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The Emerging Utility of Graphons in Applied Math

By Jason J. Bramburger

Graphs and networks are omnipresent in modern science. In their simplest form, graphs consist of three components: (i) A set of vertices, (ii) a set of edges that connect the vertices, and (iii) weights that are assigned to each edge and describe the strength of the connection between vertices. We utilize graphs to characterize almost any system with connections between two or more objects, such as social networks, chemical reactions, food webs, and neurons in the brain. The use of networks to understand complex processes in the brain has even led to theoretical advancements in neural networks, which form the foundation for the machine learning innovations that are currently transforming our society.

In applied mathematics, the question of *robustness* often arises in the context of networks. Robustness results for network problems help maintain the applicability of developed theories, as such results can guarantee that conclusions still hold under slight model variations that might originate from noisy measurements or small factors that are neglected during the modeling process. Traditional classifications of network robustness permit perturbations to a graph's edge or weight structure, but what about robustness with respect to the addition or removal of vertices? For example, models of neural networks in the brain require graphs with many vertices, but the exact number of vertices is unknown. It would therefore be useful to have a theory that works for all sufficiently large graphs and accounts for some variation in the number of vertices — as long as the graphs adhere to a certain structure or generating rule.

Recent advances in graph theory have allowed applied mathematicians to tackle the problem of graph robustness over varying numbers of vertices. The main tool is a *graphon*: a symmetric function $W:[0,1]^2\to[0,1]$ that describes the limit of a sequence of graphs with an increasing amount of vertices that grow according to some rule. Even though they vary in size, we can consider sequences of graphs that converge to a graphon as members of the same family with shared structural characteristics.

Graph Families From Graphons

Graphons provide a rule for the generation of two distinct graph types: deterministic weighted graphs and simple random graphs. First, we fix $n\geq 1$ and discretize the interval $[0,1]$ into evenly spaced points $x_j=(j-1)/n$ for $k=0,\ldots,n$. The $\{x_j\}_{j=1}^n$ serve as n vertices of an undirected graph, to which we endow an edge structure by using a graphon in one of the following two ways:

1. *Weighted deterministic graphs*: Between any two vertices x_j and x_k, assign an edge of weight $W(x_j,x_k)$
2. *Simple random graphs*: Between any two vertices x_j and x_k, assign an undirected edge of weight 1 with probability $W(x_j,x_k)$.

This rule implicitly assumes that there is no edge if $W(x_j,x_k)=0$.

Since the deterministic graphs are simply a discretization of the original graphon, a familiarity with Riemann sums can provide a sense of intuition about their

See **Graphons** *on page 4*

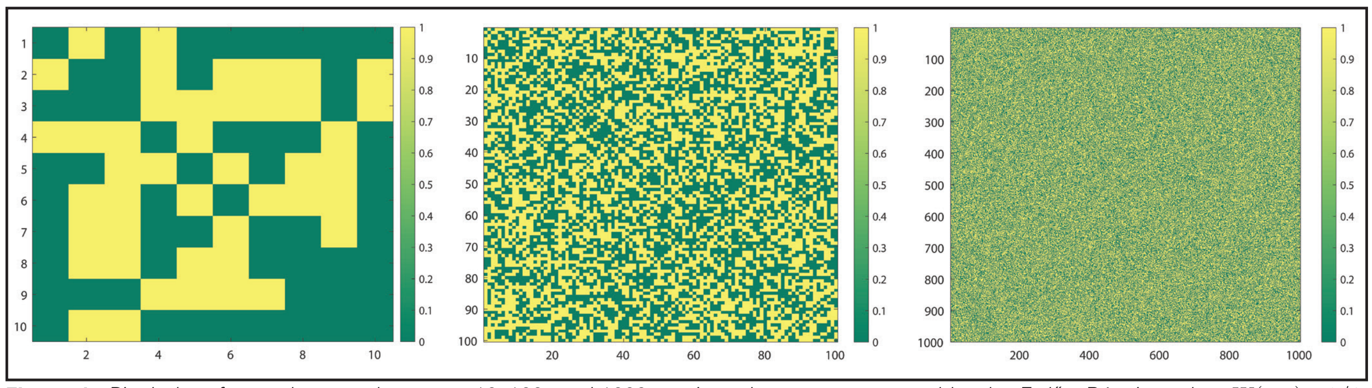

Figure 1. *Pixel plots for random graphs on $n=10$, 100, and 1000 vertices that were generated by the Erdős–Rényi graphon $W(x,y)=1/2$. Yellow squares represent an edge weight of 1 between vertices $x_k=(k-1)/n$ and $x_j=(j-1)/n$, while green represents the absence of an edge. Figure courtesy of Jason Bramburger.*

The Mathematics of Poverty, Inequality, and Oligarchy

By Bruce Boghosian and Christoph Börgers

In 2019, Oxfam[1] reported that the 26 richest people in the world held as much wealth as the poorest half of the global population [9]. Such staggering levels of inequality have precipitated much interdisciplinary discussion among economists, political scientists, sociologists, urban planners, and ethicists. Here, we outline some recent mathematical work on this subject. Our approach applies methods from the kinetic theory of gases to simplified models of the economy in order to explore both potential mechanisms by which wealth inequality arises and the effects of government interventions that attempt to reduce it.

Pareto Tails, Gini Coefficients, and Lorenz Curves

In the second half of the 19th century, Italian polymath Vilfredo Pareto found that the distribution of wealth of a randomly selected individual is often well approximated by a continuous distribution with a heavy, algebraic tail:

$$1-F(w)\sim Cw^{-\alpha}\quad\text{as}\quad w\to\infty.$$

Fits to empirical data suggest that $1<\alpha<2$ in most Western industrialized countries, including the U.S. [11]. The mean μ of F is therefore finite, but its variance is infinite; wealth variance is hence not a useful measure of wealth inequality. A well-known alternative is the *Gini coefficient* G, which Italian statistician Corrado Gini proposed in 1912. If V and W are the wealths of two individuals who are independently chosen at random from the population, then

$$G=\frac{E(|W-V|)}{2\mu}. \tag{1}$$

Finiteness of G does not require the existence of moments of F of order greater than 1. Clearly $G\geq 0$, and $G\leq 1$ by the triangle inequality. There is no distribution on $[0,\infty)$ with $G=1$, but some distributions come arbitrarily close. For instance, if $\epsilon\in(0,1)$, then the distribution with generalized density

$$(1-\epsilon)\delta(w)+\epsilon\delta\left(w-\frac{\mu}{\epsilon}\right) \tag{2}$$

has $G=1-\epsilon$.

In 1905, American economist Max Lorenz defined a function L on $[0,1]$ by

$$L(F(w))=\frac{E(W\cdot 1_{W\leq w})}{\mu}$$

(this formula defines a function on $[0,1]$ if F is continuous). Its graph is called the *Lorenz curve*. We have $L(0)=0$ and $L(1)=1$, and L is increasing and convex. Verifying the well-known geometric interpretation of G in Figure 1 is an exercise in calculus.

[1] https://www.oxfam.org/en

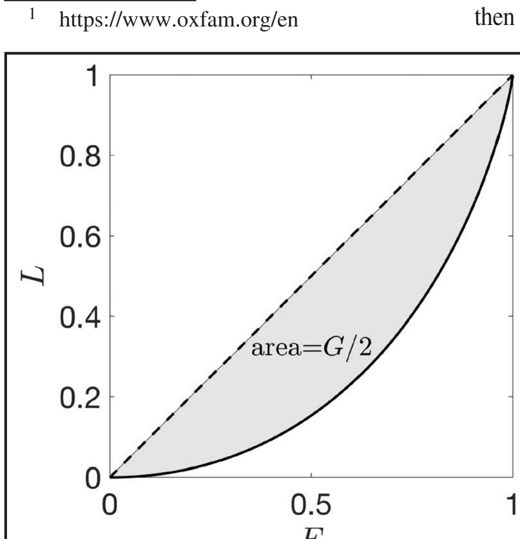

Figure 1. *Lorenz curve and Gini coefficient. Figure courtesy of the authors.*

Yard-sale Model

To understand the emergence of wealth distributions, one must study the dynamics of wealth. In 2002, Anirban Chakraborti drew from the microscopic theory of gases to propose the *yard-sale model* of an economy [7]. There are N agents in this model. In each time step, a random pair of agents interacts. When an interaction occurs between agents j and k and their pre-interaction wealths are w_j and w_k, the transaction causes a wealth transfer of size

$$\beta\ \min(w_j,w_k), \tag{3}$$

where $\beta>0$ is small. The transfer of wealth takes place because people make mistakes and over- or underpay due to imperfect information. The amount at stake in each transaction is a small fraction of the *poorer* agent's wealth because people do not usually enter transactions that jeopardize a large fraction of their total assets. A fair coin flip determines the *direction* of wealth transfer.

Though all seems fair, computer simulations reveal that the most extreme form of oligarchy invariably emerges; one agent eventually owns the entire economy. This phenomenon is called *wealth condensation* [6]. Most or all of a poor agent's transactions change the agent's wealth *multiplicatively*, by a factor of $1\pm\beta$. Since the number of unfavorable versus favorable transactions is roughly the same, one can think of the transactions in pairs. Each pair changes the agent's wealth by

$$(1+\beta)(1-\beta)=1-\beta^2<1, \tag{4}$$

meaning that a poor agent loses wealth over time. Because the model conserves wealth, somebody else must gain. The conclusion is utterly striking: free and fair trading among *identical* agents inescapably results in extreme wealth inequality.

