Channel.[5]

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Lars Ruthotto is an applied mathematician who develops computational methods for machine learning and inverse problems. He is an associate professor in the Department of Mathematics and Department of Computer Science at Emory University.

2 https://sinews.siam.org/Details-Page/deep-learning-for-covid-19-diagnosis
3 https://sinews.siam.org/Details-Page/mean-field-game-theory-a-tractable-methodology-for-large-population-problems
4 https://www.siam.org/conferences/cm/conference/an20
5 https://www.youtube.com/watch?v=-PBWA1VpT1E

Cryptocurrencies, Mining, and Mean Field Games

By A. Max Reppen and Ronnie Sircar

Most discussion about cryptocurrencies—particularly Bitcoin—concerns the wildness of their prices, which seem to follow perpetual cycles of speculative mania and ensuing collapse. This article is not about their prices. Instead, we are interested in understanding and modeling the interactions of Bitcoin miners and the consequent evolution of wealth inequality among participants. A primary debate in regulatory conversations pertains to whether cryptocurrencies are currencies or commodities (or even share-like assets with their initial coin offerings). Although this issue is not settled by any means, the U.S. Commodity Futures Trading Commission classifies cryptocurrencies as commodities, and their electronic structure of production mirrors the uncertainty and language of mining resources in finite supply.[1] The latter connects us to game theoretic models that researchers have developed to explain energy production from various sources, many of which—like oil—are exhaustible [8, 9].

Much of the promise and buzz around crypto comes from novice investors who score a quick profit off of an astounding price soar — doesn't everyone know someone who claims to have had such speculative success at one time or another?[2] But again, we are not discussing prices here. One argument maintains that data privacy concerns might conceivably be allayed by a payment and banking system that is founded on the underlying blockchain technologies, though a largely unregulated network could have myriad unintended benefits for trafficking and laundering. The hype may parallel that of the liberating internet a quarter-century ago, which promised that anyone would be able to communicate whatever they wanted to everyone. Now of course we do just that. Time will tell the future of cryptocurrencies in society.

Many interesting modern problems in financial mathematics and engineering lie at different points along the spectrum between economic and financial models. In our classification, one might think of economic models as concerned with the "why" and "how," and financial models more with the "what." Economic models are primarily intended to describe interdependencies, and for this purpose they are often simple — particularly about including evolution over time. As such, they may cover only one or two periods of time. These models largely ignore complex stochasticity, often subsuming uncertainty into expected quantities. But they focus on players—investors, producers, and consumers—whose rationales dictate demand and supply, as well as market mechanisms that clear them through prices. Financial models are phenomenological; prices look unpredictable and are modeled directly as stochastic processes that are intended for calibration from past data. Market participants are price takers, and price models are usually driven by some uncontrolled Brownian motions without addressing cause.

In the context of so-called proof-of-work cryptocurrency mining, an economic model captures the cost-reward structure of mining. The cost is typically the marginal cost of electricity, and the potential reward is the units of currency that are rewarded to successful miners. Similar to models of natural resource extraction, the miners are producers — but in this case the product is numbers. These numbers, called *hashes*, come from processing transaction data. Because of the demand for processing, there is effectively also a demand for hashes. Like in any other market, the suppliers (miners) are competing to satisfy this demand. And as with other markets, the (expected) reward per hash obtained is diminishing in the aggregate supply (mining power).

However, calling this system a market for hashes masks the actual mechanism, since it is not the numbers that are valuable. Instead, the value lies in the process that "extracts" (mines) the numbers; the numbers themselves are just a byproduct. This process is an artificial math puzzle that is meant to disincentivize bad behavior by forcing miners to provide proof-of-work that some effort has been exerted in the form of electricity paid. But because of the puzzle's construction, there is only demand for certain numbers, i.e., solutions to the puzzle. Moreover, the puzzle is constructed so that any attempted solutions have an equal chance of being correct, thus causing correct solutions to appear randomly. So while an oil producer outputs a barrel of oil with relative certainty, a miner outputs a binomial random variable that is only observable after production. The success probability of the binomial variable is adjusted by the "demand" and decreasing in the supply.

A successful outcome is the right to record the next set of transactions—the next block—on the blockchain. Simplified, miners only receive the reward (the solution hash "bought" on the market) if the block is consistent with past blocks. Since the mining cost is paid upfront, only consistent blocks are accepted. In particular, the market demand is such that the average rate of global success is constant. Altogether, a miner's success probability for the next block is their share of total hash production. Miner i who produces $\alpha^i \geq 0$ hashes has a success probability of $\alpha^i/(M\bar{\alpha})$, where M is the number of miners, α^j is the effort of miner j, and $\bar{\alpha}$ is the average hash rate $\frac{1}{M}\sum_{j=1}^{M}\alpha^j$.

We now describe a model that we developed and studied with Zongxi Li[3] [7]. For a large number of miners, α^i has a relatively small impact on the global average. Thus, $M\bar{\alpha} \approx \alpha^i + (M-1)\bar{\alpha}$ and $(M-1)\bar{\alpha}$ approximates the aggregate competition. The competition for each reward is repeated indefinitely. In continuous time, every miner chooses their hashing rate α^i_t. The binomial outcomes are represented by a counting process N^i_t with a jump intensity λ^i_t that is proportional to the share of global hashes:

$$\lambda^i_t = \frac{\alpha^i_t}{D(\alpha^i_t + (M-1)\bar{\alpha}_t)}, \quad D > 0. \tag{1}$$

With a reward r per success and a cost c per hash, a miner's wealth evolves as $\mathrm{d}X^i_t = -c\alpha^i \mathrm{d}t + r\,\mathrm{d}N^i_t$. All miners maximize their expected utility U at a fixed horizon T:

$$v(t,x;\bar{\alpha}) = \sup_{\alpha} \mathbb{E}[U(X^i_T) \,|\, X^i_t = x].$$

The interaction between agents in (1) occurs through the mean global hash rate, so we have a *mean field game of controls* — also known as an *extended mean field game* [3]. Researchers have also studied a related mean field game with individually controlled stochastic jumps that represent new oil discoveries [4]; in our model (1), the jump intensities depend on the mean field interaction.

Given the actions of other miners, which are represented by their average $\bar{\alpha}$, a representative miner finds the optimal hash rate α^*—the best response to the observed aggregate competition $(M-1)\bar{\alpha}$—by solving the Hamilton-Jacobi-Bellman (HJB) partial differential-delay equation

$$\partial_t v + \sup_{\alpha \geq 0}\left(-c\alpha\partial_x v + \frac{\alpha}{D(\alpha + (M-1)\bar{\alpha}_t)}\Delta v \right) = 0. \tag{2}$$

Here, $v(T,x) = U(x)$ and $\Delta v = v(t,x+r;\bar{\alpha}) - v(t,x;\bar{\alpha})$. To close the system, we use the Fokker-Planck equation for the probability density $m(t,x;\bar{\alpha})$ of the miner's wealth at time t:

$$\partial_t m - \partial_x(c\alpha^*(t,x)m) - \frac{1}{D}\left(\frac{\alpha^*(t,x-r)}{\alpha^*(t,x-r) + (M-1)\bar{\alpha}_t} m(t,x-r;\bar{\alpha}) - \frac{\alpha^*(t,x)}{\alpha^*(t,x) + (M-1)\bar{\alpha}_t} m(t,x;\bar{\alpha}) \right) = 0. \tag{3}$$

The mean field equilibrium is the fixed point

$$\bar{\alpha}^*_t = \int_{\mathbb{R}} \alpha^*(t,x;\bar{\alpha}^*)m(t,x;\bar{\alpha}^*)\mathrm{d}x, \tag{4}$$

which is characterized by equations (2), (3), and (4). This characterization is amenable to numerical analysis, which one can implement by iteratively solving (2) and

See **Cryptocurrencies** *on page 7*

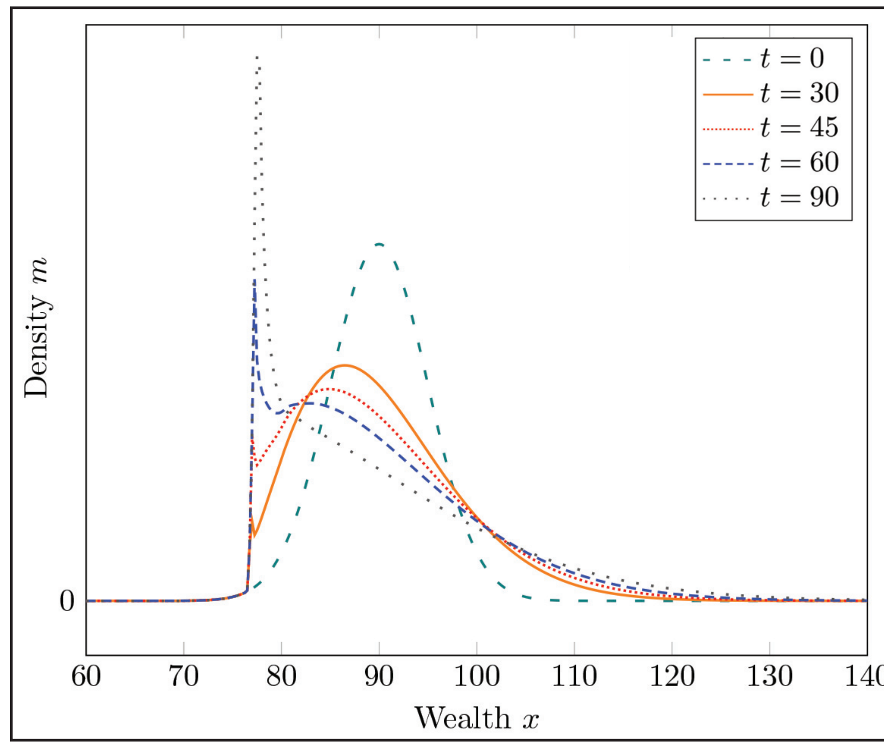

Figure 1. *Evolution of the wealth distribution of miners over time. Low-wealth miners stop mining (mass accumulates at the threshold point) because they cannot compete at a small scale, which further drives profits to wealthier miners. Figure courtesy of the authors.*

[1] For example, Bitcoin were created in January 2009 and are limited to 21 million, with about 17 million currently in circulation.

[2] There may be cryptocurrencies that are this modern commodity's analog of snake oil.

[3] Other recent studies focus on very different aspects of cryptocurrency mining [1, 2, 5].

Meet the Newest Members of the SIAM Board of Trustees and Council

By Lina Sorg

We are pleased to announce the newest members of the SIAM Board of Trustees and Council, as chosen by SIAM membership in the recent election.

Liliana Borcea (University of Michigan), Jan S. Hesthaven (École Polytechnique Fédérale de Lausanne), and Esmond G. Ng (Lawrence Berkeley National Laboratory) were elected to the SIAM Board of Trustees. The Board is responsible for overall management of SIAM—including financial aspects like budgets, funds, and investments—and simultaneous consideration of the organization's professional and scientific policies and objectives.

Elizabeth Cherry (Georgia Institute of Technology), Hans De Sterck (University of Waterloo), Alicia Dickenstein (University of Buenos Aires and CONICET), Laura Grigori (INRIA, France), and Lois Curfman McInnes (Argonne National Laboratory) were elected to the SIAM Council. The Council reviews and formulates SIAM's scientific policies, monitors the organization's technical activities, proposes new activities, and recommends actions to the Board when appropriate.

