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Control of PDEs with Boundaries Governed by ODEs

Miroslav Krstic (University of California, San Diego) delivers the W.T. and Idalia Reid Prize lecture at the 2019 SIAM Conference on Control and its Applications (CT19), which took place earlier this year in Chengdu, China. Photo courtesy of the organizers of CT19.

In an article on page 5, Miroslav Krstic describes the backstepping approach as a powerful feedback design tool for partial differential equation-ordinary differential equation systems, with applications to temperature control and traffic flow modeling. The article is based on his 2019 W.T. and Idalia Reid Prize lecture.

Electricity Markets and Renewable Energy

By Michael Ferris and Andy Philpott

Despite ongoing reluctance by some governments to respond to anthropogenic climate change, many countries are pursuing policies to generate energy with very low carbon emissions. Technologies facilitating emission reduction via electricity systems include wind turbines, hydroelectric generation, rooftop solar power, concentrated solar power, geothermal power, and nuclear power. Other tools—like battery and pumped storage, heat pumps, carbon capture and storage, and enhanced transmission infrastructure—work in concert with emission-reducing devices to improve efficiency and reliability of supply across multiple time scales. Designing an efficient next-generation electricity system that is reliable, cost effective, and environmentally clean is a major challenge.

Incentive programs, such as feed-in tariffs that pay for excess electricity generated by rooftop solar panels, have encouraged growing investment in renewable energy generation. The near-zero short-run costs of wind and solar power generation—from freely-available wind and sunlight—are lowering electricity prices based on marginal supply costs. This poses difficulties for traditional electricity market generators reliant upon infra-marginal rents (the difference between revenue earned at system marginal prices and operating costs) to cover their fixed costs.

The aforementioned topics were central to discussions during "Electricity Systems of the Future: Incentives, Regulation, and Analysis for Efficient Investment" — an invited workshop[1] at the University of Cambridge's Isaac Newton Institute for Mathematical Sciences this spring. The workshop aimed to develop mathematical models to aid the design of next-generation electricity markets that would incentivize optimal-generation investments in environments with large quantities of renewable energy. Insight from attending mathematicians, economists, engineers, and representatives from the U.K. energy industry helped generate discussions relevant to a wide range of problems, motivated by the following three subjects:

See **Electricity Markets** *on page 4*

[1] https://www.newton.ac.uk/event/mesw02

Smoothing and Thresholding: A Flexible Methodology for Image Segmentation

By Xiaohao Cai, Raymond Chan, Hongfei Yang, and Tieyong Zeng

Image segmentation aims to group objects with similar characteristics within an image. It is a fundamental task of image processing and computer vision, and has numerous engineering, medical, and commercial applications. Segmentation also serves as a preliminary step for higher-level computer vision tasks, like object recognition and interpretation.

The Mumford-Shah model, which achieves segmentation by solving a minimization problem, is one of the most influential segmentation models. However, the highly non-convex minimization problem makes the model numerically difficult to solve. A recently proposed smoothing and thresholding (SaT) model [1, 3, 7]—based on the Mumford-Shah model—provides a flexible methodology to produce superior segmentation results with fast and reliable numerical implementations.

For ease of discussion, we first consider grayscale image segmentation. One can represent a grayscale image with a function $f:\Omega\rightarrow\mathbb{R}$, where Ω is the image domain and $f(x)$ is the image's intensity at x. We aim to decompose the domain Ω into K disjoint sub-domains $\{\Omega_i\}_{i=1}^K$, where K depicts the number of phases. The SaT model is the first model to demonstrate that smoothing the observed image f before thresholding the smoothed image to obtain the subdomains can yield desirable segmentation results [3, 7]. The smoothing process in [3] solves the convex minimization problem

$$\inf_{g\in W^{1,2}(\Omega)}\Big\{\frac{\lambda}{2}\int_\Omega (f-Ag)^2\mathrm{d}x+\frac{\mu}{2}\int_\Omega|\nabla g|^2\mathrm{d}x+\int_\Omega|\nabla g|\,\mathrm{d}x\Big\},\qquad(1)$$

where λ and μ are positive parameters. A is the blurring operator if the observed image is blurred; it represents the identity operator in the absence of blurring. The minimizer of (1) is a smoothed approximation of f. The first term is the data-fitting term, the second term ensures smoothness of the minimizer, and the third term guarantees regularity of the minimizer's level sets.