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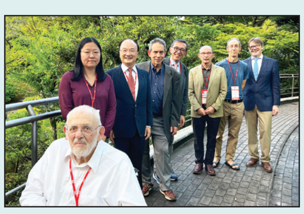

Oligarchy

Continued from page 1

This phenomenon was studied in a version of the model with a *continuum* of agents and continuous time [4]. Between agents of wealth w and x, we assume that there is a flow of wealth in time Δt of magnitude

$$\sqrt{\gamma\Delta t}\,\min(w,x), \qquad (5)$$

where $\gamma>0$ is a reciprocal time. The factor $\sqrt{\gamma\Delta t}$ in (5) plays the role of β in (3). The direction of the flow of wealth is random and unbiased, which implies that the wealth change of an agent with wealth w on account of an agent with wealth x in time Δt has a mean 0 and variance $\gamma\Delta t\min(w,x)^2$. The wealth density $f=f(w,t)$ therefore satisfies the following nonlinear, nonlocal Fokker-Planck equation [1, 2]:

$$\frac{\partial f}{\partial t}(w,t)=\frac{\gamma}{2}\left(\left(\int_0^\infty(\min(x,w))^2 f(x,t)dx\right)f(w,t)\right)_{ww}. \qquad (6)$$

The minimum $\min(x,w)$ appears because the amount at stake in a single transaction is proportional to the poorer agent's wealth.

Christophe Chorro observed that from a probabilistic point of view, convergence to total oligarchy in the yard-sale model is an almost immediate consequence of the martingale convergence theorem [8]. For a more elementary probabilistic proof, which also allows coin flips that are biased in favor of the wealthier agent, see [5].

The Extended Yard-sale Model

Over the years, various effects have been added to the yard-sale model to enhance its realism, such as *wealth redistribution* [1, 2]. We assume that the government taxes each agent a fraction $\gamma\chi$ of their wealth per unit time and redistributes it to all agents in equal shares. Doing so adds a simple linear advection term to the Fokker-Planck equation—the first advection term in (7)—and drives each agent's wealth towards the mean μ. This new term prevents wealth condensation and yields reasonably realistic wealth distributions [10].

Another addition is a *wealth-acquired advantage* [3], which reflects the fact that wealthy individuals can afford better information, better lawyers, more effective lobbyists, and so forth. We again assume that (5) describes the magnitude of the wealth shift between agents of wealth w and x in time Δt, but now we take the *direction* of wealth flow as slightly biased in favor of the wealthier agent. The probability of a shift from x to w (rather than the other way around) is

$$\frac{1}{2}\left(1+\zeta\sqrt{\gamma\Delta t}\,\frac{w-x}{\mu}\right).$$

Here, $\zeta>0$ is a new nondimensional model parameter. The *expected* total flow of wealth from x to w in time Δt is now

$$\gamma\zeta\min(x,w)\frac{w-x}{\mu}\Delta t,$$

which gives rise to the second nonlinear and nonlocal advection term in (7). The Fokker-Planck equation for the extended yard-sale model thus becomes

$$\frac{\partial f}{\partial t}(w,t)+\gamma\chi((\mu-w)f(w,t))_w+\gamma\zeta\left(\left(\int_0^\infty\min(x,w)\frac{w-x}{\mu}f(x,t)dx\right)f(w,t)\right)_w=\frac{\gamma}{2}\left(\left(\int_0^\infty(\min(x,w))^2 f(x,t)dx\right)f(w,t)\right)_{ww}. \qquad (7)$$

In the next section, we will show that (7) implies the return of partial oligarchy if the wealth-acquired advantage is strong enough, or if wealth taxation is too weak.

Oligarchy

To model situations in which a vanishingly small fraction of the population holds a positive fraction of society's wealth, we define a new distribution on $[0,\infty)$—denoted by Ξ—with total mass 0 but expectation 1:

$$\langle\Xi,1\rangle=0,\quad\langle\Xi,w\rangle=1.$$

This distribution was constructed in [2] by augmenting the Schwartz test functions with functions that have linear growth as $w\to\infty$, defining $\langle\Xi,\varphi\rangle=\lim_{w\to\infty}\frac{\varphi(w)}{w}$ or equivalently

$$\langle\Xi,\varphi\rangle=\lim_{\epsilon\to 0}\left\langle\epsilon\delta\left(w-\frac{1}{\epsilon}\right),\varphi\right\rangle.$$

Because the (generalized) density (2) has Gini coefficient $1-\epsilon$, we might say that $\delta(w)+\mu\Xi(w)$ has Gini coefficient 1 and represents total oligarchy — with a vanishingly small fraction owning everything and all others owning nothing.

In [3], it was shown that (7) admits solutions of the form

$$f(w,t)=c(t)\mu\Xi(w)+\rho(w,t).$$

The term $c(t)\mu\Xi(w)$ represents a fraction $c(t)$ of society's wealth that is held by a vanishingly small number of people, henceforth called *the oligarchs*. The term $\rho(w,t)$ is a probability density of mean $(1-c(t))\mu$ that represents the wealth distribution among everyone who is not an oligarch.

The function $c(t)$ satisfies the logistic equation

$$\frac{dc}{dt}=-\gamma\chi c+\gamma\zeta c(1-c). \qquad (8)$$

The term $-\gamma\chi c$ reflects the oligarchs' loss of wealth due to wealth taxation, and $\gamma\zeta c(1-c)$ reflects the growth of the oligarchs' wealth on account of their wealth-acquired advantage. Equation (8) has two fixed points: $c=0$ and $c=1-\frac{\chi}{\zeta}$. For $\zeta<\chi$, $c=0$ is a stable fixed point and c—starting at a non-negative value—will converge to 0; we call this the *subcritical* regime. For $\zeta>\chi$, $c=0$ is an unstable fixed point and c—again starting at a non-negative value—will converge to $1-\frac{\chi}{\zeta}>0$; we call this the *supercritical* regime. The transition from one regime to the other is a transcritical bifurcation.

In 2016, the ratio ζ/χ for the U.S. economy was estimated at about 1.39, suggesting that the U.S. was well in the supercritical (oligarchic) regime [10].

Comparison with Empirical Results

While the extended yard-sale model originally served as a rough qualitative model of wealth distribution and oligarchy, a slight modification that allows for agents of negative wealth is remarkably faithful to empirical wealth data. This modification rigidly shifts the probability density function in the direction of negative wealth by an amount $\kappa\mu$, where κ is a new parameter. The resulting three-parameter (χ,ζ,κ) *affine wealth model* admits steady-state solutions whose Lorenz curves match those of empirical wealth distributions to within one fifth of one percent for American wealth data between 1987 and 2019, and to within a half of a percent for 14 European countries that were associated with the European Central Bank circa 2010. This is far more accurate than fits to Pareto distributions; in fact, it provides perhaps the most accurate microfounded model of wealth distribution to date.

While surely not the last word on models of wealth distribution, the extended yard-sale model and affine wealth model demonstrate the utility and effectiveness of kinetic theory in modern efforts to understand and quantify the origins and time evolution of economic inequality. Despite being at odds with orthodox neoclassical economics—for example, the notion that trade is always deterministic and rational and consistently benefits both participating agents—these models can very accurately explain empirical wealth distributions, including the phenomenon of oligarchy.

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Decisions are Happening Over Dinner

By Luke Oeding

LETTER TO THE EDITOR

You've probably heard or experienced this one before: "Two men walk into a room of mostly men and discuss where and how the next conference will take place. The following year, attendance again consists of mostly men. After a shrug, they proceed to plan the subsequent iteration."

At the 2023 SIAM Conference on Applied Algebraic Geometry[1] (AG23), which took place this July in Eindhoven, the Netherlands, I presented Auburn University's bid to host the next AG meeting. Though I was of course disappointed that Auburn did not win the popular vote, I was glad that my longtime friend Jose Rodriguez's bid for the University of Wisconsin–Madison did. UW–Madison has higher-capacity lecture halls, a commitment to offer the use of dorm rooms for the conference, and a beautiful beer garden by a lake. I'm sure that it will host a fantastic conference in 2025; in my (unbiased) opinion, SIAM AG meetings are the best!

But just before the bid presentations, I was struck by a somewhat troubling observation. The chair of the SIAM Activity Group on Algebraic Geometry[2] praised the fact that women make up nearly 25 percent of the group's overall membership. Can't we do better than that? What are we missing in order to successfully bring more women into the fold?

For one thing, this business meeting occurred at 5:30 pm; anyone with children knows the challenge of early evening meetings, as childcare usually ends around this time. At the conclusion of business hours, children expect to be with their parents, have dinner, and engage in their nightly routines. Arranging childcare for a multi-day conference is both challenging and expensive.[3] Some common (but often suboptimal) solutions include employing 24/7 care at home, paying for family members' travel and bringing a caregiver to the venue, attempting to split childcare and meeting attendance with a spouse, or simply forgoing the conference entirely. It stands to reason that women—and especially women with children—were significantly underrepresented during the evening business meeting at AG23. In fact, I only recall seeing two or three mothers with children among the approximately 700 attendees across the conference's five days. Hosting decision-making events at a time when childcare is next to impossible means that few people in the room will likely advocate for the concerns of the absent parents.