The newly-elected members of the Board and Council began their tenure on January 1, 2021 and will serve through December 31, 2023. Here they share their reactions, ideas, and objectives for their time of service.

SIAM Board of Trustees

Liliana Borcea: "I am honored to serve alongside the distinguished scientists on the SIAM Board. My efforts will focus on increasing the impact and visibility of SIAM and applied mathematics as key players in addressing the ever-growing scope and complexity of problems that are driven by rapidly-developing technological discoveries and an explosion of data. I would also like SIAM to play an even stronger role in recruiting and training a versatile generation of scientists that can move easily between disciplines and have impactful careers in academia, research labs, and industry."

Jan Hesthaven: "Being elected to represent the SIAM community on the Board of Trustees is of course a special privilege and an honor. Building and reinforcing communities of applied, computational, and industrial mathematicians worldwide is as important as ever, and I look forward to contributing to the development of new initiatives that further strengthen SIAM's global footprint and ensure a lasting impact on our community — with particular emphasis on our younger colleagues."

Esmond Ng: "I am honored to be re-elected to the SIAM Board of Trustees and appreciate the support from the SIAM community. One challenge that the organization is facing is the impact of the COVID-19 pandemic, such as the effect on all SIAM conferences — some have been cancelled or rescheduled and others have occurred virtually. Such changes have implications on the operational and financial aspects of SIAM. I will work with the Board to ensure that proper financial and operational decisions are made to overcome these challenges."

SIAM Council

Elizabeth Cherry: "I am excited and honored to serve on the SIAM Council, and I look forward to helping SIAM maintain its prominence as a global leader and address new challenges and opportunities. I am optimistic that as we continue to find novel ways to connect and share knowledge during the current worldwide pandemic, we will leverage what we learn to accelerate progress on longer-term goals to engage more diverse, cross-disciplinary, and global communities."

Hans De Sterck: "It is of course a great honour to serve on the SIAM Council. SIAM plays a vital role in our community of applied and computational mathematicians at an international scale. The next few years will be important as the society reacts to the many challenges and opportunities that arise due to the ongoing pandemic and transition into the post-pandemic world. New online and hybrid conference formats will continue to reshape how we network and disseminate our work. Online publishing and the progression towards open access and reproducibility will keep evolving the "publications" cornerstone of the organization, and we're experiencing a strong momentum towards effecting real change in terms of equity and inclusion for underrepresented groups. The coming years will see many exciting evolutions for SIAM and the field of applied mathematics, and I look forward to contributing to this."

Alicia Dickenstein: "I am very honored and grateful to have been elected to the SIAM Council and am happy to serve the entire SIAM community. In particular, I look forward to representing the Latin American SIAM community that works outside of the U.S., as well as the relatively small but constantly-growing SIAM Activity Group on Algebraic Geometry.

In addition to the many usual challenges related to funding, underrepresentation, publishing, industry engagement, education, and outreach, we will need to incorporate the experiences and new scientific developments that emerged from the COVID-19 outbreak to overcome the current situation. These efforts will include changing the bad things and improving the good things that we learned from the pandemic."

Laura Grigori: "I am truly honored to continue serving as a member of the SIAM Council and look forward to working with my colleagues to ensure that the society maintains its prominent status and visibility amongst both our fellow scientists and the general public. My efforts over the next three years will focus on achieving genuine progress on some specific objectives that I particularly value: making SIAM attractive to new generations of researchers and increasing diversity among its members and in the context of specific actions that arise under its auspices."

Lois Curfman McInnes: "I am indeed honored to serve a second term as a member of the SIAM Council and am grateful to work with the entire SIAM community. A key issue from my perspective involves exploring and expanding the use of technologies to support SIAM community interaction, even while we are socially distanced. Leveraging such technologies could enable the SIAM community to reimagine events and outreach to incorporate hybrid elements that fully support remote connection, thereby expanding participation in ways that we're only beginning to fathom. Other important topics include broadening interdisciplinary education and research; extending connections among the academic, industrial, and research laboratory segments of the SIAM community; and promoting broader engagement from underrepresented groups."

The dedication of SIAM's elected members contributes to the continued success of the society, and SIAM extends its deep appreciation to the entire slate of wonderful candidates and the SIAM members who cast their votes. Thank you for your willingness to serve our community.

Lina Sorg is the managing editor of SIAM News.

How Intelligent is Artificial Intelligence?

BOOK REVIEW
By Oana Marin

Rebooting AI: Building Artificial Intelligence We Can Trust. *By Gary Marcus and Ernest Davis. Pantheon Books, New York, NY, September 2019. 288 pages, $28.95.*

"*To reboot, or not to reboot?*" is an almost Shakespearean question that all users face when their computers fail to respond to simple commands. This universal query gains even more depth when humans relinquish their intelligence—the competitive advantage of their species—to a computer, referring to this machine capability as artificial intelligence (AI). *Rebooting AI* by Gary Marcus and Ernest Davis is both a "food for thought" text as well as a scientific assessment of AI's status in a world that is overwhelmed with information.

"To boot" is a contronym, as it has two opposite meanings. Intended or not, the pun in the book's title is not lost on the reader. Depending on the context, "to boot" can either mean to start or be kicked out. The authors do not position themselves on either side of the word, but caution readers as to where relevant pitfalls may lie. The first chapter of *Rebooting AI*, entitled "Mind the Gap," makes this point clear. The text is packed with lexical musings, such as "deep learning just ain't that deep." This is a jab at the word "depth," which in the context of deep learning refers solely to the depth of a neural network. So perhaps we may conclude that Marcus and Davis are indeed toying with the vocabulary at a level of subtlety that is only accessible to humans, possibly to strengthen the point made in the title of chapter four: "If Computers Are So Smart, How Come They Can't Read?"

Historical accounts take the reader from incipient promises made as early as the 1960s, which predicted that computers would flawlessly mimic human intelligence within 20 years, to the present day, where the mirror of our own biases leaves us confounded. Although impartially written and safely grounded in references, the book allows several questions to transpire. Where can we expect AI to succeed? How can AI best serve humankind? In what ways should AI improve? The wealth of facts in the text is not devoid of emotion; the authors express concern when appropriate, and the tone is almost tender and tolerant of the human condition's fragility.

Rebooting AI: Building Artificial Intelligence We Can Trust. By Gary Marcus and Ernest Davis. Courtesy of Pantheon Books.

Marcus and Davis' exposition follows the basic steps of scientific procedure: problem, hypothesis, and solution. In this spirit, the authors reveal AI's foundational insufficiencies, hypothesize on their nature, and quickly reassure readers with an array of possible solutions.

The essential distinction between AI and machine learning is often muddled in casual language — particularly in the physics-dominated branches of applied mathematics, where AI robotics applications are of lesser relevance. *Rebooting AI* clarifies that machine learning is merely a subset of AI that is focused on learning from data, while AI also includes topics like reasoning and knowledge representation.

As the most promising subfield of machine learning, deep learning receives its deconstructive treatment in chapter three (entitled "Deep Learning, and Beyond") and is not entrenched in the overly-standard supervised/unsupervised/reinforcement learning classification. The authors' path is instead rather pragmatic, as they explore the extent to which a neural network can perform "end-to-end" tasks. Their discussion about the role of graphical processing units in propelling the AI revolution and consolidating the belief that machines could outperform humans in terms of processing speed (only to hit the wall of big data soon after) would likely be of interest to applied mathematicians.

Proceeding on the assumption that an "end-to-end" machine might be possible, the next chapters bring the reader into the fields of neuroscience, linguistics, and cognitive psychology. Marcus and Davis posit that an "inventory of knowledge" and a "representation of knowledge" are the prerequisites of any reliable AI machine that is free of human confirmation bias. To support this stance, the book establishes a set of 11 clues from the cognitive sciences to guide AI's development. My personal favorite is "Concepts are embedded in theories," with its punchline that "no fact is an island."

From a technical viewpoint, the major challenge of AI pertains to the integration of elusive concepts like common sense. As such, the authors browse various key components in an effort to determine how to render common sense programmable. The text pivots from linguistic theory, following Noam Chomsky's assertion that "the essence of language is...infinite use of finite means," to the computer science limitations of finite-bit representations. Similarly, semantic networks—like ConceptNet,[1] which is intended to facilitate reasoning tasks—are swiftly reinterpreted via formal logic.

It is refreshing that *Rebooting AI* does not shy away from AI's delicate failures, such as algorithms that displayed discriminatory tendencies (as with image-labeling technology for Google photos in 2015) or anti-Semitic behavior (as with Microsoft's experimental chatbot, Tay, in 2016). Although the algorithms themselves are not inherently prejudiced, they reinforce human bias through their very nature. Does this fact call for a change in the machine

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[1] https://conceptnet.io

SIAM Sponsors Two New Project NExT Fellows

By Kathleen Kavanagh, Manuchehr Aminian, and Alvaro Ortiz

SIAM recognizes the importance of supporting the professional development of junior faculty, especially in the areas of teaching and applied mathematics education. While the Activity Group on Applied Mathematics Education[1] (SIAG/ED) certainly addresses this need, SIAM began annually sponsoring two Project NExT (New Experiences in Teaching) Fellows for the first time last year. Project NExT,[2] which is run by the Mathematical Association of America (MAA), supports the professional development of new or recent Ph.D.s in the mathematical sciences. As per the MAA, the program "addresses all aspects of an academic career: improving the teaching and learning of mathematics, engaging in research and scholarship, finding exciting and interesting service opportunities, and participating in professional activities."

Workforce preparation and the fulfilment of industry requirements begin with excellence in applied mathematics education. Junior faculty actively foster a global appreciation for mathematics by inspiring and empowering students from different backgrounds to solve complex, real-world problems. However, not everyone who graduates with a Ph.D. in mathematics inherently possesses the right resources or training experience to thrive in an academic setting. One of Project NExT's most valuable features is the network of peers and mentors that it provides to Fellows as they navigate their new careers.

During their first year in the program, each cohort of Project NExT Fellows participates in a range of workshops at MAA's MathFest and the Joint Mathematics Meetings (JMM). Recent workshop topics included managing time efficiently, forming a vibrant and inclusive community, incorporating modeling in differential equations, orienting one's classroom around inquiry, and preparing students for industry careers. SIAM's Project NExT Fellows are also strongly encouraged to participate in SIAG/ED meetings and partake in activities that are associated with the SIAM Education Committee, such as the organization of SIAM-sponsored events at JMM and MathFest.

In 2020, Carl Giuffre (Adelphi University) and Lidia Mrad (Mount Holyoke College) became the first two SIAM Project NExT Fellows. The 2021 SIAM Project NExT Fellowship was recently awarded to Manuchehr Aminian and Alvaro Ortiz. Aminian is an assistant professor at California State Polytechnic University, Pomona. His research interests include the analysis of passive tracers in advection-diffusion systems, anomaly detection and feature selection in large biological data sets, and mathematical data science in general. Aminain strongly believes that genuine application problems and numerical mathematics can positively impact both mathematics students and other majors. Math educators must take a leading role in familiarizing students—the future leaders—with modeling, data, and algorithms, all of which already play a central role in everyday life. He has incorporated these ideas into a variety of classes during his early teaching career, ranging from first-semester calculus for biologists to undergraduate numerical analysis.