After we obtain g in (1), assume that we are given the thresholds

$$\min\{g\}=\rho_0<\rho_1<\cdots<\rho_{K-1}<\rho_K=\max\{g\}.$$

We then threshold g by setting $x\in\Omega$ in the subdomain Ω_i if $\rho_{i-1}\le g(x)<\rho_i$. Applying a popular clustering method—called the K-means method—on the intensity of g can yield the values $\{\rho_i\}_{i=1}^{K-1}$. One can also obtain them by trial and error to produce a finer segmentation (see Figure 1).

The SaT approach has several advantages. First, the smoothing model with (1) is strictly convex, which guarantees a unique solution that many optimization methods can efficiently solve. Secondly, the thresholding step is independent of the smoothing step; this lets the SaT approach accomplish segmentations with arbitrary phases, allowing one to easily try different thresholds without recalculation (1). On the contrary, other segmentation methods require determination of the number of phases K prior to calculation, making it computationally expensive to regenerate a new segmentation for changes to K.

The SaT approach is also very flexible. One can easily modify the smoothing step to better segment images with specific properties. For example, [7] applies a modified SaT method to images corrupted with multiplicative noises and blurs, and [13]

See **Image Segmentation** *on page 3*

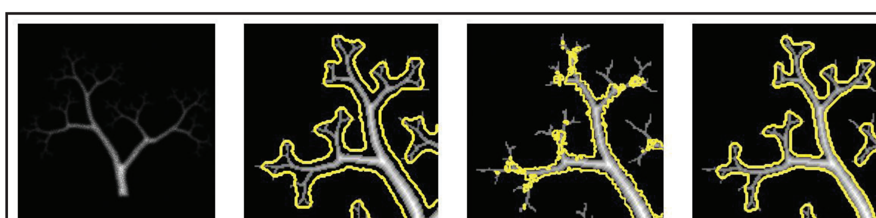

Figure 2. *Segmentations of a fractal image corrupted with Gamma noise and blur.* **2a.** *Degraded image.* **2b.** *Max-flow method [16].* **2c.** *Frame-based method [10].* **2d.** *Smoothing and thresholding (SaT) with user-provided thresholds [7]. For clarity, only the upper-left corner of the segmentations are shown. We see that the SaT method produces the best result, with the yellow segmentation line closest to the real boundary. Image adapted from [7].*

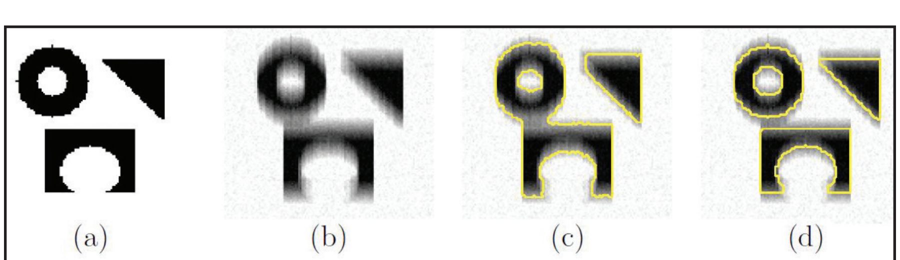

Figure 1. *Segmentations with Gaussian noise and blur.* **1a.** *Original image.* **1b.** *Degraded image.* **1c.** *Chan-Vese method [9].* **1d.** *Smoothing and thresholding (SaT) segmentation with K-means thresholding [3]. Image adapted from [3].*

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Obituary: John G. Lewis

By Thomas A. Grandine

John G. Lewis, a SIAM Fellow and longtime member, died peacefully in his sleep on June 10 after a three-year battle with amyotrophic lateral sclerosis (ALS). He was 74 years old.

After his undergraduate studies and a short teaching stint at St. Olaf College in Minnesota, John enrolled in the Computer Science Department at Stanford University as a graduate student. In 1976, he completed his Ph.D. in numerical analysis with a thesis on the Lanczos algorithm under the direction of Gene Golub. Upon earning his degree, John joined the applied mathematics staff of The Boeing Company, where his influence shaped the development of mathematical algorithms and software. His ideas live on in the very fabric of the way Boeing solves its largest and most difficult analysis problems, and are especially evident in the company's approach to large, sparse linear and nonlinear systems of equations.