My wonderful wife and our three small children did come with me to Eindhoven, and we had a great time — we even all rode around in a cargo bike together! Nevertheless, my wife and I are very aware of the challenges and necessary sacrifices that accompany our participation in professional events. We try our best to share parenting responsibilities, but my wife often does more of the childcare in part because I am further along in my career. I see firsthand the difficulties that she faces while trying to start a career in academia as a woman with young children.

Of course, parenting is challenging and requires sacrifice. To me, it's worth it! But we must also admit that historical scarcity and structural issues continue to limit the participation of women—particularly mothers—in scientific events. In order to make gains toward gender equity in science and mathematics, perhaps we should consider the following recommendations:

- Host business meetings at a time when childcare is typically available.
- Solicit input from people who are not physically present at the meeting or conference in question.
- Create a pool of funds (separate from the usual scientific budget) to support dependent care for invited speakers, which will enable the scientific committee to secure a variety of speakers regardless of their childcare needs.
- Brainstorm! Can we provide childcare at dinners so parents can fully participate in the networking that transpires at these events? Can we plan family-friendly social events as well?

Progress will continue to be limited until we include those who were not in "the room where it happens."

Luke Oeding is an associate professor of mathematics and statistics at Auburn University.

Luke Oeding and his children explore the campus of Eindhoven University of Technology in a cargo bike during a break from the technical sessions at the 2023 SIAM Conference on Applied Algebraic Geometry, which took place in July 2023. Image courtesy of Michael Burr.

[1] https://www.siam.org/conferences/cm/conference/ag23

[2] https://www.siam.org/membership/activity-groups/detail/algebraic-geometry-si-ag-2

[3] Since 2013, SIAM has offered child care grants at its conferences. This benefit began with the SIAM Annual Meeting and now applies to all conferences over which SIAM has financial control. The grant amount for each meeting is determined by the number of conference days, and eligible expenses can include care at the attendee's home. For more information, visit "Child Care" under "Lodging & Support" on the webpage of the SIAM conference in question.

SIAM Industry Panel Offers Firsthand Look at Careers in Data Science and Machine Learning

By Jillian Kunze

CAREERS IN MATHEMATICAL SCIENCES

Exciting new opportunities in machine learning and data science are drawing a large number of applied mathematicians and computational scientists to industry. In August 2023, the SIAM Industry Committee[1] organized a virtual panel in which researchers from different industrial sectors shared their experiences outside of the academic sphere. Panelists Amr El-Bakry (Exxon), Ben Fogelson (Recursion Pharmaceuticals), Genetha Gray (Edward Jones), Nandi Leslie (Raytheon), and Emmy Smith (Amazon) offered insights based on their individual career paths, while moderators Christine Harvey (Mitre Corporation) and Nessy Tania (Pfizer) fielded audience questions about the broad and rewarding pathways that are available in industry.

El-Bakry opened the session by acknowledging that he worked in academia for a few years after earning his Ph.D. before trying an industry position on the advice of a friend. He thought that it would be a short-term venture; instead, he ended up staying. "What made it a long-term career is that I have always had a fascination with math and statistics technology," El-Bakry said. "The second thing [that attracted me to industry] was seeing a day-to-day impact, including making money for the company where I work."

Several other panelists also disclosed that they had originally planned to pursue careers in academia, but were attracted to industry for a multitude of reasons. "I had every intention of being a math professor," Smith said. "Then I took statistics and kind of fell in love with how applicable it was and everything you could do with it." Fogelson similarly intended to become a professor of mathematical biology, but he was unenthused by the lack of control that academics often have over the course and location of their career. However, he had initial concerns about industry as well. "Like a lot of people coming out of academia, I was nervous about industry and worried that it would be boring and repetitive," Fogelson said. But on the contrary, he stated that his industry experience has involved fruitful collaborations with people from a wide variety of backgrounds to develop rapid impacts for interesting problems — with the added bonus of higher pay and an easier work-life balance than academia.

When discussion turned to the most relevant educational components for an industrial career, Smith touted so-called "soft skills"—such as communication, active listening, and the ability to respond to constructive criticism—as critical for success in any work environment. "A lot of times, I do work with folks for whom you put numbers in front of them and they glaze over," she said. "I had to learn a lot along the way; I had a lot of missteps and good lessons learned." The ability to see data at a granular level, then pull back to understand the entire context of a business and tell a compelling story, is essential.

"I'd echo the soft skills," Fogelson said. "That was something I quickly learned when I made the switch to industry." He also recommended that listeners practice the art of closely reading technical papers. "One of my superpowers at work is being able to read something and quickly learn a new practice," Fogelson continued. "Bringing that value is a big part of how I make an impact." Academic courses on optimization, statistics, mathematical logic, and programming are all likewise useful, as is the ability to read and write code documentation.

An attendee then asked about common misconceptions that students might have regarding machine learning in industrial settings. "One is that the data is clean and ready for analysis, and two is that the algorithm will work right away the first time we try it," El-Bakry said. The panelists all agreed that contrary to popular belief, companies do not always have perfect setups with the newest technologies. Additionally, the process of determining whether systems are working correctly is often murky and

See **Industry Panel** *on page 6*

[1] https://www.siam.org/about-siam/committees/industry-committee

Graphons

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"convergence" to the generating graphon as $n \to \infty$. Although the random graphs are quite different on the superficial level because their edge weights are entirely binary, we can similarly achieve convergence to the generating graphon as $n \to \infty$ in a *probabilistic* sense. The convergence of graphs to graphons does not occur through typical function or vector norms, but rather through the convergence of the operator norm of the associated adjacency matrices. This operator convergence is advantageous, as it means that functional analytic properties of the graphon—such as the spectrum—approximate those of both the deterministic and random graphs that it generates for large n. A proper mathematical formalism of these concepts is available in [2], but one can develop an intuition for the random graphs' convergence to their graphons by examining the pixel plots of the associated adjacency matrices. For example, Figure 1 (on page 1) contains pixel plots for random graphs from the Erdős–Rényi graphon $W(x,y)=1/2$ for $n=10$, 100, and 1000. The visual blending of colors in the plot for large n resembles the uniform graphon that generated it.

A History of Coupled Oscillators

Graphs and dynamics have long come together in the study of coupled oscillators. In this setting, theoretical results from graph theory help researchers understand the synchronization behavior of collective oscillation patterns. In fact, previous synchronization studies reveal a longstanding presence of graphons in the theory of coupled oscillators — often without explicit mention [6]. While early applications focused primarily on graphons as limits of deterministic graphs, research within the last decade has employed graphons to understand the dynamics of coupled oscillators on random graphs [3]. The result is a mature and well-developed research program that uses graphons to understand coupled oscillators on large, random networks.

Predicting Patterns on Random Networks

Informed by the success of graphons in the study of coupled oscillators, we have initiated an investigation into pattern formation on random networks [1]. This work seeks to understand the emergence of inhomogeneous patterns from featureless background states—i.e., Turing bifurcations—on random networks. We utilize converging sequences of random graphs that are generated from a graphon to predict (up to small variations) the emerging small-amplitude patterns in networked dynamical systems on large graphs. By applying techniques from bifurcation theory to a limiting deterministic graphon equation, our results ultimately provide information for high-probability pattern formation across large random networks. We are currently conducting a follow-up investigation into the persistence of patterned solutions over large random networks that are separate from the bifurcation regime; this is joint work with Ph.D. student Jackson Williams from George Mason University, who presented a related poster[1] at the 2023 SIAM Conference on Applications of Dynamics Systems[2] in Portland, Ore., this May.

Graphons and Neural Networks

Data scientists also utilize graphons to quantify the robustness of graph neural networks (GNNs). GNNs are variations of standard neural networks that process data that can be represented on a graph and thus contain layers that incorporate graph structure. One important property of GNNs is *transferability* — the ability to transport a trained GNN between different graphs and maintain performance without retraining it. A simple example stems from recommender systems. Consider a platform that organizes users into a graph structure that weights connections according to their similarities. The goal is to use a GNN to leverage knowledge of one user's interests and provide recommendations for other similar users. The number of users constantly varies as some sign up for the platform while others end their subscriptions. We certainly do not wish to retrain the network every time the number of users changes; instead, we simply want to train a single GNN that can be transferred between the user networks with varying numbers of vertices.

A 2020 study aimed to employ graphons to capture GNNs' transferability [5]. This work provides a GNN architecture and proves bounds on its output between deterministic graphs that were generated by the same graphon — importantly, these bounds vanish as the graph grows in size. The researchers also demonstrate performance on movie recommendation data and citation networks. A recent collaboration sought to strengthen these results by presenting an explicit two-layer GNN architecture that can be transferred—without retraining—between sequences of graphs that converge to a graphon [4]. In particular, we allow for sequences of both deterministic and random graphs and demonstrate that the presence of a limiting graphon helps to overcome the curse of dimensionality that often arises in similar theoretical outcomes for neural networks. This effort provides the first analytical results of the minimum network sizes for transferable GNNs that achieve a fixed output within a desired error tolerance, along with an explicit architecture that does not require any training.

Outlook

Graphons are only just beginning to find their niche within applied mathematics. These powerful tools capture the similarities of differently-sized networks and retain a strongly developed underlying theory that practitioners can exploit to better understand problems in dynamics, pattern formation, and neural network approximation. Further applications of graphons have arisen in game theory and other fields that value network robustness.