Manuchehr Aminian, California State Polytechnic University, Pomona.

Aminian has found his SIAM membership to be extremely useful for keeping up with the cutting edge of applied mathematics via conferences, activity groups, and the print version of *SIAM News*. Project NExT complements his objectives by promoting evidence-based teaching practices—such as inquiry-based learning and projects—and providing a peer network of early-career faculty with whom to compare notes and effect broader change in the applied mathematics community and beyond.

Alvaro Ortiz is currently an assistant professor in the School of Science and Technology at Georgia Gwinnett College (GGC). He earned his Ph.D. in mathematics from the University of Cincinnati, where he utilized a blend of network modeling, differential equations, and numerical methods to study the dynamics of biological contamination in water distribution systems with biofilms. Now he calls on applied mathematics for academic research and teaching. As an advocate for active and project-based learning and teaching philosophies, Ortiz uses real-world occurrences to illustrate and promote the discovery of mathematical ideas. The Project NExT Fellowship has connected him with like-minded educators and fostered hands-on experience with new technologies for information and communication, which are essential in classrooms during the ongoing COVID-19 pandemic. Ortiz plans to rely on both SIAM and Project NExT as resources and points of support as he continues to create engaging courses and bolster the applied mathematics major at GGC through projects in mathematical biology, video game design, and network modeling.

Alvaro Ortiz, Georgia Gwinnett College.

To apply for the Project NExT Fellowship, candidates must submit a personal statement, research statement, one-page curriculum vitae, and letter of support from their department chairs. Eligibility requirements include a recent Ph.D. in mathematics, statistics, mathematics education, or another math-intensive field. Applicants must also currently hold a teaching position and have experiences, attitudes, ideas, and leadership abilities that would positively contribute to the cohort. To be considered for the SIAM position, candidates must indicate their SIAM membership on their applications. An MAA committee makes all final selections. The next application deadline is April 15, 2021; more information is available online.[3]

There is no doubt that the impact of one exceptional faculty member can have a far reach within both SIAM and the wider scientific community. SIAM is eager to advance applied mathematics education for the next generation of interdisciplinary problem-solvers.

Kathleen Kavanagh is a professor of mathematics at Clarkson University and the Vice President for Education at SIAM. Manuchehr Aminian is an assistant professor in the Department of Mathematics and Statistics at California State Polytechnic University, Pomona. His interests include mathematical modeling, visualization, and mathematical methods in data science. Alvaro Ortiz is an assistant professor of mathematics in the School of Science and Technology at Georgia Gwinnett College. He is interested in mathematical biology, network modeling, math methods for game design, and math education.

[1] https://www.siam.org/membership/activity-groups/detail/applied-mathematics-education

[2] https://www.maa.org/programs-and-communities/professional-development/project-next

[3] https://www.maa.org/programs-and-communities/professional-development/project-next

Artificial Intelligence

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learning paradigm, or is it entirely due to the training data sets?

The closing chapter, "Trust," launches with an epigraph that is attributed to Zora Neale Hurston: "Gods always behave like the people who make them." Readers are left to wonder about the identity of the gods. Are they the computers who may overtake humanity in doomsday scenarios, or the humans who—as AI creators—will always hold the advantage of untranslatable infinity of depth (much as the universe has for them)? This last chapter dives deeper into robust engineering design, safeguards, and general scientific practices to answer the question of trust, which is understood as reliability. Readers are also made aware of one of the central puzzles of scientific progress; in interdisciplinary fields like AI, the individual scientific branches that comprise the whole unit do not advance at the same speeds. If this detail already causes difficulties in the physical sciences, having to co-opt the humanities and establish a bridge between these fields is an even more significant challenge.

Though it abounds with warnings about AI, the book ends on an optimistic note and assures readers of AI's transformative power. Marcus and Davis even voice their collective belief that a machine that can teach itself to be an expert is within reach. When discussing overall impact on humanity, the authors ultimately compare the AI revolution with the Industrial Revolution. The Epilogue idealistically suggests that while automation might lead to higher unemployment rates, it may eventually make way for Oscar Wilde's vision of life as reduced to "enjoying cultivated leisure."

In summary, *Rebooting AI* offers something for everyone: the scientist learning about the historical evolution of AI, the sociologist concerned with AI's impact on society, the neuroscientist interested in constructing a replica of the human brain, the anthropologist intrigued by the naissance of human intelligence, the science fiction writer searching for a dystopian angle, etc. It is invaluable for a popular science book to seamlessly unite so many types of readers and incite joint efforts to answer major questions that pertain to civilization. Given the authors' backgrounds, it is not accidental that *Rebooting AI* inspires en masse, and we are thankful that Marcus and Davis continue to reach popular audiences with their work.

Oana Marin is an Assistant Applied Mathematics Specialist at Argonne National Laboratory. She is active in machine learning applications to mathematical physics.

The Task Force Report on Future Research Directions for NSF in the Era of COVID-19

By Suzanne L. Weekes

The July 2020 installment of *Unwrapped*,[1] SIAM's monthly e-newsletter, included a heading that read "*SIAM Establishes Task Force on Future Research Directions for NSF in the Era of COVID-19*." This task force was an ad hoc working group of the SIAM Committee on Science Policy (CSP) that was informed by conversations from the spring CSP meeting with federal agency officials, which took place virtually in April 2020. Recognizing that COVID-19 would dramatically impact the National Science Foundation's (NSF) agenda and the broader federal research enterprise, the CSP charged the task force with drafting a report to help inform the NSF's response to present needs associated with the pandemic and lay the groundwork for a more robust disaster response regime and future economic security and prosperity. The full task force report is available online.[2]

Anne Gelb (Dartmouth College), SIAM's Vice President for Science Policy, and then-executive director James Crowley asked me to chair the task force effort. Working with such wonderfully committed and informed SIAM members was a highlight of the summer of 2020. We met weekly in July, bringing people together over a nine-hour time difference — which meant that breakfast, lunch, and cocktails were occasionally consumed during the same meeting!

I would like to thank Marsha Berger (New York University), Amr El-Bakry (ExxonMobil), Tom Grandine (Boeing), Jan Hesthaven (École Polytechnique Fédérale de Lausanne), Peter March (Rutgers University), Madhav Marethe (University of Virginia), Lois Curfman McInnes (Argonne National Laboratory), Rosemary Renaut (Arizona State University), Fadil Santosa (Johns Hopkins University), and Padmanabhan Seshaiyer (George Mason University), in addition to Anne Gelb and James Crowley, for sharing their personal experiences, professional expertise, and keen vision. We all received excellent support for our work from Ben Kallen, Miriam Quintal, and Eliana Perlmutter of Lewis-Burke Associates LLC. Lewis-Burke, which has represented SIAM in Washington, D.C. since 2001, helps the CSP and the SIAM executive director connect with federal agency officials and advocate for research funding and sound research policy in Congress.

The task force also solicited and incorporated input from SIAM membership. The aforementioned notice in July's *Unwrapped* directed readers to a survey that requested input in the following categories: Research and Related Activities Specific to COVID-19 Response and Recovery, Near-term Response to COVID-19 Impacts on the Larger Research Enterprise, "Shovel Ready" Research Infrastructure, and Long-term Economic Stimulus and Recovery. The survey responses are available online.[3] Thank you to all readers who shared their thoughts with us!

Several themes emerged from the rigorous discussions in the task force as well as the survey responses. The following paragraphs detail these themes.

Mathematics of Disaster Planning, Response, Recovery, and Resilience

Research in applied mathematics, modeling, and computational science should continue to address the challenges associated with the ongoing pandemic through contributions to forecasting, diagnostics, treatments, vaccines, and studies of societal impacts. However, it is also critical to encourage and support research and modeling efforts that can prepare us to better handle future outbreaks and catastrophes. Mathematics, computational science, and data science will be vital to laying the foundation for a more robust disaster planning and response regime, particularly by strengthening supply chain resilience and optimization, improving decision-making amid uncertainty, and understanding group dynamics in crises. The Working Group on Predictive Modeling and Uncertainty Quantification, which is an open working group of the NSF Advisory Committee on Cyberinfrastructure, provided a document[4] that further demonstrated the critical need to support decision-making with uncertainty quantification and predictive modeling, especially—but not exclusively—during the current pandemic.

SIAM's task force report highlighted additional topics as general areas of emphasis, including network science and network analysis; secure and protected real-time data integration and analytics for accurate forecasting; predictive and informed modeling of disease spread, control, and mitigation; and mathematical foundations of artificial intelligence and machine learning. Because it is important that our members are aware of these critical topics, let us know if you are interested in organizing or presenting in a relevant area. Please contact Richard Moore, SIAM's Director of Programs and Services, and/or me with your ideas. We can be reached at **moore@siam.org** and **weekes@siam.org**.

Partnerships

Many areas of disaster response and mitigation suffer from a gap in the pipeline between research and operations. Basic science and research and operational readiness often have quite separate communities and stakeholders, and cross-sectoral and interagency partnerships can help bridge that divide. We hope for more active engagement with the NSF's Directorate for Social and Behavioral Sciences, which sits at the center of many decision-making and behavioral questions, and where modeling tools and understanding are underdeveloped relative to other fields.

The NSF should look to develop more partnerships that are relevant to pandemics and build resilience against future disasters. For example, the task force report recommends connecting the mathematical and computational science communities to disciplines or agencies that currently lack strong ties to our population, such as those within the Department of Health and Human Services (aside from the National Institutes of Health).

Task force members also discussed the unique need to translate foundational or applied mathematics research, and encouraged the NSF to consider incentives in partnerships between industry and universities. These incentives could motivate industry partners to make corresponding investments in their own development enterprises to ensure that university research is meeting customer demands.

Workforce Development

Task force members and survey responders expressed universal concern about workforce development and COVID-19's negative ramifications for students and early-career researchers. The group urged that those at critical transition points in their careers, underrepresented and underserved groups hit hard by the pandemic, and primary caretakers who face especially challenging dynamics all receive special focus. The report goes into more detail about this topic and contains several ideas that SIAM members could help move forward. I encourage members who are interested in developing relevant grant proposals or programs that meet these needs to reach out to Richard Moore and/or me.

Infrastructure and Collaboration Tools

Most SIAM members are now nearly a year into the paradigm of remote work, though of course some of you were working remotely even before the pandemic. Regardless, we now have some sense of the promises and limitations of this mode of operation. We must consider the future of research in the applied mathematics, modeling, and computational science communities, as well as the specific infrastructure and tools that are required to enable that vision. The report identifies the need to build a cyber infrastructure that can catalogue, store, access, parse, manage, and process data. Supporting digital management tools is also necessary.

SIAM is committed to raising the profile of applied mathematics, computational science, and modeling within the federal research enterprise, and ensuring the application of high-quality research results to solve real-world problems through industry, government, and other avenues to ultimately benefit society. The task force report was delivered to key personnel in the NSF's Directorate for Education and Human Resources; Directorate for Computer and Information Science and Engineering; Directorate for Social, Behavioral, and Economic Sciences; and the Division of Mathematical Sciences.