John G. Lewis, 1945-2019. Photo courtesy of Timothy O'Leary.

I first met John when I joined the Boeing Math Group as a freshly-minted Ph.D. in the summer of 1986. At the time, he was a thriving, talented, and well-respected mid-career professional who immediately awed me. Having worked there for many years, John had managed to assemble a team of world-class researchers in computational linear algebra, including Phuong Vu, Horst Simon, Cleve Ashcraft, Roger Grimes, Barry Peyton, and Dan Pierce. Boeing was preparing to develop the 777, and the team—under John's direction—was gearing up to implement the structural analysis and computational fluid dynamics necessary to do so. At the time, this work embodied some of the largest structural analysis problems ever solved. The group received the 1988 Gordon Bell Prize for achieving the then-unheard of performance of one gigaflop on a statics structures problem involving over a million variables. They managed to reduce the runtime from more than 15 minutes to less than 30 seconds.

In 1989, John was selected for the first cohort of Boeing's Technical Fellowship program. He embodied the very ideals of the program: world-class technical knowledge and judgment, an uncanny ability to bring those talents to bear on Boeing's toughest challenges, a willingness and capacity to mentor and teach others, and visionary technical leadership. Many scientists who successfully rose through the technical ranks at Boeing in subsequent years did so by following John's example.

Although I was not a member of John's amazing linear algebra team, we talked frequently and I learned a great deal from him. At one point early in my career, I was providing support to a team of airplane configurators (designers) attempting to develop an airplane wing planform design tool. The wing planform is essentially a two-dimensional top view of an airplane wing. Simple planforms are specified in terms of approximately 20 design variables, which unfortunately are not independent of one another and must satisfy 10 or so nonlinear relationships. The configurators wished to create an interactive tool enabling specification of any 10 design variables, with the remaining 10 to be interactively solved for in real time. I had no idea how to go about this, so I asked John for help. After a day or so, he came back with the Dulmage-Mendelsohn decomposition and a clear idea of its application to the problem. It worked perfectly and has been a cornerstone in Boeing airplane design ever since.

John always treated the problems and struggles of his colleagues and acquaintances like they were his own, and constantly made time for me and other junior staff members. Among the lessons I learned from John is the importance of continuing to think and act like a mathematician, even when surrounded by engineers with different backgrounds and approaches to problem solving. The point is not so much to maintain independence as it is to provide a perspective that could bring greater value to the company's efforts. It was an early lesson for me in the significant benefit of diversity; careful, independent analysis; and the great technical progress that arises from the comingling and cultivation of other ideas with one's own.

John was a member of SIAM throughout his entire professional life. He believed in the society's merit, especially the advantages of membership to the careers of industrial mathematicians with the wherewithal to leverage applied mathematical research to solve the world's toughest applied and industrial challenges.

John will be greatly missed by all who had the privilege of knowing him, learning from him, and experiencing his passion for mathematics, computing, and life. He will be missed even more by his wife Fran, his sons Steven and David, and his two grandchildren.

Thomas A. Grandine is a Senior Technical Fellow at The Boeing Company.

First SIAM Conference on Mathematics of Data Science

SIAM is proud to introduce the first Conference on Mathematics of Data Science (MDS). The meeting, which will be held May 5-7, 2020, in Cincinnati, Ohio, intends to provide a forum for attendees to present work that advances mathematical, statistical, and computational methods in the context of data and information sciences. MDS20 aims to unite researchers who are building mathematical foundations for data science and contributing principled applications to science, engineering, technology, and society as a whole.

The 2020 SIAM International Conference on Data Mining (SDM20) will be co-located with MDS20 and take place May 7-9. Attendees who register for either conference will be able to access sessions from both meetings. Those who submit a proceedings paper to SDM20 can also submit an abstract to present a talk at MDS20.

MDS20 will follow a traditional SIAM minisymposium-style format with no proceedings. The deadline for minisymposium proposals is October 7th. Contributed lectures, posters, and minisymposium presentation abstracts are due by November 4th.