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Jason J. Bramburger is an assistant professor at Concordia University in Canada. He has broad interests in applied mathematics, with a primary focus on computational and analytical aspects of dynamical systems.

[1] https://meetings.siam.org/sess/dsp_talk.cfm?p=127784

[2] https://www.siam.org/conferences/cm/conference/ds23

Photos from the 10th International Congress on Industrial and Applied Mathematics

SIAM President Sven Leyffer (left) of Argonne National Laboratory congratulates Thomas Yizhao Hou of the California Institute of Technology for his receipt of the 2023 Ralph E. Kleinman Prize. Hou was honored during the SIAM Reception for Prize Winners at the 10th International Congress on Industrial and Applied Mathematics, which took place in Tokyo, Japan, this August. He was commended for "highly original and pioneering research contributions positioned at the meeting point between analytical and computational approaches to partial differential equations with multiscale or singular behavior." SIAM photo.

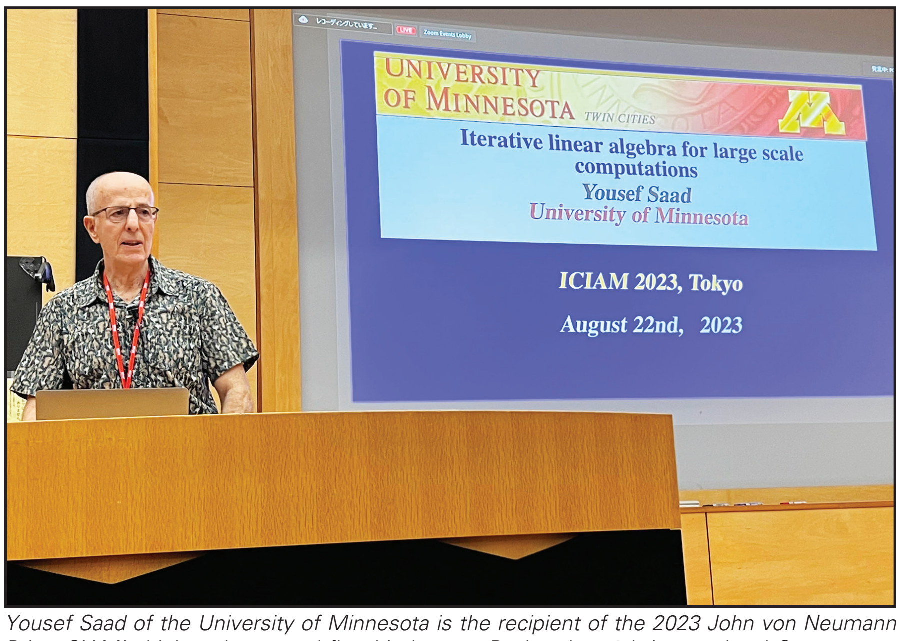
SIAM President Sven Leyffer (left) of Argonne National Laboratory shakes hands with Yingda Cheng of Virginia Polytechnic Institute and State University and Michigan State University, who received the 2023 Germund Dahlquist Prize. Cheng was honored at the SIAM Reception for Prize Winners during the 10th International Congress on Industrial and Applied Mathematics, which was held this August in Tokyo, Japan. The prize notation praised her "outstanding work on discontinuous Galerkin methods, including structure preservation and sparse grid methods for kinetic and transport equations." SIAM photo.

Douglas Arnold of the University of Minnesota received the 2023 Peter Henrici Prize for his "fundamental contributions of extraordinary originality, depth, and impact to the finite element analysis of partial differential equations, ranking amongst the classics in numerical analysis literature." Arnold was recognized at the SIAM Reception for Prize Winners during the 10th International Congress on Industrial and Applied Mathematics, which was held this August in Tokyo, Japan. He later delivered a corresponding prize talk entitled "What the @#$! is Cohomology Doing in Numerical Analysis?" SIAM photo.

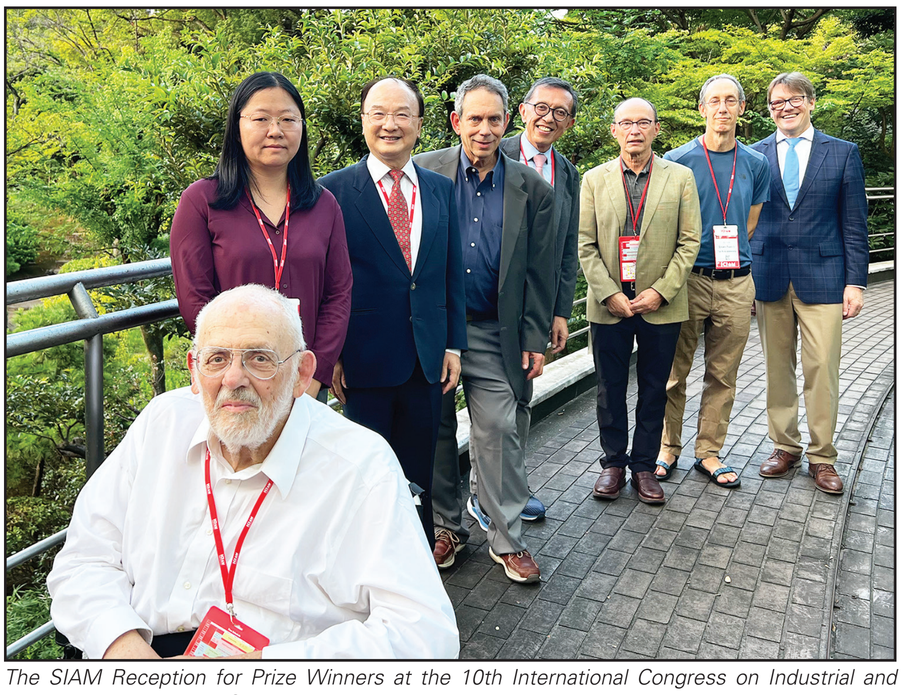
Learn more about the 2023 SIAM major prize recipients at https://sinews.siam.org/Details-Page/august-prize-spotlight.

A full list of the 2023 Fellows is available at https://go.siam.org/eUHHVw.

During the SIAM Reception for Prize Winners at the 10th International Congress on Industrial and Applied Mathematics, which took place this August in Tokyo, Japan, SIAM President Sven Leyffer (left) of Argonne National Laboratory acknowledges Fadil Santosa of Johns Hopkins University as the recipient of the 2023 SIAM Prize for Distinguished Service to the Profession. Santosa was recognized for his "extraordinary dedication to bridging the gap between industry and academia" throughout his career. SIAM photo.



Yousef Saad of the University of Minnesota is the recipient of the 2023 John von Neumann Prize: SIAM's highest honor and flagship lecture. During the 10th International Congress on Industrial and Applied Mathematics, which was held in August in Tokyo, Japan, Saad was acknowledged for his fundamental contributions to scientific computing and effective communication of these ideas to the community. His "work on algorithms is especially impactful to the fields of sparse linear systems, eigenvalue problems, nonlinear equations, and graph algorithms, and can be applied to a wide range of problems in computational science and engineering." Saad delivered an associated prize lecture on "Iterative Linear Algebra for Large Scale Computations" at the conference. SIAM photo.



The SIAM Reception for Prize Winners at the 10th International Congress on Industrial and Applied Mathematics (ICIAM 2023)—which took place in August in Tokyo, Japan—celebrated this year's SIAM major prize recipients who were present at ICIAM 2023, as well as several other SIAM members who were recognized at the conference. From left to right: Cleve Moler of MathWorks, who received the first-ever ICIAM Industry Prize; Yingda Cheng of Virginia Polytechnic Institute and State University and Michigan State University, who received the Germund Dahlquist Prize; Thomas Yizhao Hou of the California Institute of Technology, who received the Ralph E. Kleinman Prize; Douglas Arnold of the University of Minnesota, who received the Peter Henrici Prize; Fadil Santosa of John Hopkins University, who received the SIAM Prize for Distinguished Service to the Profession; Leslie Greengard of New York University and the Flatiron Institute, who received the ICIAM Pioneer Prize; Sivan Toledo of Tel Aviv University, a class of 2023 SIAM Fellow; and SIAM President Sven Leyffer of Argonne National Laboratory. Annalisa Buffa of École Polytechnique Fédérale de Lausanne, who received the AWM-SIAM Sonia Kovalevsky Lecture, and Hannah Fry of University College London, who received the George Pólya Prize for Mathematical Exposition, are not pictured. SIAM photo.

Industry Panel

Continued from page 3

costly, and data for certain questions might not exist or be legally accessible.

"Another misconception is that you can bring your full innovative and creative self to every problem," Leslie said. "Sometimes you have to use a canned algorithm that has already been tested." Smith concurred, noting that researchers are often eager to experiment with fun, innovative techniques that are unnecessarily complex for the question at hand. She advised attendees to maintain simplicity in order to avoid the trap of over-innovation.

Next, an audience member inquired about the significance of publication in industry. "One of the misconceptions of industry is that it's one wholistic thing," El-Bakry replied. "We have many different sectors, and the culture might be different [in each]." Businesses emphasize the factors that bring value to them, so winning contracts or contributing to successful proposals may be more beneficial than publishing papers; moreover, the level of importance of these activities at one company can even change over time.

Leslie offered her own take on the publications query. "I'd like to add patents and other intellectual property to that question," she said. "Some companies may not care as much about publications in a journal, but they might care about patents." The relevance of publishing also varies based on whether one is pursuing a management or research track.