Suzanne L. Weekes is the executive director of SIAM.

[1] https://sinews.siam.org/Details-Page/siam-unwrapped-july-2020

[2] https://www.siam.org/Portals/0/reports/Report%20on%20Future%20Research%20Directions%20for%20NSF.pdf?ver=2020-12-10-144744-750

[3] https://drive.google.com/file/d/1XNvg6ltCAIpMMTpc8o-098NjzD5JPXRD/view

[4] https://drive.google.com/file/d/1ho1w3tEcT4V5Un4pjSLJCNcnYM83F_Uz/view

Cryptocurrencies

Continued from page 4

(3), together with an updating step based on (4) in between.

Numerical computations reveal the presence of a phenomenon called *preferential attachment*, or "*the rich get richer*," which means that those who have more also receive more in a manner that is disproportionate to the wealth difference. These results are consistent with empirical findings [6]. Figure 1 (on page 4) shows the evolution of the wealth distribution of miners. The source of this preferential attachment is the fact that wealthier miners have disproportionally strong incentives to mine, which leads to the emergence of mining pools in the real world. This growth of wealth imbalances has the potential to drive mining centralization, which weakens the security of cryptocurrency. These effects are exacerbated when some miners have a cost advantage over the competition, i.e., lower costs c than others. This last point is illustrated in Figure 2, where one miner has a cost advantage and captures most of the net profits in the market.

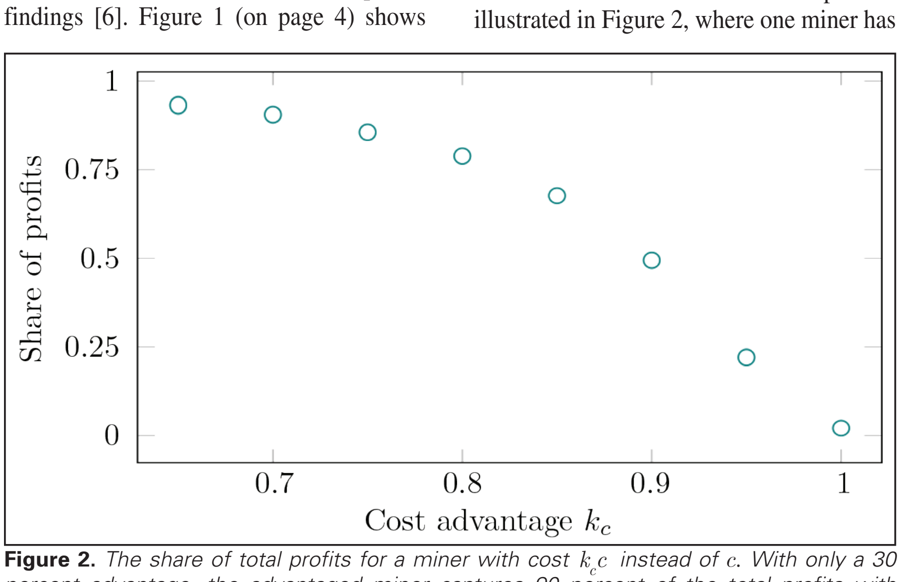

Figure 2. *The share of total profits for a miner with cost $k_c c$ instead of c. With only a 30 percent advantage, the advantaged miner captures 90 percent of the total profits with $M = 1000$ competitors. Figure courtesy of the authors.*

Thus far, our analysis has been primarily numerical. However, this application motivates the mathematical study of these novel mean field games of intensity control, as well as their coupled system of partial differential-delay backward HJB and forward Fokker-Planck equations.

This work is based on Ronnie Sircar's invited talk at the 2020 SIAM Annual Meeting,[4] which took place virtually last July. Sircar's presentation is available on SIAM's YouTube channel.[5]

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[6] Kondor, D., Pósfai, M., Csabai, I., & Vattay, G. (2014). Do the rich get richer? An empirical analysis of the Bitcoin transaction network. *PLoS ONE*, *9*(2), e86197.

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[4] https://www.siam.org/conferences/cm/conference/an20

[5] https://www.youtube.com/watch?v=-7TXltBtYA8

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xSDK: Building an Ecosystem of Highly Efficient Math Libraries for Exascale

By Ulrike Meier Yang and Lois Curfman McInnes

Ongoing efforts to build increasingly powerful computer architectures are establishing new avenues for more complex and higher-fidelity simulations. When coupled with data analytics and learning, these simulations inspire novel scientific insights and deeper understanding. Exascale computers will be much faster than previous computer generations, performing 10^{18} operations per second — or 1,000 times faster than petascale. To achieve these performance improvements, computer architectures are becoming increasingly complex and incorporating deep memory hierarchies, very high node and core counts, and heterogeneous features like graphics processing units (GPUs). Such architectural changes impact the full breadth of computing scales, as heterogeneity pervades even current-generation laptops, workstations, and moderate-sized clusters.

While emerging advanced architectures provide unprecedented opportunities, they also present significant challenges for developers of scientific applications—such as multiphysics and multiscale codes—who must adapt their software to handle disruptive changes in architectures and innovative programming models that have not yet stabilized. Developers need to consider increasing concurrency while reducing communication and synchronization, as well as other complexities like the potential use of mixed precision to leverage the computing power that is available in low-precision tensor cores. On the one hand, developers should implement new scientific capabilities that in turn increase code complexity. On the other hand, these codes must be portable to new architectures, which requires the inclusion of novel programming models and the restructuring of code to achieve good performance. Addressing these issues is beyond the capability of any single person or team, thus necessitating collaboration among many teams that can encapsulate their expertise in reusable software and work together to create sustainable software ecosystems.

The Need for Software Ecosystem Perspectives

Sophisticated mathematical algorithms—which are required by many application codes—come from scientific libraries that are independently developed by experts who possess deep knowledge of these methods[1] [2]. This approach moves much of the burden of porting to new architectures—possibly including novel programming models—and ensuring the correct and efficient performance of these components to library developers, who know their codes best. Large multiphysics applications often require the utilization of many independent libraries, which can lead to additional difficulties.

As many application developers have likely experienced, developing and compiling a large code that uses multiple, independently-developed libraries can be tricky. Issues like inconsistent header files, inconsistent versions, and namespace collisions can prevent a seamless build and cause hours or even days of frustration. The ability to effortlessly build a set of complementary libraries and use them in combination is crucial. Such libraries must be sustainable, well tested, and interoperable. To address these issues, developers are embracing software ecosystem perspectives as they work towards the common goals of productivity, sustainability, and portability.

xSDK History

The Extreme-scale Scientific Software Development Kit (xSDK)[2] is an example of one such ecosystem. Work on the xSDK began in 2014 as part of the Interoperable Design of Extreme-scale Application Software (IDEAS) project,[3] which was sponsored by the U.S. Department of Energy (DOE) Office of Science as a partnership between the Offices of Advanced Scientific Computing Research (ASCR) and Biological and Environmental Research (BER). IDEAS aimed to address challenges in software productivity and sustainability, with an emphasis on terrestrial ecosystem modeling. Research involved several subsurface simulation codes on the application side and four high-performance math libraries: hypre, PETSc, SuperLU, and Trilinos. Even with this limited number of packages, it was impossible to reliably build, link, and run a single executable due to various incompatibilities. As summarized in a recent community report [1], work on xSDK and IDEAS expanded in 2017 with the DOE Exascale Computing Project (ECP),[4] which requires

SOFTWARE AND PROGRAMMING

[1] https://sinews.siam.org/Details-Page/computational-research-software-challenges-and-community-organizations-working-for-culture-change
[2] https://xsdk.info
[3] https://ideas-productivity.org
[4] https://www.exascaleproject.org

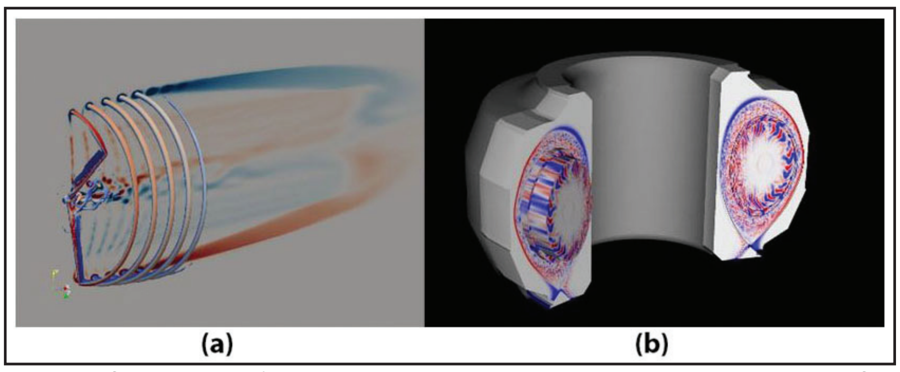

Figure 2. *Simulations performed by the ExaWind and WDMApp projects that utilize xSDK libraries.* **2a.** *Flow structure around an NREL five-megawatt wind turbine rotor generated by the ExaWind Nalu-Wind high-performance computational code.* **2b.** *Core-edge coupled turbulence simulation in a realistic tokamak geometry. The color contours represent perturbed plasma density. Figure 2a courtesy of Shreyas Ananthan and Ganesh Vijayakumar; 2b courtesy of Julian Dominski, Choong-Seock Chang, and Amitava Bhattacharjee.*

intensive development of applications and software technologies while anticipating and adapting to continuous advances in computing architectures.

A Set of Guidelines

To overcome some of the difficulties of building a code with multiple independently-developed math libraries, we created xSDK community policies[5] — a set of rules or guidelines that each package agrees to follow. These mandatory policies address the topics of configuration, installation, testing, Message Passing Interface usage, portability, contact and version information, open-source licensing, namespacing, and repository access. They help improve software quality, usability, access, and sustainability. In addition, several recommended policies focus on error handling and use of a public repository, among other topics. A software package may become an xSDK member if it achieves sustainable compatibility with the community policies and interoperability with another xSDK library — either by using or being used by a different xSDK package. This approach addresses a variety of potential pitfalls in the combined utilization of diverse packages but is simultaneously not so heavy-handed as to interfere with the software strategies of individual libraries. The xSDK project regularly reviews the policies, makes changes when appropriate, and encourages ongoing input from the broader community to ensure that the policies do not become stale.

Testing and Releases

The xSDK developers provide regular releases that generally include new member packages. The xSDK currently comprises 23 math libraries and two domain components. It employs Spack,[6] a flexible package manager that supports multiple versions, configurations, compilers, and platforms. Spack automatically detects any dependencies between packages based on scripts that are provided by library developers, which facilitates smooth and fast builds of large application codes. Before each xSDK release, ongoing regular testing is extended to include a variety of different platforms; this ensures a seamless build and helps handle any issues that have arisen during the libraries' continual development. Developers also regularly update xSDK documentation, including instructions for platforms (such as DOE leadership computing facilities) where further commands are necessary for the build process. In addition, a suite of example codes called *xsdk-examples*[7] demonstrates interoperability among packages. These examples provide both a training tool for users and a test suite that confirms correct xSDK builds. The xSDK project also offers training presentations at conferences, tutorials, and webinars for current and (hopefully) future users and collaborators.