MDS20 promises to be an exciting meeting with a stellar lineup of invited speakers, comprising the following:

- **Andrea L. Bertozzi**, *University of California, Los Angeles*
- **Jennifer Chayes,** *Microsoft Research*
- **David Donoho**, *Stanford University*
- **Cynthia Dwork**, *Harvard University*
- **Michael Jordan**, *University of California, Berkeley*
- **Yann LeCun**, *Facebook*
- **Yurii Nesterov**, *CORE/INMA, Catholic University of Louvain, Belgium.*

The organizing committee includes Gitta Kutyniok (Technische Universität Berlin), Ali Pinar (Sandia National Laboratories), and Joel Tropp (California Institute of Technology). For more information, please visit the conference website.[1]

[1] https://www.siam.org/Conferences/CM/Conference/mds20

SIAM Members Among National Academy of Sciences Inductees

In April, the National Academy of Sciences announced the election of 100 new members and 25 foreign associates in recognition of their distinguished and ongoing achievements in original research. 40 percent of the newly-elected members are female — the highest percentage ever elected in any one year. SIAM would like to congratulate all inductees, with a special mention of the three SIAM members among those recognized:

- **Russel E. Caflisch**, *director and professor, Courant Institute of Mathematical Sciences, New York University*
- **Jennifer T. Chayes**, *managing director, Microsoft Research New York and Microsoft Research New England*
- **Barry Simon**, *IBM Professor of Mathematics and Theoretical Physics, Division of Physics, Mathematics and Astronomy, California Institute of Technology.*

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Image Segmentation

Continued from page 1

uses a modified SaT method on tubular and medical images (see Figure 2, on page 1). We combined the SaT approach with a Retinex model—which explains how human eyes perceive constant colors under various illuminations—to obtain a segmentation method for images with intensity inhomogeneity (see Figure 3) [8].

There is clear evidence of the SaT approach's superior performance. If we set the parameter μ in (1) to zero, we can show that the SaT method is equivalent to the famous Chan-Vese segmentation method, which is a simplified Mumford-Shah model [4]. Furthermore, numerical experiments show that a properly-selected μ typically increases segmentation accuracies. Extending grayscale image segmentation techniques to methods for color images is not inconsequential. A color image is usually represented by a vector-valued function $f=(f_1,f_2,f_3):\Omega\rightarrow\mathbb{R}^3$, where f_1, f_2, and f_3 generally signify red, green, and blue channels respectively. The difficulty of color image segmentation partly stems from the strong inter-channel correlation. The smoothing, lifting, and thresholding (SLaT) method is a novel extension of the SaT approach [1]. One first solves (1) for f_1, f_2, and f_3 to obtain three smooth functions: g_1, g_2, and g_3. This is followed by transformation of (g_1,g_2,g_3) to another color space $(\overline{g}_1,\overline{g}_2,\overline{g}_3)$, which can reduce inter-channel correlation. The Lab color space is generally a good choice for this lifting process. During the thresholding step, performing K-means thresholds the lifted image with six channels $(g_1,g_2,g_3,\overline{g}_1,\overline{g}_2,\overline{g}_3)$ to obtain the respective phases. The SLaT method is easy to implement and yields promising results (see Figure 4).

Model (1) in the smoothing step is also used in [15] (with $\mu=0$) and [11] for image restoration. Given this unexpected relationship, we recently explored smoothing steps where advanced image restoration models inspired minimization models. For example, the authors of [6] replace the last two terms (the regularization terms) in (1) with a carefully-designed, non-convex regularization term. Non-convex regularization terms are known to produce better results in image restoration. Precise construction enables the new smoothing step to maintain an overall convex objective function with non-convex regularization (the convex non-convex (CNC) approach). Numerical experiments demonstrate improvements in segmentation results via the SaT approach with CNC regularization.

Recent studies successfully apply the SaT approach to classification tasks, which assign a label to each data point. The core of a wide range of classification methods is a support-vector machine (SVM). One first trains the SVM on a set of training data to understand the relationship between labels and data points. After training, feeding the SVM data points from a test data set obtains scores for each label. The label with the largest score is assigned to the corresponding new data point. Our studies indicate that combining the SaT approach with SVM models can improve classification accuracies and achieve state-of-the-art results. We have tested classification models with SVM for hyperspectral image classifications and point cloud classifications (see Figures 5 and 6).