Conversation then shifted to the topic of qualifications, as it is sometimes difficult to discern the appropriate level of formal education for industry positions. "In your interview and at certain companies, a Ph.D. is going to open a lot of doors," Gray said. However, people with Ph.D.s do not automatically receive senior roles or titles; in some cases, their managers may not have doctorates but might nonetheless possess far more experience and knowledge about the business. Gray advised listeners to find their own spaces and refrain from comparing their stations with those of their colleagues, especially since Ph.D.s do not affect industry promotions in the same way as academia.

Furthermore, some industry-based machine learning and data science roles do not require Ph.D.s at all. A master's degree, however, does often allow for more interesting research possibilities than a bachelor's degree, while a Ph.D. is generally required for positions that actively shape the future direction of an organization. Job seekers should carefully review position listings to judge the requirements and discern the responsibilities beyond a potentially ambiguous title. "Take a look at different job descriptions and what they actually ask for," Smith said. "Companies don't always name what they want, and it's important to read those job descriptions and ask questions."

Because industry resumes are written and formatted differently than academic CVs, prospective applicants might want to solicit feedback from an acquaintance who already works in industry. Specific details about the *impact* of one's work are essential; even if candidates do not have much actual work experience, they can describe their involvement in a hackathon or other substantial project based on its hypothetical outcome in a real-world setting. This emphasis on impact helps candidates stand out against the many other job seekers who likely have similar credentials.

When interviewing potential employees, Smith looks for individuals who know about the industry, have done their research on the company, and can articulate their reasons for wanting to work there. Gray observed that most people who flounder during the interview process do so due to their lack of presentation skills; as such, she emphasized the importance of talking about impacts in a way that would appeal to a director or human resources leader. Fogelson, on the other hand, finds that many interviewees drop out in the coding stage due to gaps in their ability to translate their abstract knowledge into the creation of something useful.

Professional conferences,[2] university career events, and SIAM career fairs[3] all offer opportunities for interested individuals to learn more about the job market for machine learning and data science, and begin to make valuable connections. "My number one thing is your network," Gray said. "Make sure your network is strong, and make sure that you're connecting with people who do what you want to do." In fact, having an acquaintance at a company increases the likelihood that one's application will be viewed and progress to the next stage. "You have your colleagues from academia, but I suggest that you also go to conferences, meetings, and workshops and engage through talking to the people you meet — folks at your level or above," Leslie said. "Exchange information in order to continue to build your network."

To round out the hourlong session, the panelists emphasized that robust mathematical training provides an abundance of translatable skills to the data science and machine learning space. By keeping an open mind, applied mathematicians can encounter new and unexpected challenges from all corners of industry.

Jillian Kunze is the associate editor of SIAM News.

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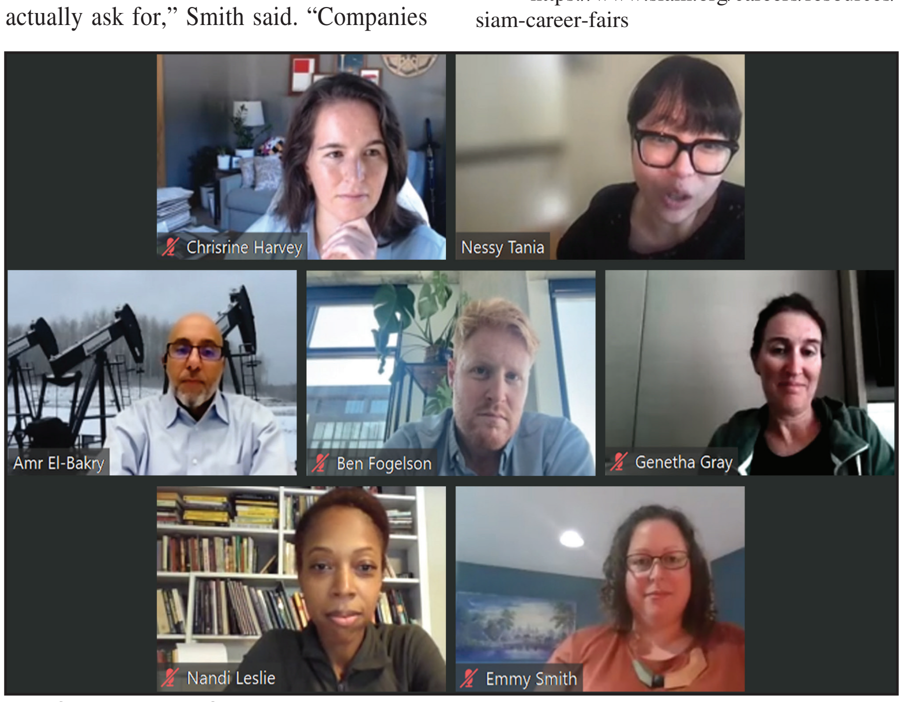
[2] https://www.siam.org/conferences/calendar

[3] https://www.siam.org/careers/resources/siam-career-fairs



The SIAM Industry Committee sponsored a virtual career panel this August that explored career opportunities in data science and machine learning for applied mathematicians and computational scientists outside the realm of academia. Top row, left to right: moderators Christine Harvey (Mitre Corporation) and Nessy Tania (Pfizer). Middle row, left to right: Amr El-Bakry (Exxon), Ben Fogelson (Recursion Pharmaceuticals), and Genetha Gray (Edward Jones). Bottom row, left to right: Nandi Leslie (Raytheon) and Emmy Smith (Amazon).

Lowering the Entry Barrier to Uncertainty Quantification

By Linus Seelinger and Anne Reinarz

Uncertainties in data are omnipresent, encompassing factors such as measurement errors, incomplete information, and random processes. The goal of *uncertainty quantification* (UQ) is to determine the effect of uncertain data on model predictions or inferences. UQ's myriad applications include safe aircraft design, medical decision-making, and nuclear waste disposal, among many others.

UQ problems typically fall into two categories: propagation problems and inverse problems. *Propagation problems* start from a model parameter θ, which we treat as random with density π in order to represent a range of plausible parameter values. We use F to denote our model map that takes parameters to observations, then aim to find the distribution of $F(\theta)$. Conversely, *inverse problems* originate from uncertain observations of a physical process and seek to determine the underlying model parameters.

Solving UQ problems on realistic models can be computationally challenging and often necessitates a large number of costly model evaluations. Doing so therefore requires a combination of advanced UQ methods, efficient numerical model solvers, and possibly even high-performance computing (HPC) support [5].

UQ and Realistic Models: Simple in Theory, Complex in Practice

The Monte Carlo method is a basic, inefficient approach to uncertainty propagation. First, we generate a number of independent samples $\theta_1,\ldots,\theta_N$ from π. Upon applying the model map, $F(\theta_1),\ldots,F(\theta_N)$ become samples of the desired distribution.

Despite the wide variety of more sophisticated UQ methods—which mainly differ in the amount of information they offer about the desired distributions, the number of assumptions they make on model F, and their level of efficiency—many of these methods require similar information about the model in question. In fact, they often come down to a subset of the following pointwise operations: evaluations $F(\theta)$, Jacobian actions $J(\theta)v$, gradients $v^\top J(\theta)$, and Hessian actions.

SOFTWARE AND PROGRAMMING

An emerging ecosystem of software packages is expediting the implementation of advanced UQ methods. Examples include CUQIpy,[1] Lagun,[2] MUQ,[3] PyMC,[4] QMCPy,[5] Sparse Grids Matlab Kit,[6] tinyDA,[7] UQLab,[8] UQ Toolkit,[9] and TT-Toolbox.[10]

Considering the simple mathematical "interface" and availability of software packages, the application of UQ methods to even complex models should be straightforward. So why is UQ not nearly as ubiquitous or well-integrated as deterministic numerical simulations, even though information about uncertainty is crucial to a variety of applications?

First, combining state-of-the-art UQ methods with advanced numerical solvers and HPC capabilities entails a high level of technical complexity, since the relevant communities tend to use very different tools (for good reason). Second, experts from each field often must collaborate closely throughout the entire project; technical issues and a lack of separation of concerns are frequent limiting factors.

UM-Bridge: A Universal Link between UQ and Models

UM-Bridge[11] breaks down the technical complexity by providing a link between any UQ code and any model software that is as universal as the aforementioned mathematical operations [3]. We utilize a network protocol to transfer inputs to and outputs from these operations.

The result is the architecture in Figure 1. UQ (the "client") and the numerical model (the "server") run as separate applications and use whatever programming languages, dependencies, or data that they each require. Due to the unified interface, we can easily interchange both the model and UQ code with alternatives. Furthermore, we can containerize UM-Bridge models for portability and even scale them to large clusters.

UM-Bridge provides straightforward integrations for C++, Julia, Python, MATLAB, and R. Framework-specific integrations also exist for emcee,[12] MUQ, PyMC, QMCPy, Sparse Grids Matlab Kit, tinyDA, and TT-Toolbox. In addition, a selection of benchmark problems are available as ready-to-run Docker[13] container images [2]. For example, we can download and run the tsunami simulation from Figure 2 with a single Docker command:

```
docker run -it -p 4242:4242
linusseelinger/model-exahype-
tsunami
```

Now we can connect to the model server from any UM-Bridge client.