[5] https://xsdk.info/policies
[6] https://spack.io
[7] https://github.com/xsdk-project/xsdk-examples

Application Impact

The xSDK community serves as a strong foundation of advanced numerical software for next-generation scientific applications. Adoption of xSDK community policies has improved the quality of member packages and enables a seamless combined build. Increasing the interoperability layers among packages supplies additional options for algorithms and data structures, thus allowing applications to explore cutting-edge advances across multiple packages. Figures 1 and 2 depict several simulations that were generated with multiple xSDK libraries in combination. The BER-integrated hydrology and reactive transport simulation[8] (see Figure 1a) requires a variety of solvers and time integration methods that come from the xSDK libraries hypre, Trilinos, PETSc, and SuperLU. Figure 1 also shows two simulations from the ECP's Center for Efficient Exascale Discretizations (CEED),[9] which addresses applications like fluid dynamics, radiation hydrodynamics, multiscale coupled urban systems, and climate modeling. CEED applications in turn require discretization packages MFEM and PUMI, time integration schemes provided by PETSc and SUNDIALS, and a variety of solvers that are available in Gingko, hypre, MAGMA, PETSc, STRUMPACK, and SuperLU. The ECP's ExaWind project[10]—which investigates complex fluid physics in wind farms (see Figure 2)—employed xSDK to discover new methods that researchers had previously not considered but now utilize regularly through the interoperability of Trilinos and hypre. The ECP project WDMApp[11]—which pursues a high-fidelity whole device model of magnetically confined fusion plasma (see Figure 2)—requires solvers for linear, nonlinear, and eigen systems that are available in the xSDK libraries hypre, PETSc, MAGMA, SLEPc, and SuperLU. Figure 3 (on page 9) illustrates the xSDK packages that researchers used for the simulations in Figures 1 and 2, as well as their interoperabilities.

Future Plans

We will routinely modify xSDK's community policies to ensure that they meet community needs as software strategies evolve over time. To facilitate policy changes—be it the modification or removal of an existing policy or the addition of a new one—we have established a well-defined

See **Libraries for Exascale** *on page 9*

[8] https://ideas-productivity.org/ideas-watersheds
[9] https://ceed.exascaleproject.org
[10] https://cleantechnica.com/2020/10/14/exawind-supercharges-wind-power-plant-simulations-on-land-at-sea
[11] https://wdmapp.readthedocs.io/en/latest

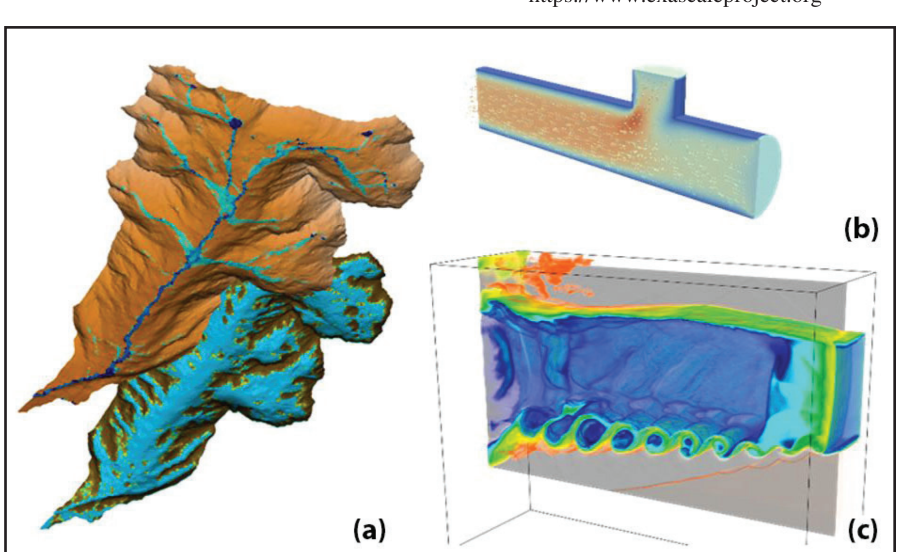

Figure 1. *A Biological and Environmental Research (BER)-integrated hydrology and reactive transport simulation at the Copper Creek watershed in Colorado's East River, and two simulations performed by the Center for Efficient Exascale Discretizations (CEED).* **1a.** *Advanced Terrestrial Simulator (ATS)-integrated hydrology spin-up phase. The surface plot shows the depth of ponded water and the subsurface plot depicts water saturation.* **1b.** *Injector: incompressible Navier-Stokes with fully implicit mass transport.* **1c.** *Simulation of a laser-driven radiating Kelvin-Helmholtz instability using a high-order multi-material arbitrary Lagrangian-Eulerian radiation-hydrodynamics discretization. Figure 1a courtesy of David Moulton and Zexuan Xu; 1b courtesy of Julian Andrej; and 1c courtesy of Tzanio Kolev, Robert Rieben, Vladimir Tomov, and Veselin Dobrev.*

Writing an Interactive Textbook

By David I. Ketcheson, Randall J. LeVeque, and Mauricio J. del Razo

Mathematics is often taught and illustrated through visual representations that depict both abstract and concrete concepts. Unfortunately, traditional texts are limited to static two-dimensional plots and diagrams, which are not well-suited for illustrating dynamic, time-dependent phenomena or the broad spectrum of situations that can arise with varying parameters. One might refer to this as the "curse of dimensionality" in teaching, wherein the medium has far fewer dimensions than the subject matter.

Another important challenge in computational mathematics is the conveyance of detailed algorithms. High-level pseudocode may not fully communicate important details, while a complete runnable program might interrupt the text's flow and be difficult for users to digest. Although one can sometimes include elegant and short programs fairly easily (Nick Trefethen's classic *Spectral Methods in MATLAB*[1] [2] is an example), this is often not feasible.

While traditional texts have served us well for thousands of years, new media provide exciting possibilities to radically alter the way in which we write textbooks. A number of authors in applied mathematics have already begun to explore opportunities to present material in a much more engaging and illuminating manner. Our goal is to describe some of our own recent experiences in this direction, focusing on a few of the challenges that we faced and how we dealt with them.

Just last year, we published *Riemann Problems and Jupyter Solutions*[2] [1] as a SIAM text that we wrote entirely as a set of Jupyter[3] notebooks. Though we hope that the softcover book will be a useful resource in its own right, we invite readers to explore the notebooks themselves, as they make it possible to visualize the time-dependent nature of solutions and easily vary parameters to observe their effects. The ambitious reader can even extend the notebooks by modifying the embedded Python code to set up and solve related problems. To facilitate the notebooks' usage, we provide both a clear list of dependencies and a Dockerfile. We also make it very easy for users to launch an instance on the cloud server Binder;[4] the notebooks can thus run in any browser and do not require the installation of software. Readers who wish to view some of the time-dependent solutions without running the notebooks can consult the pure HTML version with embedded animations. SIAM has kindly allowed the notebooks and HTML rendition to remain open access, and we encourage you to explore the notebooks using the online links.[5]

The "Riemann problem" in our book refers to a one-dimensional hyperbolic partial differential equation (PDE), together with piecewise-constant initial data. The resulting time-dependent solution consists of waves that propagate away from the initial discontinuity (shocks and/or rarefaction waves in the nonlinear case). The notebooks illustrate a variety of different hyperbolic problems—including acoustics, Burgers' equation, shallow water equations, and the Euler equations of compressible flow—with dynamic illustrations of the time-dependent solutions and their corresponding changes as the initial data vary. We also illustrate some of the key ideas in the development of cheap-to-compute approximate Riemann solvers, a critical building block for many numerical "shock-capturing methods" for the solution of hyperbolic PDEs. Other textbooks may describe these ideas in more detail, but we believe that the notebook version makes it far easier for readers to understand and explore many of the concepts. Therefore, *Riemann Problems and Jupyter Solutions* could also serve as a supplement to a broader course that is based on alternative textbooks.

The Jupyter notebook is a browser-based interactive notebook that incorporates Markdown text (including mathematics in LaTeX form), images, computer code, and so-called "widgets" within a JavaScript Object Notation (JSON) file. Users execute notebooks by first starting a notebook server; a computational kernel then executes the code cells within the notebook. We utilize Python for our notebooks, but the notebook interface works with other languages as well, notably Julia and R (as suggested by the name "Jupyter"). The widgets expedite the creation of visualizations with menus, sliders, and other tools that advance time or modify parameters. The visualization updates in real time to reflect the chosen values, and users can modify and execute the computer code directly in the notebooks and immediately see the results. Figure 1 depicts some of the widgets that are used for the shallow water equations.

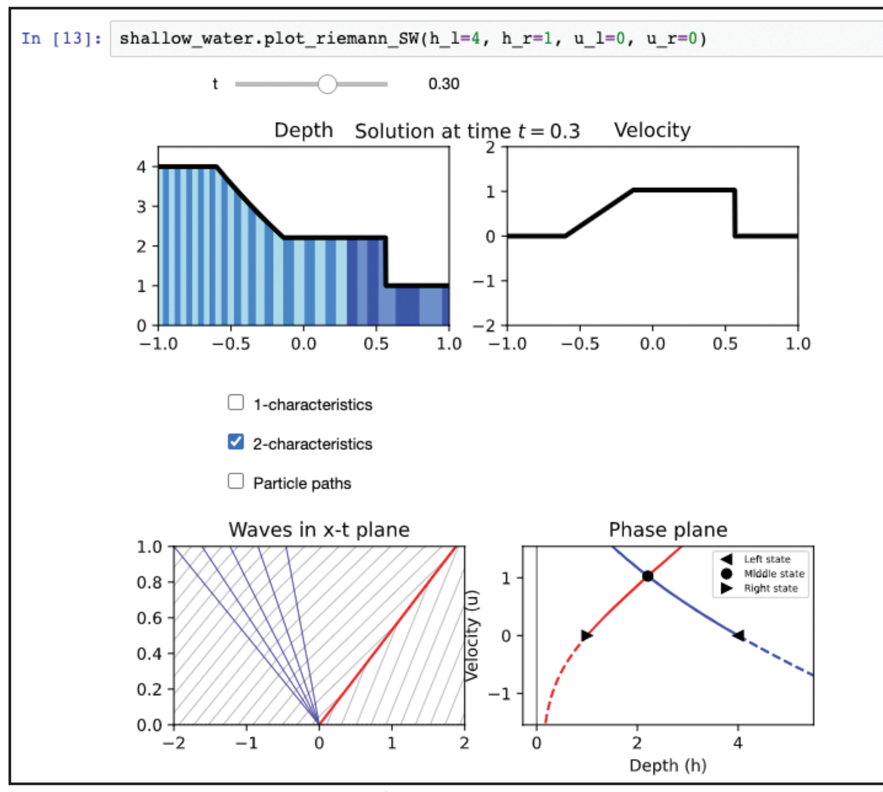

Figure 1. *A Jupyter notebook widget for exploring the solution to the Riemann problem for shallow water equations. Figure courtesy of [1].*

Challenges

We encountered a number of unique challenges while writing an interactive textbook. While we always intended our book to exist in multiple formats—notebooks, HTML pages, and PDF/print—we knew that manually synchronizing the different formats would be unwieldy. We designated the Jupyter notebooks as the authoritative format from which we would generate the other formats. Fortunately, the `nbconvert` tool already facilitates this automatic conversion, at least for a single notebook. By combining it with Thomas Kluyver's `bookbook`[6] project and some additional scripting (e.g., to convert all of the widgets into one or two static figures that would make sense in the print version), we adapted it to function for a collection of notebooks. Creating a unified bibliography, incorporating links and LaTeX references across chapters, and applying a set of LaTeX macros throughout the notebooks all required additional work. In the end, we were able to generate a fairly short Python script to convert all of the notebooks into a single LaTeX file that was suitable for the SIAM compositors, who then copyedited and typeset it into the beautiful printed book. We wrote another Python script (again using `nbconvert`) to turn all of the notebooks into HTML form, incorporating additional processing to change some of the widgets into animations that play in the HTML.