In conclusion, the SaT technique provides an efficient, flexible methodology for image segmentation and is easily adapted for various segmentation tasks. It connects the segmentation problem with the image restoration problem. Recent research also demonstrates the SaT method's application to classification problems. We hope to inspire use of the method in more cross-disciplinary work.

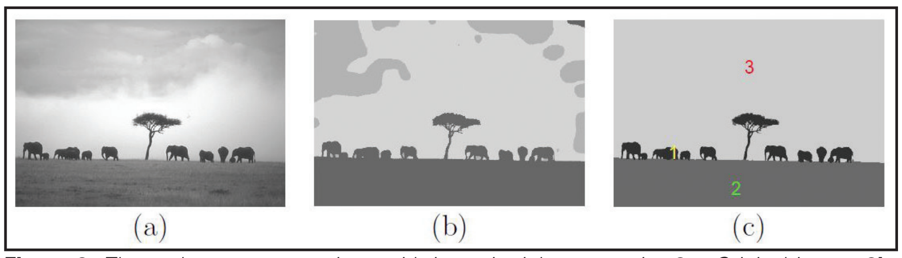

Figure 3. *Three phase segmentations with intensity inhomogeneity.* **3a.** *Original image.* **3b.** *Level-set method [12].* **3c.** *Smoothing and thresholding (SaT) with Retinex segmentation [8]. The sky and the ground both exhibit uneven illuminations. Our SaT method with Retinex can successfully separate the three phases. Image adapted from [8].*

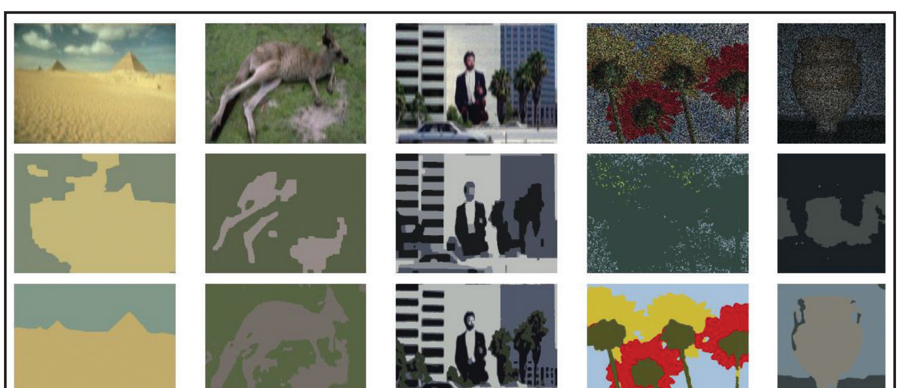

Figure 4. *Color image segmentation for degraded images. The top row depicts degraded color images. The first three images are degraded by various noise and blur, and the last two are degraded by 60 percent information loss and noise. The middle row illustrates the convex minimal partition method [14], and the bottom row portrays the smoothing, lifting, and thresholding (SLaT) method [1]. Image adapted from [1].*

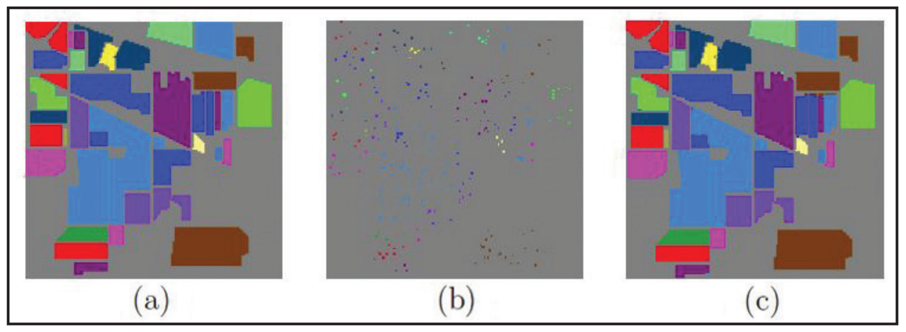

Figure 5. *Hyperspectral image classification of the Indian Pines data set.* **5a.** *Ground truth.* **5b.** *Training set (10 percent of total pixels).* **5c.** *Classification with smoothing and thresholding (SaT) (98.83 percent overall accuracy). Image adapted from [5].*