In the Python example in Figure 3, we point UM-Bridge to a model named "`forward`" that runs on the same machine, and proceed to request a model evaluation $F((0,10)^\top)$. We also request a Jacobian action $J((0,10)^\top)(1,4)^\top$ from the model, provided that it is supported. As such, defining a model comes down to defining the mathematical operations in an UM-Bridge server.

Figure 4 (on page 8) depicts a minimal Python example that implements $F:\mathbb{R}^2\to\mathbb{R}, F(\theta)=\theta_1+\theta_2$. We can connect this Python model to any UM-Bridge client, e.g., in place of the tsunami model in Figure 2.

Finally, we demonstrate the application of UQ packages to UM-Bridge models. The QMCPy example in Figure 5 (on page 8) propagates a uniform distribution through the model via the quasi-Monte Carlo (QMC) method [1]. The code focuses solely on the setup of QMC. Instead of defining the model, it connects to an UM-Bridge model and passes it to QMCPy's UM-Bridge wrapper. We can apply the exact same QMCPy code to both the aforementioned custom model and the tsunami simulation (of course, the latter is much more costly).

Scaling to Clusters

Scaling up UQ applications to large clusters brings its own set of challenges, as many UQ packages are not prepared for that setting and thus require costly reimplementations.[14] The few that are able to run on large clusters are typically tied to a specific parallelization technology, such as message passing interface (MPI) or Ray.[15]

UM-Bridge includes an easy-to-use Kubernetes[16] configuration that runs parallel instances of arbitrary model containers in the cloud (see Figure 6, on page 8). A predefined load balancer distributes model evaluation requests from the UQ client among these instances. As a result, UQ applications based on UM-Bridge are easy to scale up; no model modifications are necessary because each model instance runs in a portable container exactly as before. Likewise, the UQ software still makes evaluation requests through UM-Bridge. The only difference is that the software may now make parallel requests via any parallelization technique [4].

Many UQ algorithms themselves are rather inexpensive when compared to costly model evaluations. Even prototype-grade, thread-parallel UQ codes that run on a laptop can transparently offload model evaluations to remote clusters with thousands of processor cores.

Discussion

UM-Bridge enables complex UQ applications by breaking down complexity and accelerating development — from prototypes

See **Uncertainty Quantification** *on page 8*

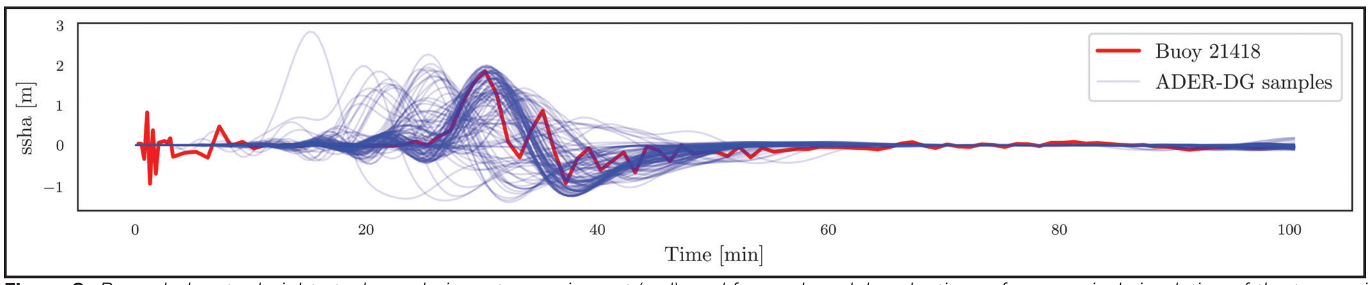


Figure 2. *Recorded water height at a buoy during a tsunami event (red), and forward model evaluations of a numerical simulation of the tsunami event with uncertain input parameters (blue). Figure courtesy of [5].*

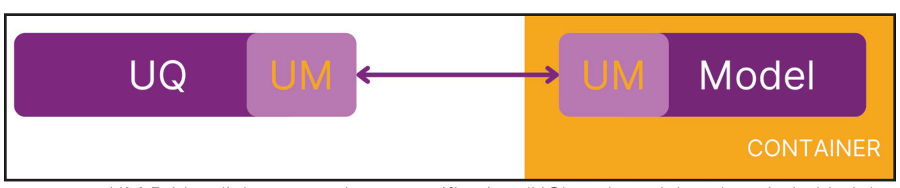


Figure 1. *UM-Bridge links uncertainty quantification (UQ) and model codes via behind-the-scenes HTTP-based network communication that is inspired by microservice architectures. Figure courtesy of Anne Reinarz.*

```
import umbridge

model = umbridge.HTTPModel("http://localhost:4242", "forward")

print(model([[0.0, 10.0]]))

if model.supports_apply_jacobian():
  print(model.apply_jacobian(0, 0, [[0.0, 10.0]], [1.0, 4.0]))
```

Figure 3. *Python example that points UM-Bridge to a model named "*`forward`*" and requests a model evaluation $F((0,10)^\top)$ and Jacobian action $J((0,10)^\top)(1,4)^\top$.*

[1] https://cuqi-dtu.github.io/CUQIpy
[2] https://gitlab.com/drti/lagun
[3] https://mituq.bitbucket.io/source/_site/index.html
[4] https://www.pymc.io/welcome.html
[5] https://qmcpy.org
[6] https://sites.google.com/view/sparse-grids-kit
[7] https://github.com/mikkelbue/tinyDA
[8] https://www.uqlab.com
[9] https://www.sandia.gov/uqtoolkit
[10] https://github.com/oseledets/TT-Toolbox
[11] https://um-bridge-benchmarks.readthedocs.io
[12] https://emcee.readthedocs.io/en/stable
[13] https://www.docker.com
[14] https://bssw.io/blog_posts/enabling-complex-scientific-applications
[15] https://www.ray.io
[16] https://kubernetes.io

National University of Singapore SIAM Student Chapter Hosts 12th Symposium

By Chushan Wang

The National University of Singapore (NUS) SIAM Student Chapter[1] hosted its 12th symposium[2] on May 18, 2023. This symposium—the first in-person chapter activity since the onset of the COVID-19 pandemic—owes its success to the concerted efforts of NUS professors Weizhu Bao and Yao Yao, who organized the event jointly with the East Asia Section of SIAM[3] (EASIAM) Workshop on Applied and Computational Mathematics. This collaboration attracted a wide variety of esteemed speakers and attendees (both students and professors) from the EASIAM section and beyond, including SIAM Past President Susanne Brenner of Louisiana State University and EASIAM President Yang Xiang of the Hong Kong University of Science and Technology (HKUST).

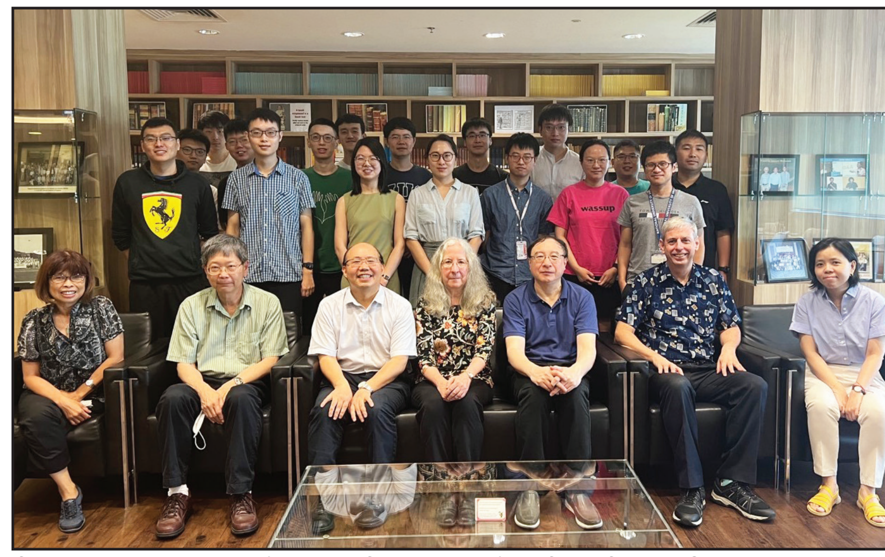
The one-day 12th Symposium of the SIAM Student Chapter at NUS comprised a significant part of the larger, three-day EASIAM event. NUS SIAM Student Chapter officers invited 10 senior Ph.D. students to speak at the symposium. Eight of these speakers were from NUS—one from the Department of Statistics and the rest from the Department of Mathematics—and the remaining two hailed from Sun Yat-sen University and HKUST. Each individual delivered a 30-minute presentation on their ongoing research; topics included optimization, statistics, machine learning, data science, probability, and pure and numerical partial differential equations.

After the morning session, attendees enjoyed a buffet lunch that encouraged participating students to engage in fruitful discourse with both their peers and more senior academics. During the lunch, Brenner—who gave a plenary talk on "Novel Finite Element Methods for Elliptic Optimal Control Problems with Pointwise State Constraints" at the EASIAM workshop the day before—shared valuable insights about the organization of post-pandemic student chapter activities. She encouraged students to take advantage of the SIAM Visiting Lecturer Program[4] and free SIAM student membership,[5] along with the various opportunities that accompany it; this guidance was exceptionally pertinent for future NUS chapter officers. Brenner also discussed her own academic journey and personal research experiences, and offered heartfelt advice to female attendees in particular — endorsing their persistent involvement and advancement in the fields of applied mathematics and computational science.