The scripts we used are all included in our book's GitHub repository. For new projects, we also suggest investigating the

See **Interactive Textbook** *on page 10*

[1] https://my.siam.org/Store/Product/viewproduct/?ProductId=1186
[2] https://bookstore.siam.org/fa16
[3] https://jupyter.org
[4] https://mybinder.org
[5] https://bookstore.siam.org/fa16/bonus
[6] https://github.com/takluyver/bookbook

Libraries for Exascale

Continued from page 8

process that requires agreement between the majority of xSDK package developers. For example, in response to a request by DOE computing facilities, we recently added a recommended policy that asks users to include specific material (such as contacts, license information, and a changelog) in each package's top source directory, as well as a policy on documentation quality.

Finally, we will continue to add suitable packages to xSDK based on application code needs; these additions will be accompanied by required testing to ensure robust build and execution. We will increase interoperability layers between libraries when it makes sense to do so, and add new example codes to the test suite that demonstrate interoperabilities. Plans also exist for xSDK builds with special functionalities, such as CUDA or OpenMP capabilities for computers with GPUs or multicore nodes. Moreover, we note that the Extreme-scale Scientific Software Stack (E4S.io) effort[12] addresses broader work across the entire software stack.

Building a successful and sustainable software ecosystem requires the contributions of all kinds of people. We welcome your input on a variety of platforms:

– Send comments and questions to **xsdk-developers@xsdk.info**

– Provide comments and pull requests for changes to the online community policies[13]

– Consider incorporating xSDK community policies into your software and contributing to xSDK.

We look forward to hearing from you.

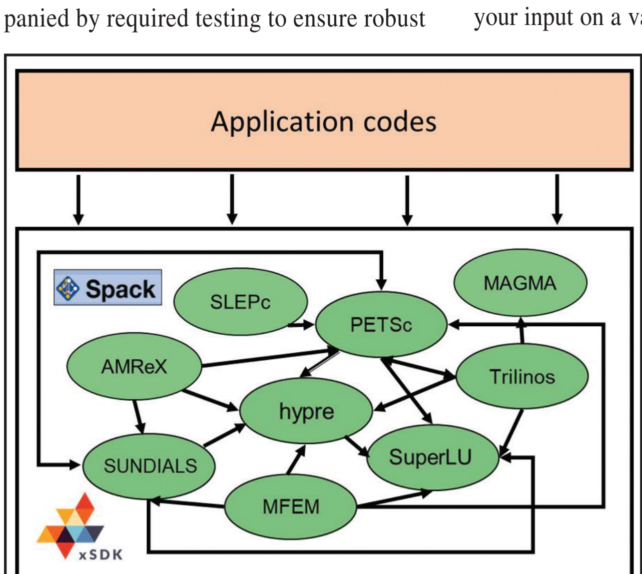

Figure 3. *A subset of xSDK that displays the libraries used in the applications in Figures 1 and 2 (on page 8). $A \rightarrow B$ indicates that library A calls library B. Figure courtesy of the authors.*

This article is based on Ulrike Meier Yang's invited talk at the 2020 SIAM Annual Meeting,[14] which took place virtually last July. Yang's presentation is available on SIAM's YouTube Channel.[15]

References

[1] Heroux, M.A., McInnes, L.C., Bernholdt, D., Dubey, A., Gonsiorowski, E., Marques, O., & Wolfenbarger, P. (2020). *Advancing scientific productivity through better scientific software: Developer productivity and software sustainability report*. Oak Ridge, TN: U.S. Department of Energy Office of Science. DOI: 10.2172/1606662.

[2] McInnes, L.C., Katz, D.S., & Lathrop, S. (2019, December 2). Computational research software: Challenges and community organizations working for culture change. *SIAM News, 52*(10), p. 5.

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[12] https://e4s-project.github.io
[13] https://github.com/xsdk-project/xsdk-community-policies
[14] https://www.siam.org/conferences/cm/conference/an20
[15] https://www.youtube.com/watch?v=BXJeUuU4Ne4

A Coriolis Pair Paradox

MATHEMATICAL CURIOSITIES

By Mark Levi

I am walking the straight chalk line AB drawn through the center of a rotating platform. Although my path is straight and my speed is constant in the platform's frame, neither is true in the inertial frame of the ground observer. The nonzero acceleration at the center O in Figure 1 is precisely the Coriolis acceleration.[1] Its magnitude is

$$a_{\text{coriolis}} = 2v\omega, \qquad (1)$$

where v is the speed relative to the disk (which at O is the same as the ground speed).

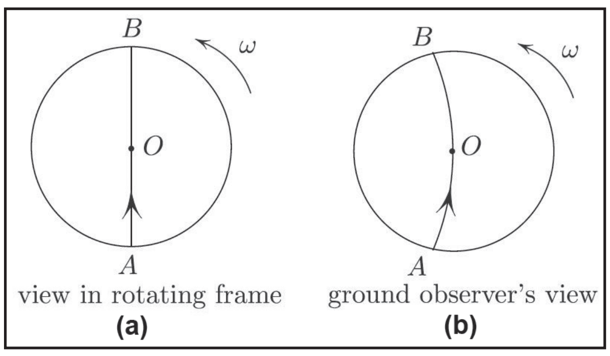

Figure 1. *Coriolis acceleration at O.*

A Side Note

There is some ambiguity in the Coriolis terminology, similar to that between centrifugal and centripetal forces. Coriolis force sometimes refers to the inertial (i.e., fictitious) force that is equal and opposite to the aforementioned force. The walker in Figure 1a, who cannot see outside the carousel, feels as if some force is pulling him to the *right* — just like a passenger in an accelerating car feels a backward pull. Since nothing actually pulls them backwards, one speaks of inertial, fictitious (D'Alembert's) force. As a more formal example, the position vector $\mathrm{x} \in \mathbb{R}^2$ of a free particle that is expressed in the rotating frame does not satisfy $\ddot{\mathrm{x}} = 0$ but rather $\ddot{\mathrm{x}} = -2i\omega\dot{\mathrm{x}} + \omega^2\mathrm{x}$, using the complex notation, i.e., identifying $\mathrm{x} = (x, y) \equiv x + iy$.

[1] The centripetal force vanishes at O, but away from O the Coriolis force is only one part of the inertial force — specifically the part due to the motion that is relative to the platform. The other part is the centripetal force (pointing to the center and preventing the walker from flying uncontrollably outwards), which only depends on the position and not the velocity [1, 2].

The Paradox

Figure 2 illustrates a back-of-the-envelope attempt to derive (1) by computing the change of speed in the x-direction relative to the ground in a short time from $t=0$ to $t>0$. At time $t>0$, the walker has traveled the distance $r=vt$ from O; the platform's rotation imparts speed $\omega r = \omega vt$ to the walker. The x-component is $\omega r \cos\omega t = \omega vt \cos\omega t$, and the x-acceleration at O is therefore

$$\lim_{t\to 0} \frac{\omega vt \cos\omega t - 0}{t} = \omega v.$$

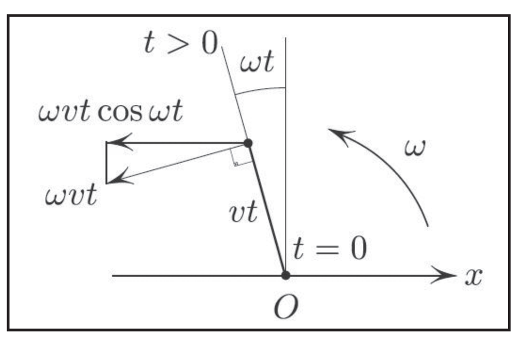

Figure 2. *Speed change in the x-direction that is caused by the platform's rotation. The x-axis is affixed to the ground.*

But this is only half of the correct answer (1). Where is the other half?

The Missing Half

Walking on the platform has *two* effects, and I overlooked one: At $t>0$, my velocity relative to the ground has rotated together with the disk, thus contributing the missing ingredient to the x-speed. Figure 3 shows this overlooked contribution as $v\sin\omega t$. The missing part of the Coriolis acceleration is thus

$$\lim_{t\to 0} \frac{v\sin\omega t}{t} = v\omega.$$

Interestingly, the two contributions end up being equal, but with a subtle difference: ωv and $v\omega$. Figure 4 shows the two effects together.

Coriolis Force in a Jetliner

What is the Coriolis force acting on a jet that is flying over the North Pole? For a Boeing 747, let us take $v = 250\ m/sec$, $m = 400 \cdot 10^3\ kg$. Substituting Earth's angular velocity $\omega = 2\pi/(24 \cdot 3,600)\ rad/sec$ into $F = 2m\omega v$ yields a Coriolis force of roughly 3,000 pounds. It is as if the plane were pulled to the right with a force that is equal to the weight of a small elephant. I never expected such a large Coriolis force and recalculated it several times, anticipating a different result each time and thinking of the famous quote: "*Insanity is doing the same thing over and over again and expecting different results.*"

The figures in this article were provided by the author.

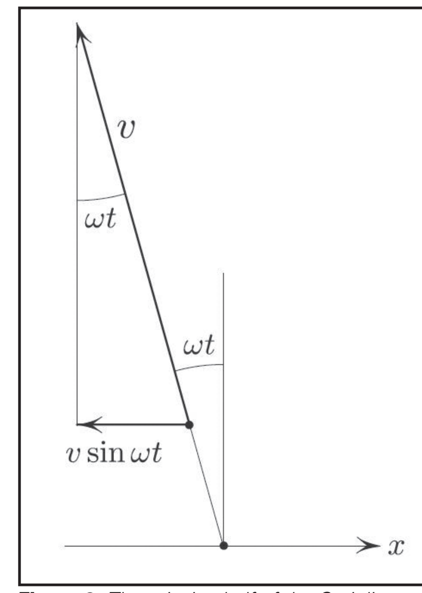

Figure 3. *The missing half of the Coriolis acceleration (from the ground observer's view).*

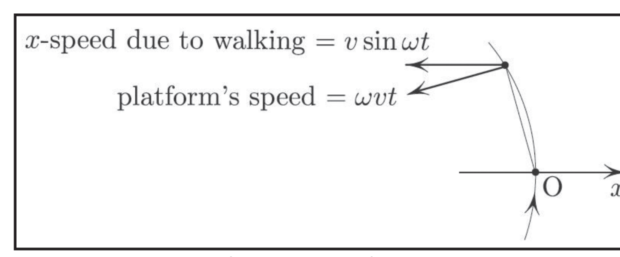

Figure 4. *The pair of ingredients (from the ground observer's view), each producing acceleration $v\omega = \omega v$ at O and resulting in the factor 2 in (1).*

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[1] Arnold, V.I. (1989). *Mathematical Methods of Classical Mechanics*. New York, NY: Springer-Verlag.