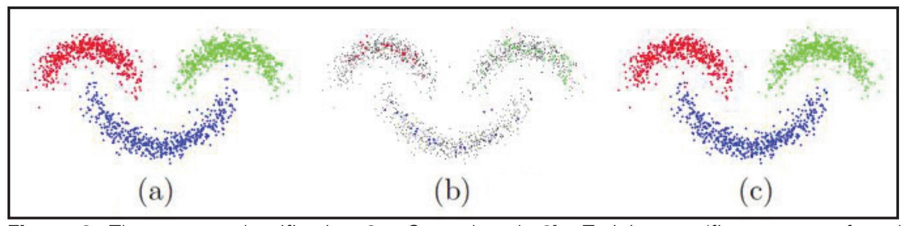

Figure 6. *Three-moon classification.* **6a.** *Ground truth.* **6b.** *Training set (five percent of total data points).* **6c.** *Classification with smoothing and thresholding (SaT) (99.5 percent accuracy) Image adapted from [2].*

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Electricity Markets

Continued from page 1

1. Optimization of generation capacity: what, where, and when one should build;
2. Factors that might prevent investors in an electricity market from making socially-optimal decisions;
3. Possible incentive structures to alleviate market failures.

Multiple countries are moving towards a deregulated, market-based electricity system in which competing agents make generation investments on a commercial basis. However, planners often consider system optimization problems to understand the best possible system design and operation. One can formulate the optimization of generation capacity as a stochastic program that chooses each generation technology's capacity levels before operating in various conditions and states. More sophisticated multi-stage stochastic models design a sequence of investments over a multi-year planning horizon, where each investment decision is contingent upon an observed history of events — such as electricity demand growth from electric vehicles. Stochasticity at finer time scales accounts for variability in wind or solar generation. The objective is typically the expected social or overall benefit from investment creation and efficient operation. If demand for electricity is inelastic (i.e., insensitive to price changes), minimizing expected capital and operating costs will maximize expected social benefit.

We illustrate this concept with a two-stage model in which one selects investments of quantity x_k in technology k in the first stage at cost C_k per unit to optimize capital costs plus the expected cost $\mathbb{E}_\omega(g_k y_k(\omega)) := \Sigma_\omega p(\omega) g_k y_k(\omega)$ of electricity generation $y_k(\omega)$. In this case, g_k is the operating cost, ω denotes a random state of the world, and $p(\omega)$ represents its probability. A social planner totals the costs and solves a model SP to meet demand $d(\omega)$ in every future state of the world, possibly shedding load $q(\omega)$ at some very high penalty cost V:

$$\text{SP:}\ \min\ \Sigma_{a\in\mathcal{A}}\Sigma_{k\in a}[C_k x_k + \mathbb{E}_\omega(g_k y_k(\omega) + Vq(\omega))]$$

$$\text{s.t.}\quad \Sigma_a\Sigma_{k\in a} y_k(\omega) + q(\omega) \ge d(\omega),$$

$$0 \le y_k(\omega) \le x_k + u_k,$$

$$0 \le q(\omega) \le d(\omega), x_k \ge 0.$$

Here, $k \in a$ denotes technologies owned by agent a. The solution to SP yields Lagrange multipliers for the first constraint of model SP, expressed as $p(\omega)\pi(\omega)$ to demonstrate the way in which they account for the probability of ω. The social planner may also choose to add a constraint E on greenhouse gas emissions to this problem. For example,

$$\Sigma_a\Sigma_{k\in a}\mathbb{E}_\omega(\alpha_k y_k(\omega)) \le E, \quad [\sigma]$$

where α_k denotes a conversion factor to emissions and σ is the constraint's multiplier. It is important to understand the implications of different forms of this constraint, which in the above equation confines average emissions. Variations that impose a bound on emissions in (almost) every state of the world—or with high probability—engender different policies [3]. A constraint imposed on non-renewable capacity x_k also produces different results (see Figure 1). A particular example shows that reducing capacity of thermal plants without extra renewable investment can lead to *increased* emissions from the hedging strategies of remaining plants.