After an additional five talks in the afternoon session, all of the speakers were invited for dinner and a leisurely walk around Marina Bay. This excursion provided them with the chance to appreciate the splendid night views of Singapore while engaging in conversation about a variety of scientific and nonscientific topics alike.

As the first in-person endeavor of the NUS SIAM Student Chapter in recent years, the symposium sought to revive and reconnect the community. With continued support from the NUS Department of Mathematics and its students, the chapter intends to maintain its vigor and dynamism with similar events in the coming years.

Chushan Wang is a Ph.D. student in the Department of Mathematics at the National University of Singapore (NUS). He served as president of the NUS SIAM Student Chapter from July 2022 to July 2023.



Speakers and attendees of the 12th Symposium of the SIAM Student Chapter at the National University of Singapore, which was held in May 2023, gather for a group photo before the buffet lunch. Photo courtesy of Jinfeng Song.

During the 12th Symposium of the SIAM Student Chapter at the National University of Singapore (NUS), which took place in May 2023, Yifei Li of NUS answers audience questions after his talk about "A Symmetrized Parametric Finite Element Method for Anisotropic Surface Diffusion." Photo courtesy of Di Hou.

1 https://siamnus.github.io/website
2 https://sites.google.com/view/easiam2023workshop
3 https://www.easiam.org
4 https://www.siam.org/students-education/programs-initiatives/siam-visiting-lecturer-program
5 https://www.siam.org/membership/join-siam/individual-members/student

Uncertainty Quantification

Continued from page 7

all the way to large-scale runs on clusters. Support for Slurm-based HPC systems[17] will become available soon. The separation of concerns facilitates efficient collaboration between experts, shifting the focus from technical issues to truly relevant mathematical questions. Model specialists gain access to a wide variety of UQ packages and can easily share models with their collaborators. Furthermore, UQ method developers can readily apply UQ codes to any numerical model (including standardized benchmark problems) and offer UQ software to a wide audience. They also do not need to develop dedicated HPC versions of their codes.

Although UM-Bridge is a young project, it is already gaining traction. Multiple UQ packages have added support for UM-Bridge, and more than 15 collaborators from over 10 institutions are working to develop the UM-Bridge benchmark library. Additionally, we received a Google Open Source Peer Bonus award[18] in 2023, and early industry adoption is ongoing.

Documentation, tutorials, and benchmark problems for UM-Bridge are all available online.[19] Feel free to contact us via email at **anne.k.reinarz@durham.ac.uk** and **mail@linusseelinger.de**, or join our Slack workspace from the documentation's main page. We are still working to grow the community around UM-Bridge and are happy to actively support new applications and integrations in UQ packages. In fact, we are organizing an online, two-day workshop[20] for UM-Bridge on December 11-12 and invite any interested individuals to attend. Registration is open until December 1.

17 https://slurm.schedmd.com
18 https://opensource.googleblog.com/2023/05/google-open-source-peer-bonus-program-announces-first-group-of-winners-2023.html
19 https://um-bridge-benchmarks.readthedocs.io
20 https://um-bridge.github.io/workshop

```
class TestModel(umbridge.Model):
    def __init__(self):
        super().__init__("forward") # Give a name to the model

    def get_input_sizes(self, config): # Input dimensions
        return [2]

    def get_output_sizes(self, config): # Output dimensions
        return [1]

    def __call__(self, parameters, config):
        output = parameters[0][0] + parameters[0][1] # Function evaluation
        return [[output]]

    def supports_evaluate(self):
        return True
```

Figure 4. *Minimal Python example that implements* $F: \mathbb{R}^2 \to \mathbb{R},\ F(\theta) = \theta_1 + \theta_2$.

```
model = umbridge.HTTPModel("http://localhost:4242", "forward")

d = model.get_input_sizes()[0] # Get input dimension from model

# Choose a distribution of suitable dimension to sample via QMC
dnb2 = qp.DigitalNetB2(d)
gauss_sobol = qp.Uniform(dnb2, lower_bound=[0]*d, upper_bound=[100]*d)

# Create integrand based on UM-Bridge model
integrand = UMBridgeWrapper(gauss_sobol, model)

# Run QMC integration to some accuracy and print results
qmc_sobol_algorithm = qp.CubQMCSobolG(integrand, rel_tol=1e-1)
solution,data = qmc_sobol_algorithm.integrate()
print(data)
```

Figure 5. *QMCPy example that propagates a uniform distribution through the model via the quasi-Monte Carlo (QMC) method.*

References

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[2] Merkel, D. (2014). Docker: Lightweight Linux containers for consistent development and deployment. *Linux J.*, *2014*(239), 2.

[3] Seelinger, L., Cheng-Seelinger, V., Davis, A., Parno, M., & Reinarz, A. (2023). UM-Bridge: Uncertainty quantification and modeling bridge. *J. Open Source Soft.*, *8*(83), 4748.

[4] Seelinger, L., Reinarz, A., Benezech, J., Lykkegaard, M.B., Tamellini, L., & Scheichl, R. (2023). Lowering the entry bar to HPC-scale uncertainty quantification. Preprint, *arXiv:2304.14087*.

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Linus Seelinger is a postdoctoral researcher in the Institute for Mathematics at Heidelberg University. He has contributed to the DUNE numerical framework, is a core developer of the MIT Uncertainty Quantification Library, and started the UM-Bridge project. Anne Reinarz is an assistant professor of computer science in the Scientific Computing research group at Durham University and director of the Durham MSc in Scientific Computing and Data Analysis. She has worked on numerous open-source software projects, including UM-Bridge and the hyperbolic partial differential equation solver ExaHyPE.

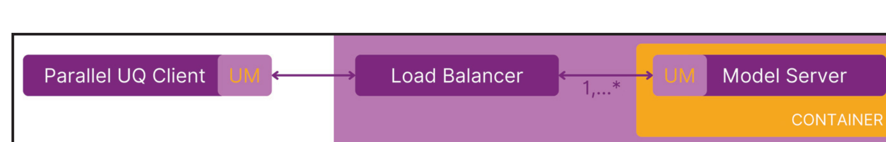

Figure 6. *Cloud cluster configuration that distributes evaluation requests across many instances of any UM-Bridge model. Figure courtesy of Anne Reinarz.*

InsideSIAM

Conferences, books, journals, and activities of Society for Industrial and Applied Mathematics

SIAM | PROGRAMS AND AWARDS

Nominate | Apply | Network

Nominations Close October 18 for the SIAM Fellows Class of 2024! Support your profession by nominating colleagues for excellence related to the goals of SIAM at *nominatefellows.siam.org*.

Nominate a Colleague for 2024 Major Awards and SIAM Activity Group Prizes

siam.org/deadline-calendar

SIAM is accepting nominations for major prizes and activity group prizes that will be awarded in 2024. These prizes identify outstanding contributions to specific fields by recognizing published papers and individuals in various stages of their careers.

Selection committees require at least three nominations to award a prize, so every nomination counts! Visit the website for full requirements. Contact *prizeadmin@siam.org* with questions.

The deadline for nominations is October 15, 2023. Submit your nominations at *go.siam.org/prizes-nominate*.

Apply Now for the SIAM Science Policy Fellowship Program

siam.org/science-policy-fellowship

The SIAM Science Policy Fellowship Program develops postdoctoral fellows and early career researchers into strong advocates for U.S. federal support in applied mathematics and computational science. The program enables participants to gain in-depth knowledge of the policy processes that determine science funding and policy decisions while still pursuing their research and teaching.

The SIAM Science Policy Fellowship Program is open to SIAM members currently working and living in the United States. SIAM encourages all qualified individuals to apply.

Three to five fellowship recipients will be selected each year to serve two-year terms that include:

- In-person and remote training
- Attending biannual SIAM Committee on Science Policy meetings
- Interfacing with federal officials, congressional staff, and policy-makers
- Participating in an advocacy day in Washington, D.C.

The deadline to apply is November 1, 2023.

Don't Forget to Renew SIAM for 2024 at *my.siam.org*

If your SIAM membership expires December 31, 2023 and you have not yet renewed for 2024, please log in to your account at ***my.siam.org*** and click on the "My Renewals" tab, where you can either pay your dues online or print out a renewal invoice to mail your payment. Contact *membership@siam.org* with questions.

Free student members must renew their membership in order to continue receiving benefits in 2024.

SIAM Postdoctoral Support Program Seeks Applicants

siam.org/postdoctoral-support

The SIAM Postdoctoral Support Program provides financial support for postdoctoral scholars to foster direct research experience and professional development. Up to $15,000 in financial support is available for postdoctoral researchers who design a research and collaboration plan with a mentor from a different institution. Up to four postdoc/mentor pairs are selected annually.

Priority deadline for applications is November 1, 2023.

Gene Golub SIAM Summer School Seeks Letters of Intent for 2025

siam.org/gene-golub-school

SIAM is calling for Letters of Intent submitted in advance of possible proposals of sites, topics, and organizers for the Gene Golub SIAM Summer School (G2S3) offered over two weeks to approximately 40 graduate students in 2025.

Courses in the G2S3 are expected to be at the research level, have a computational component, and cover topics not usually found in regular university courses. The G2S3 should have an overall theme of current interest, with lectures and exercises/project sessions on complementary topics for this area.

Information about the 2024 G2S3 on *Iterative and Randomized Methods for Large-Scale Inverse Problems*, an archive of prior summer schools, and the full call for proposals for the 2025 G2S3 can be found at the URL above.