[2] Levi, M. (2014). *Classical Mechanics with Calculus of Variations and Optimal Control: An Intuitive Introduction*. In *Student Mathematical Library* (Vol. 69). Providence, RI: American Mathematical Society.

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Interactive Textbook

Continued from page 9

latest tools that are available to ease some of these challenges. For example, we discovered the Jupyter Book[7] project too late to use for *Riemann Problems and Jupyter Solutions*, but it looks very promising.

The Jupyter notebook interface itself has also been rapidly evolving and improving, and one challenge we faced was its evolution during our writing process. In particular, the notebook widget code fundamentally changed multiple times. This occasionally broke the textbook and required several revisions for our code. In order to ensure that the code was always in working order, we used the Travis CI[8] continuous integration service and some test scripts that automatically executed each notebook whenever the book was modified on GitHub. Future changes to libraries will likely continue to pose difficulties, although one can easily specify the required version of Jupyter in the Dockerfile for our now-published book.

Version control tools (such as Git) and the command-line tool "diff" are widely used to facilitate collaborative scientific writing and were particularly essential to our writing process since we live on three different continents. The Jupyter notebook slightly complicated this approach because it uses a JSON format with extra markup, in addition to the text and computer code. It also stores the images and animations that the code produces in a serialized format within the notebook (as embedded PNG files). As a result, notebook files that include the output can be quite large and not at all suitable for diffing. Fortunately, community-developed tools like `nbdime` and `nbstripout` allowed us to effectively handle these complications.

[7] https://jupyterbook.org
[8] https://travis-ci.org

Outlook

We are very happy with the finished *Riemann Problems and Jupyter Solutions*, but we do not expect it to be the final word on interactive texts. On the contrary, we see it as a contribution to the ongoing evolution of textbooks that are taking advantage of improved technology. We hope that our work—along with similar in-progress projects in our community—will inspire other authors to continue innovating and improving our collective ability to communicate and teach mathematics.

References

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[2] Trefethen, L.N. (2000). *Spectral Methods in MATLAB*. In *Software, Environments and Tools*. Philadelphia, PA: Society for Industrial and Applied Mathematics.

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Two New SciDAC Institutes Promote Mathematical Tools and Software Technology for High-Performance Computing

By Gail Pieper, Karen Devine, Esmond G. Ng, Leonid Oliker, and Robert Ross

Bigger is often said to be better, and the newest extreme-scale computers—which have millions of processing units—are certainly bigger. Moreover, the breadth of science performed at the U.S. Department of Energy's (DOE) computing facilities continues to expand with the emergence of new technologies like artificial intelligence (AI). While these exciting advances create new opportunities for scientific discovery, they also raise novel questions for researchers who want to exploit these advances and tackle more complex problems. Will my simulation code be able to utilize the accelerators in extreme-scale computing systems? Can I take advantage of the deepening memory hierarchy in heterogeneous processors? Is there a way around the bottlenecks that are caused by the widening ratio of peak floating-point operations per second to input/output bandwidth? How can I effectively manage huge amounts of data? Can I analyze data *in situ*, or must I transfer it to offline storage for later analysis?

To address such questions, DOE announced that it will provide 57.5 million dollars over the next five years for two multidisciplinary teams—FASTMath and RAPIDS2—to harness supercomputers for scientific discovery. The teams are part of the Scientific Discovery through Advanced Computing[1] (SciDAC) program and are thus called SciDAC institutes.

A Brief Background of SciDAC

The SciDAC program began in 2001 with the goal of accelerating scientific discovery using high-performance computing (HPC). SciDAC is a joint effort that involves DOE's Office of Nuclear Energy and the six major program offices within the Office of Science (SC): Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics. It addresses problems in disciplines such as high energy and nuclear physics, condensed matter physics, materials science, chemistry, fusion energy sciences, and Earth systems research.

SciDAC aims to ensure that scientists from national laboratories, universities, and other research organizations take full advantage of DOE's HPC resources. Its key objective is to bridge the gap between mathematics and computer science research and domain science research, potentially enabling significant advances in scientific discovery. Since its establishment, the SciDAC program has enjoyed tremendous success and produced significant achievements that range from new insights into the actions of supernovae to combustion improvements that reduce pollution.

Now in its fourth five-year cycle, SciDAC is recognized worldwide as a leading force in accelerating the use of HPC to advance the state of scientific knowledge.

The Two New SciDAC Institutes

In March 2020 as SciDAC-4 approached its end, DOE announced a plan to establish multidisciplinary teams to develop new tools and techniques in mathematics and computer science. These teams, which are part of SciDAC-5, will harness state-of-the-art supercomputers for scientific discovery and take advantage of DOE supercomputing facilities at Argonne, Oak Ridge, and Lawrence Berkeley National Laboratories. Following an open competition, DOE revealed in August 2020 that it had selected two institutes to be funded under the SciDAC-5 program:

- "Frameworks, Algorithms, and Scalable Technologies for Mathematics"[2] (FASTMath) will focus on the creation of new scalable mathematical algorithms and software tools that can exploit the power of extreme-scale computers.
- "RAPIDS2: A SciDAC Institute for Computer Science, Data, and Artificial Intelligence"[3] will help application developers tackle challenges that are arising from the increasing deluge of data, new technologies, and extreme-scale computing.

Both FASTMath and RAPIDS2 involve large research collaborations between academia and national laboratories. Members of the two institutes have a significant record of successful collaboration within both SciDAC and the larger scientific community over the last 15 years; indeed, strong collaboration between FASTMath and RAPIDS was a highlight of SciDAC-4.

Impact on scientific applications remains the primary focus of both SciDAC-5 institutes. As such, FASTMath and RAPIDS2 researchers will engage with application developers and domain experts in science-focused SciDAC partnerships and DOE SC projects to address some of the most complex computational problems that are of interest to DOE. They will build on their

See **SciDAC Institutes** *on page 12*

1 https://www.scidac.gov

2 https://scidac5-fastmath.lbl.gov

3 https://rapids.lbl.gov

Keep Calm and Carry On Publishing

By Kivmars Bowling

Well, 2020 was certainly an interesting year. As we look forward to better days ahead in 2021, now seems like a good moment to draw breath and reflect on the response of SIAM Publications during this unrelenting time.

Let me begin with a heartfelt thanks and expression of admiration for all of the SIAM editors, authors, referees, and staff members who have kept things running amidst all the uncertainty. Many of us have had to handle divided and increased responsibilities as we attempted to pivot (such a graceful word) to remote work. The fact that SIAM Publications have continued so smoothly is a testament to the committed efforts of everyone involved.

2020 journal submissions approached another all-time high for the third year in a row, underlining the esteemed regard that authors hold for SIAM journals. Despite the significant, temporary drop in March, journal article downloads are up three percent overall compared to 2019; this indicates that many researchers have successfully transitioned to working from home.

In response to the COVID-19 pandemic, we created the SIAM Epidemiology Collection[1] to offer free access to over 184 papers, e-books, and *SIAM News* articles that relate to epidemiology, disease modeling, and vaccines. We are adding additional content to the collection as it publishes.

In addition, SIAM's significant presence in the field of data science continues to grow. *The SIAM Journal on Mathematics of Data Science (SIMODS)*[2] again received very strong submissions over the last year; it will be freely available through the end of 2021 as part of an extended launch period. The recently-launched *Data Science* book series[3] also published its first two books in 2020.[4,5] This is an unusually quick start for a new book series, and more titles are already in the pipeline. And of course, both the new SIAM Conference on Mathematics of Data Science[6] and rescoped SIAM Activity Group on Data Science[7] made their successful debuts as well.

2020 saw SIAM publish its first book that is available both in print and as a Jupyter notebook: *Riemann Problems and Jupyter Solutions*[8] by David Ketcheson, Randall LeVeque, and Mauricio del Razo. SIAM will continue to remain open to experimentation as we look to enhance the digital versions of our books — a concept that is especially important in the context of remote teaching and learning. If you have any project ideas for monographs or textbooks, please contact Elizabeth Greenspan (executive editor of SIAM Books) at **greenspan@siam.org**.

This past year, SIAM and a number of other societies joined the "Joint commitment for action on inclusion and diversity in publishing."[9] Meetings and working groups will explore how to best amass meaningful data to measure progress in improving diversity, equity, and inclusion. Securely collecting data in a manner that is trusted by all parties is of course complex and will require careful analysis and discussion.

SIAM has also joined the Society Publishers' Coalition,[10] a collection of nonprofit societies with a "common ambition to see an orderly and sustainable transition to open scholarship and to improve the efficiency of the scholarly communication ecosystem for the benefit of researchers and society at large in a fair and sustainable way." SIAM has very liberal green open-access policies, and most articles are available as preprints on arXiv. But the increasing number of open-access mandates from funders has inspired us to actively investigate open-access models and assess their ability to deliver a financially sustainable path to open access while maintaining SIAM's independence and high standards. And in compliance with Plan S, the European open-access mandate for scientific publications that comes into effect in 2021, *all SIAM journals will be Plan S-compliant via the green open-access route*.

Publication	Outgoing Editor-in-Chief	Incoming Editor-in-Chief
JUQ	Andrew Stuart	Sebastian Reich
SIAP	Paul Martin	Qiang Du
SIFIN	Jean-Pierre Fouque	Mete Soner
SIMAX	Daniel Szyld	Michele Benzi
SIURO	Luis Melara	Joanna Wares

Figure 1. *The outgoing and incoming editors-in-chief for the SIAM Journal on Uncertainty Quantification (JUQ), SIAM Journal on Applied Mathematics (SIAP), SIAM Journal on Financial Mathematics (SIFIN), SIAM Journal on Matrix Analysis and Applications (SIMAX), and SIAM Undergraduate Research Online (SIURO).*

In 2020, SIAM ran a pilot program for peer reviewer recognition via ORCID.[11] As of last July, reviewers for the *SIAM Journal on Mathematical Analysis*, *SIAM Journal on Optimization*, and *SIAM Journal on Scientific Computing* can now display their review activity on their ORCID profiles by simply clicking a link in a thank-you message that they immediately receive after submitting their reviews. Over 100 reviewers have already done so, and we will consider expanding this choice to all SIAM journals in the future if the pilot goes well.

Many thanks to the more than 700 people who responded to our recent survey about the current Publications platform.[12] The upgrade process is now underway with our third-party vendor, and we are factoring in as much feedback as possible.

As usual, the turn of the year comes with various editorial transitions. SIAM extends its sincere thanks to the outgoing journal editors-in-chief for all of their work over the years and offers a warm welcome to their successors (see Figure 1).

Finally, I want to end with an appeal to you, our members, as we enter the challenging 2021 renewal season for journal subscriptions. Many university libraries are facing difficult budgetary decisions due to the pandemic's impact. If you become aware that your library may be planning to cancel its subscription to SIAM journals, please let us know. We will try to help you advocate for their renewal, assuming that you view them as important tools for research and teaching at your institution. We have also seen some cases where faculty are not made aware of such plans, and will contact you if we hear about potential cancellations.