How do we incentivize agents to build the right plants? If all agents minimize expected costs using probabilities $p(\omega)$, then a Lagrangian decomposition yields an emissions price σ and energy prices $\pi(\omega)$ that decouple SP into agent problems

$$P(a): \min\ \Sigma_{k\in a}[C_k x_k + \mathbb{E}_\omega(g_k y_k(\omega) + \sigma\alpha_k y_k(\omega) - \pi(\omega) y_k(\omega))]$$

$$\text{s.t.}\quad 0 \le y_k(\omega) \le x_k + u_k,\ x_k \ge 0,$$

a consumer problem

$$P(d): \min\ \mathbb{E}_\omega((V - \pi(\omega))q(\omega))$$

$$\text{s.t.}\quad 0 \le q(\omega) \le d(\omega),$$

and market-clearing complementarity conditions

$$0 \le \sum_a\sum_{k\in a} y_k(\omega) + q(\omega) - d(\omega) \perp \pi(\omega) \ge 0,$$

$$0 \le E - \sum_a\sum_{k\in a}\mathbb{E}_\omega(\alpha_k y_k(\omega)) \perp \sigma \ge 0.$$

This is a competitive equilibrium with the same solution as social planning.

Several caveats accompany this model. The equivalence between system optimization and equilibrium requires that the social planning optimization problem be convex. This precludes integer variables that might represent indivisible costs in investment or startup costs in operations. Alternative suggestions for out-of-market interventions and payments may create incentive problems and compromise many of the benefits that accompany efficient markets. The equivalence also demands that agents act nonstrategically, as though the price emerging from equilibrium is fixed and independent of their actions. Finally, all products in the social plan must be priced by the market under consideration, i.e., the market must be *complete*. This last criterion is critically absent when agents are reluctant to take risks and there are insufficient financial instruments to hedge their risk.

Much of the invited workshop was devoted to the study of incentives for efficient investment. Regulators set the *value of lost load* (V in formulation SP) as a price cap when demand is unable to respond to price spikes. Some of the load is shed when capacity cannot sufficiently meet demand; this renders price V. In a competitive equilibrium with unrestricted entry, the number of periods each year when this occurs for a new peaking plant yields just enough profit on average to cover its annualized fixed cost. In *energy-only* markets, the theoretical choice of V is based on a desired level of reliability defined by an annual frequency of load shedding. Typical values of V are around $10,000/megawatt-hour.

Historically, price caps in many markets have been kept lower than necessary for reliability targets. This practice arises partly from regulators' desire to curb possible exercise of market power (where agents or firms strategically choose generation levels $y_k(\omega)$), or government motivation to keep prices low. If V is low, peaking plants need more frequent load shedding to make enough money to cover their fixed costs. Low V thus means less reliability, unless generators are compensated for providing capacity. This is the so-called *missing money* problem.

A *capacity market* is one way to provide the missing money. These markets typically take the form of procurement auctions, in which system operators seek to acquire required electricity generation capacity at minimum cost. One caveat is the need for regulators to determine the system's required level of capacity. While some jurisdictions treat all capacity equally, certain types (e.g., one megawatt of flexible plant) are clearly more valuable than others (e.g., one megawatt of wind capacity), thus necessitating adjustments for effectiveness.

The argument for capacity markets becomes stronger as renewable energy increases. As mentioned before, most renewable plants have almost no operating costs; this means that increasing renewable penetration lowers wholesale electricity prices. One must recover the capital cost for solar panels, wind turbines, and backup peaking plants in shortage periods. Several years without shortage periods might pass before a year with substantial shortage (when no income is earned) transpires. Over a long period of time, a capacity market can provide more certainty to investors who seek to build renewable generation.

The workshop also explored new mathematical techniques for modeling capacity expansion in risky markets, with particular emphasis on risky competitive equilibrium [2, 4]. In this scenario, agents are endowed with risk measures that convert random operating surpluses into certainty-equivalent values. Expectation is a risk-neutral measure; more interesting models use the rich class of *coherent risk measures* [1] to understand the relationship between competitive equilibrium and system optimization.

Future work in this area must link energy models to other sectors of the economy and consider pricing information related to abatement. Such integrated assessment models could investigate carbon taxes to encourage investments in combined heat and power technologies, anaerobic digestion, and forms of compensated demand reduction. For example, the use of carbon capture with storage combined with renewable biomass generation actually removes carbon dioxide from the atmosphere.