The deadline for Letters of Intent is January 31, 2024.

Applications are Being Accepted for the 2024 Class of MGB-SIAM Early Career Fellows

siam.org/msec-fellowship

The MGB-SIAM Early Career Fellowship aims to recognize the achievements of early-career applied mathematicians and provide support for professional activities and career development — particularly for those who belong to racial and ethnic groups that are historically excluded from the mathematical sciences in the United States. The Fellowship is a joint program of Mathematically Gifted & Black (MGB) and SIAM.

Fellows receive:

- Complimentary SIAM membership for the duration of the fellowship
- Complimentary registration to SIAM Annual Meetings and one additional SIAM Activity Group conference
- Travel support to attend SIAM conferences
- Mentoring and professional development opportunities
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The deadline to apply is November 1, 2023.

FOR MORE INFORMATION: ***siam.org/programs*** AND ***siam.org/prizes-recognition***

SIAM | BOOKS

Quality and Value in Mathematical Science Literature

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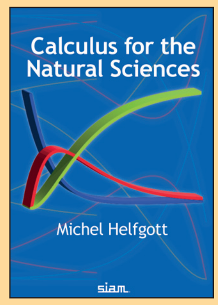
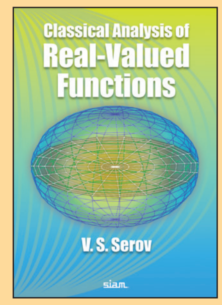


Calculus for the Natural Sciences

Michel Helfgott

In this textbook on calculus of one variable, applications to the natural sciences play a central role. Examples from biology, chemistry, and physics are discussed in detail without compromising the mathematical aspects essential to learning differential and integral calculus. It distinguishes itself from other textbooks on the topic by balancing theory, mathematical techniques, and applications to motivate students and bridge the gap between mathematics and the natural sciences and engineering; employing real data to convey the main ideas underlying the scientific method; and using SageMath and R to perform calculations and write short programs, thus giving the teacher more time to explain important concepts.

2023 / xii + 444 pages / Softcover / 978-1-61197-768-4
List $94.00 / SIAM Member $65.80 / OT194



Classical Analysis of Real-Valued Functions

V.S. Serov

Divided into two self-contained parts, this textbook is an introduction to modern real analysis. The first part covers the theorems of existence of supremum and infimum of bounded sets on the real line and the Lagrange formula for differentiable functions. Applications of these results are crucial for classical mathematical analysis and many are threaded through the text. In the second part of the book, the implicit function theorem plays a central role, while the Gauss–Ostrogradskii formula, surface integration, Heine–Borel lemma, the Ascoli–Arzelà theorem, and the one-dimensional indefinite Lebesgue integral are also covered. More than 350 exercises and 100 examples are integrated into the text to help clarify the theoretical considerations and the practical applications to differential geometry, Fourier series, differential equations, and other subjects.

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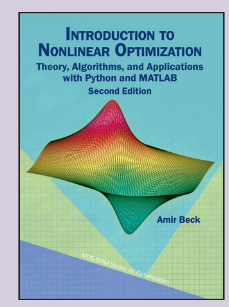


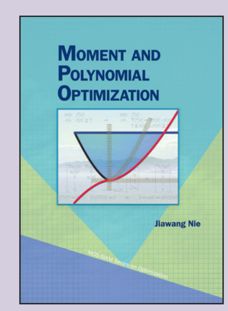
Introduction to Nonlinear Optimization

Theory, Algorithms, and Applications with Python and MATLAB, Second Edition

Amir Beck

Built on the framework of the successful first edition, this book serves as a modern introduction to the field of optimization. The author's objective is to provide the foundations of theory and algorithms of nonlinear optimization, as well as to present a variety of applications from diverse areas of applied sciences. Python and MATLAB programs are used to show how the theory can be implemented. The extremely popular CVX toolbox (MATLAB) and CVXPY module (Python) are described and used.

2023 / xii + 354 / Softcover / 978-1-61197-761-5 / List $84.00 / SIAM Member $58.80 / MO32



Moment and Polynomial Optimization

Jiawang Nie

Moment and polynomial optimization is an active research field used to solve difficult questions in many areas, including global optimization, tensor computation, saddle points, Nash equilibrium, and bilevel programs, and it has many applications. Synthesizing current research and applications, this book provides a systematic introduction to theory and methods, a comprehensive approach for extracting optimizers and solving truncated moment problems, and a creative methodology for using optimality conditions to construct tight Moment-SOS relaxations.

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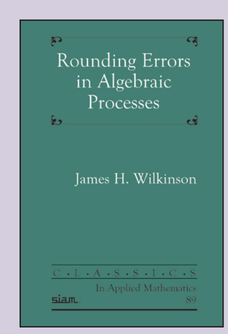

Rounding Errors in Algebraic Processes

James Hardy Wilkinson

"[This book] combines a rigorous mathematical analysis with a practicality that stems from an obvious first-hand contact with the actual numerical computation. The well-chosen examples alone show vividly both the importance of the study of rounding errors and the perils of its neglect."

— A. A. Grau, *SIAM Review* (1966)

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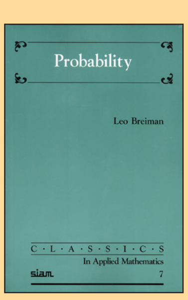

Probability

Leo Breiman

Well known for the clear, inductive nature of its exposition, this reprint volume is an excellent introduction to mathematical probability theory.

1992 / xiv + 421 pages / Softcover / 978-0-898712-96-4
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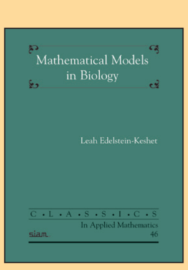

Mathematical Models in Biology

Leah Edelstein-Keshet

A favorite in the mathematical biology community since its first publication in 1988, this introductory book shows how relatively simple mathematics can be applied to a variety of models to draw interesting conclusions.

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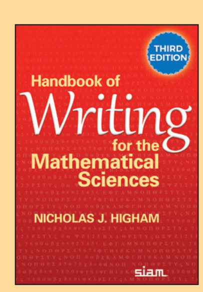

Handbook of Writing for the Mathematical Sciences, *Third Edition*

Nicholas J. Higham

This third edition revises, updates, and expands the best-selling second edition to reflect modern writing and publishing practices and builds on the author's extensive experience in writing and speaking about mathematics. It provides advice on all aspects of scientific writing, with a particular focus on writing mathematics.

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A Place to Network and Exchange Ideas

Upcoming Deadlines

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Conference on the Life Sciences (LS24) — Co-located with MPE24

June 10–13, 2024 | Portland, Oregon, U.S.
go.siam.org/ls24 | #SIAMLS24

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SUBMISSION AND TRAVEL AWARD DEADLINES
November 13, 2023: Minisymposium Proposal Submissions
December 11, 2023: Contributed Lecture, Poster, & Minisymposium Presentation Abstracts
March 11, 2024: Travel Fund Application Deadline

SIAM 2024

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go.siam.org/mpe24 | #SIAMMPE24

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December 11, 2023: Contributed Lecture, Poster, & Minisymposium Presentation Abstracts
March 11, 2024: Travel Fund Application Deadline

SIAM 2024

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July 8–12, 2024 | Spokane, Washington, U.S.
go.siam.org/an24 | #SIAMAN24

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April 8, 2024: Travel Fund Application Deadline

SIAM 2024

Conference on Applied Mathematics Education (ED24) — Co-located with AN24 & DM24

June 8–9, 2024 | Spokane, Washington, U.S.
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June 8–11, 2024 | Spokane, Washington, U.S.
go.siam.org/dm24 | #SIAMDM24

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Information is current as of September 14, 2023. Visit *siam.org/conferences* for the most up-to-date information.

Upcoming SIAM Events

ACM-SIAM Symposium on Discrete Algorithms
January 7–10, 2024
Alexandria, Virginia, U.S.
Sponsored by the SIAM Activity Group on Discrete Mathematics and the ACM Special Interest Group on Algorithms and Computation Theory

SIAM Symposium on Algorithm Engineering and Experiments
January 7–8, 2024
Alexandria, Virginia, U.S.

SIAM Symposium on Simplicity in Algorithms
January 8–9, 2024
Alexandria, Virginia, U.S.

SIAM Conference on Uncertainty Quantification
February 27–March 1, 2024
Trieste, Italy
Sponsored by the SIAM Activity Group on Uncertainty Quantification

SIAM Conference on Parallel Processing for Scientific Computing
March 5–8, 2024
Baltimore, Maryland, U.S.
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March 5–8, 2024
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April 18–20, 2024
Houston, Texas, U.S.
Sponsored by the SIAM Activity Group on Data Science

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May 13–17, 2024
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SIAM Conference on Mathematical Aspects of Materials Science
May 19–23, 2024
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Sponsored by the SIAM Activity Group on Mathematical Aspects of Materials Science

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May 28–31, 2023
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Sponsored by the SIAM Activity Group on Imaging Science

SIAM Conference on the Life Sciences
June 10–13, 2024
Portland, Oregon, U.S.
Sponsored by the SIAM Activity Group on Life Sciences

SIAM Conference on Mathematics of Planet Earth
June 10–12, 2024
Portland, Oregon, U.S.
Sponsored by the SIAM Activity Group on Mathematics of Planet Earth

SIAM Conference on Nonlinear Waves and Coherent Structures
June 24–27, 2024
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