Faculty members who voice their support for SIAM journals can often inspire their renewal. SIAM is always competing against the large commercial publishers in terms of library budgets, so any support that you can offer will ensure that our society remains healthy and able to continue our many programs and services.

If you have any questions or comments, please feel free to reach out to me at **bowling@siam.org**. I look forward to meeting in person again once we overcome this pandemic. In the meantime, the SIAM team will keep calm and carry on publishing.

Kivmars Bowling is the Director of Publications at SIAM.

1 https://epubs.siam.org/page/EpidemiologyCollection

2 https://epubs.siam.org/journal/sjmdaq

3 https://my.siam.org/Store/Home/BookSeries/22

4 https://my.siam.org/Store/Product/viewproduct/?ProductId=32863041

5 https://my.siam.org/Store/Product/viewproduct/?ProductId=32898069

6 https://www.siam.org/conferences/cm/conference/mds20

7 https://sinews.siam.org/Details-Page/new-siam-activity-group-on-data-science

8 See page 9 for an article by the authors about their writing process.

9 https://www.rsc.org/new-perspectives/talent/joint-commitment-for-action-inclusion-and-diversity-in-publishing

10 https://www.socpc.org

11 https://orcid.org

12 https://epubs.siam.org

Thank You for Staying Engaged in 2020

By Becky M. Kerner

As for most people, 2020 has been a whirlwind for SIAM staff. From virtual committee meetings and staff retirement celebrations to the first-ever SIAM-branded Zoom backgrounds[1] (see Figure 1), SIAM faced many changes in all of its departments this year, including Conferences,[2] Development,[3] Membership (see page 3), and Publications (see page 11). The Marketing team has worked to assist each department as we collectively tackled unique questions, while also thinking critically and creatively about how SIAM—as your professional society—can best respond to and support our community during these unforeseen circumstances. Here are some of the ways in which we have addressed new challenges and opportunities and kept up community engagement throughout this unusual year.

1 https://www.siam.org/newsroom
2 https://sinews.siam.org/Details-Page/siam-conferences-reinvented
3 https://sinews.siam.org/Details-Page/at-last-our-hindsight-is-truly-2020

Online Community

This January, we are launching our new online member community: SIAM Engage![4] At its outset, the site will have individual community pages for SIAM committees and activity groups, as well as a member directory and lots of lively dialogue. Over time, SIAM Engage will likely grow to include discussion pages for more subgroups of our community, such as geographic sections, industry members, and student chapters. The purpose of this platform is to give our members an online space for easy collaboration and communication. Log into Engage and get active!

Video Engagement

In 2020, the videos on our YouTube channel[5] were viewed upwards of 190,000 times, amounting to an impressive 6,100+ hours of watch time to date — a more than 35 percent increase from 2019. We are also currently working on an informational video about the mathematical elements of vaccine development, which will depict the lifesaving impact of our community's work. This forthcoming video will be publicly available in the near future. Subscribe to SIAM's YouTube channel to stay up to date with the latest content.

4 https://engage.siam.org
5 https://www.youtube.com/user/SIAMConnects

Figure 1. *SIAM-branded Zoom backgrounds are available for download and use by all members.*

Public Relations

One of our goals at SIAM is to promote coverage of applied mathematics and computational science in mainstream media. Last year, we capitalized on our community's participation in the COVID-19 conversation and active research contributions on everything from testing to symptom monitoring, vaccines, supply chain management, and more. We distributed many press releases this year that landed coverage twice in *Forbes* — one article[6] considered mathematical and statistical methods when addressing how to reopen the U.S., and the other[7] highlighted an infectious disease model to forecast the U.S. election. Our community's work was also featured in *California Business Journal*, *NPR*, and *Radio Health Journal*, among other outlets. In fact, SIAM and the names of our members have been cited in well over 160 U.S.-based news articles in 2020, a more than 45 percent increase from the previous year.

Social Media

Do you follow us on Facebook,[8] Twitter,[9] LinkedIn,[10] and YouTube? We now have a combined 56,000 followers on these channels, all of whom are remaining up to date with SIAM happenings and general math in the news. We are also thrilled to see that our monthly *Unwrapped*[11] e-newsletter was opened more than 100,000 times in 2020 — a 33 percent increase from the year prior. Thank you for staying engaged within our community!

6 https://www.forbes.com/sites/kevinanderton/2020/08/27/statistical-math-may-hold-the-key-to-reopening-the-country-infographic
7 https://www.forbes.com/sites/kevinanderton/2020/10/30/infectious-disease-model-predicts-the-next-president-infographic
8 https://www.facebook.com/SocietyforIndustrialandAppliedMath
9 https://twitter.com/TheSIAMNews
10 https://www.linkedin.com/company/societyforindustrialandappliedmathematicssiam

SIAM Websites

Based on feedback from volunteers and members—much of which was derived from last year's website survey—we are in the midst of a significant upgrade to **www.siam.org**, the goal of which is to simplify and professionalize the website and better integrate the entire suite of SIAM sites for ease of use. We will go live with these updates in 2021, so keep an eye out. As a teaser, you'll see updates to the Epubs website and *SIAM News* as part of this overarching project.

The ongoing pandemic has brought many things to light, not least of which is mathematics' vital role in solving some of the biggest challenges that the world is facing. Our members were more involved than ever in 2020, and applied mathematics and computational science have been at the forefront of some of the most crucial conversations around the globe. Thank you to the SIAM community for the important work you continue to do—especially under difficult circumstances this year—which allows us to communicate the value and critical applications of mathematics to a broader audience. Cheers to a healthy and productive year ahead!

Becky M. Kerner is the Director of Marketing and Communications at SIAM.

11 https://sinews.siam.org/Happening-Now/Unwrapped

SciDAC Institutes

Continued from page 11

suites of high-quality software, placing particular focus on lowering the barriers to achieving high performance and high productivity on DOE computers.

Both institutes are active in outreach to the broader scientific community. Through activities such as summer schools, tutorials, and workshops, the teams train the scientific computing community to leverage their software and help educate the next generation of computational mathematicians and scientists.

The FASTMath Institute

The FASTMath Institute, led by Esmond Ng (Lawrence Berkeley National Laboratory) and Karen Devine (Sandia National Laboratories), is committed to providing robust mathematical techniques and expertise that enhance the performance and effectiveness of scientific simulations. FASTMath pursues three key goals:

• Deliver highly performant software with strong software engineering that runs efficiently on current and next-generation advanced computer architectures at major DOE computing facilities

• Work closely with domain scientists to share the FASTMath team's mathematical and machine learning knowledge and deploy its software in large-scale modeling and simulation codes

• Build and support the broader computational mathematics and computational science communities across the DOE complex.

Several mathematical and computational challenges require the proficiency of a team like FASTMath. For example, the integration of graphics processing units into emerging exascale computers means that computational scientists must redesign their software in order to take full advantage of these accelerators. To tackle multiscale multiphysics problems, researchers need to quantify the uncertainty in their computations and be assured of higher fidelity. Domain scientists also have to leverage new technologies—such as machine learning—in modeling and workflow simulations to quickly and accurately analyze the torrents of generated data. FASTMath's efforts to address these issues will span eight technical areas: structured mesh discretization, unstructured mesh discretization, time integration, linear and nonlinear equation solvers, eigensolvers, numerical optimization, uncertainty quantification, and data analytics. Machine learning is a cross-cutting theme among these topical fields, with planned activities that include numerical methods for machine learning and employment of machine learning techniques to optimize the usage of FASTMath software in applications.

The FASTMath team comprises more than 50 mathematicians from five national laboratories (Argonne, Lawrence Berkeley, Lawrence Livermore, Oak Ridge, and Sandia) and five universities (Massachusetts Institute of Technology, Rensselaer Polytechnic Institute, Southern Methodist University, University of Colorado Boulder, and University of Southern California). Many FASTMath researchers also participate in SciDAC-4 partnerships and DOE SC base math projects, thus enabling them to incorporate research developments into new tools for deployment in scientific applications.

The RAPIDS2 Institute

The RAPIDS2 Institute, led by Robert Ross (Argonne National Laboratory) and Leonid Oliker (Lawrence Berkeley National Laboratory), seeks to provide high-performance computer science and data management tools to help DOE SC's application teams, which use leadership computing resources to achieve scientific breakthroughs. To accomplish this objective, the institute has identified the following goals:

• Solve computer science, data, and AI technical challenges for SciDAC and DOE science teams

• Engage and work directly with SC scientists and facilities to identify needs and deploy new technologies

• Coordinate with other DOE computer science and applied mathematics activities, as well as the DOE Exascale Computing Project,[4] to maximize impact on DOE science.

RAPIDS2 will build on the successes of the SciDAC-4 RAPIDS project and expand into several new areas of broad impact. It specifically addresses four technology thrusts:

(i) Data understanding, including ensemble analysis and feature detection

(ii) HPC platform readiness, including heterogeneous programming and autotuning

(iii) Scientific data management, including workflow automation, storage systems, and input/output

(iv) AI, including representation learning and surrogate modeling.

These thrusts provide a toolbox of advanced computation, information, and data science technologies that focus on the common challenges of scientific applications. AI is a particularly exciting cross-cutting technology because of its potential to transform numerous scientific domains that utilize HPC, such as materials science, high energy physics, and chemistry.

RAPIDS2 brings together researchers from five national laboratories (Argonne, Lawrence Berkeley, Lawrence Livermore, Los Alamos, and Oak Ridge); six universities (Northwestern University, Ohio State University, Rutgers University, University of Delaware, University of Florida, and University of Oregon); and one software research and development company (Kitware, Inc.). These collaborators offer a broad range of expertise and a strong history of success in engagement with DOE scientists.

4 https://www.exascaleproject.org

The Power of Two

By combining the knowledge and experience of mathematicians and computer scientists who work jointly with domain scientists, the FASTMath and RAPIDS2 institutes complement each other and collectively cover a wide spectrum of scientific computing needs. The groups' researchers are confident that they possess the prowess, algorithms, software, and computational tools to provide end-to-end solutions that will help application developers satisfy the SciDAC mission of advancing scientific discoveries through modeling and simulation on DOE's most advanced computers. Scientists who are interested in collaborating with the FASTMath and RAPIDS2 teams should contact the institute leaders or any institute members.

The DOE press announcement[5] is available online, as is a list of lead and partner institutions for the two teams.[6]

Gail Pieper is senior coordinator of technical editing and writing in the Mathematics and Computer Science Division at Argonne National Laboratory (ANL). Karen Devine is deputy director of the FASTMath Institute and a distinguished member of technical staff in the Center for Computing Research at Sandia National Laboratories. Esmond G. Ng is director of the FASTMath Institute and a senior scientist in the Computational Research Division at Lawrence Berkeley National Laboratory (LBNL). Leonid Oliker is deputy director of the RAPIDS2 Institute and a senior scientist in the Computational Research Division at LBNL. Robert Ross is director of the RAPIDS2 Institute and a senior computer scientist in the Mathematics and Computer Science Division at ANL.

5 https://www.energy.gov/articles/department-energy-provide-575-million-science-computing-teams
6 https://bit.ly/3kYCHF5