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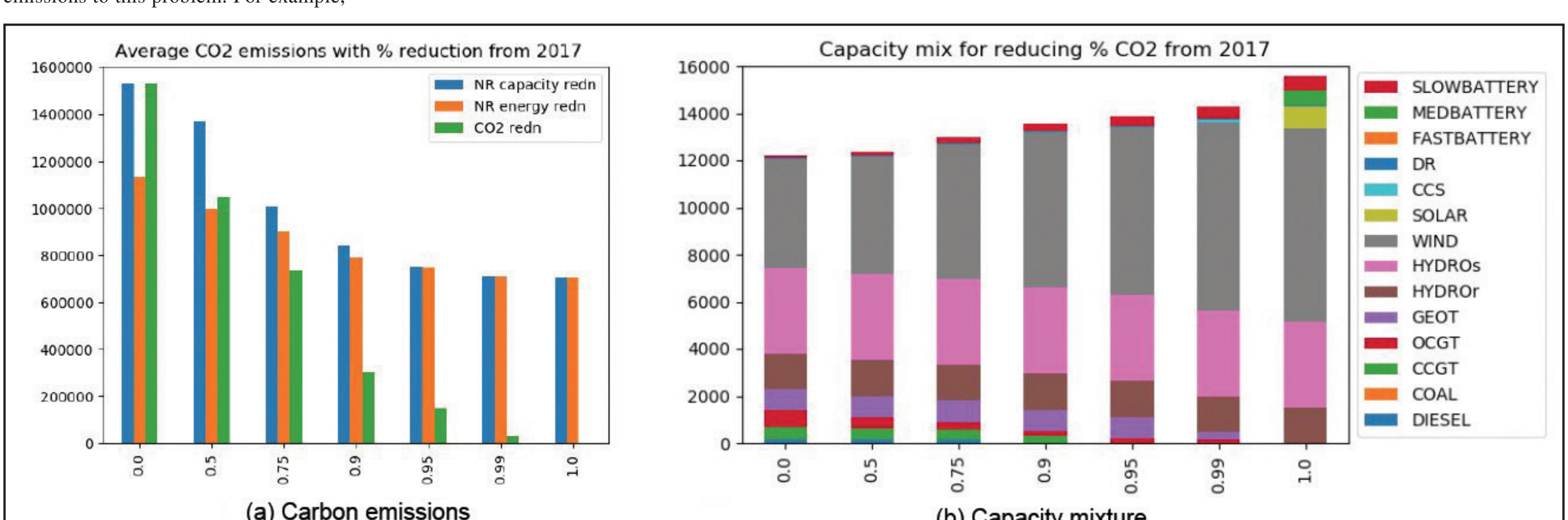

Figure 1. *The effects of increased renewable penetration on New Zealand's electricity system in 2030.* **1a.** *Impact on emissions when constraint is on capacity, energy, or carbon dioxide (CO_2).* **1b.** *Change in technology mix as renewable penetration increases. Figure courtesy of [3].*

Control of PDEs with Boundaries Governed by ODEs

By Miroslav Krstic

The following article is based on the author's W.T. and Idalia Reid Prize Lecture at the 2019 SIAM Conference on Control and its Applications, which took place earlier this year in Chengdu, China.

Control Systems

For dynamical systems modeled by ordinary or partial differential equations (PDEs) with significantly fewer input variables than state variables—like a scalar input variable for a PDE with a spatially-distributed or infinite-dimensional state—control theory formulates the input as a function(al) of the state. This achieves stability for the dynamical system, where "stability" in a technically rigorous sense refers to a set of properties and forces the state to converge to zero as time approaches infinity.

Constructing such input functions—also called "feedback laws" because input depends on the measurable state—is part of the design of most technological systems. A simple example is the Segway, whose driver would nosedive or fall backward in the absence of a feedback system that feeds the pitch angle measurements into the wheel angle inputs to keep the apparatus and rider upright. Less obvious feedback systems include those that developed through evolution to both keep organisms alive and prevent them from making drastic changes to themselves, regardless of how much they desire said modifications. For instance, feedback systems that regulate metabolism prevent people from achieving significant weight loss by starving themselves over several days. We generated these feedback systems to maintain our energy reserves in periods of famine and strenuous travel.

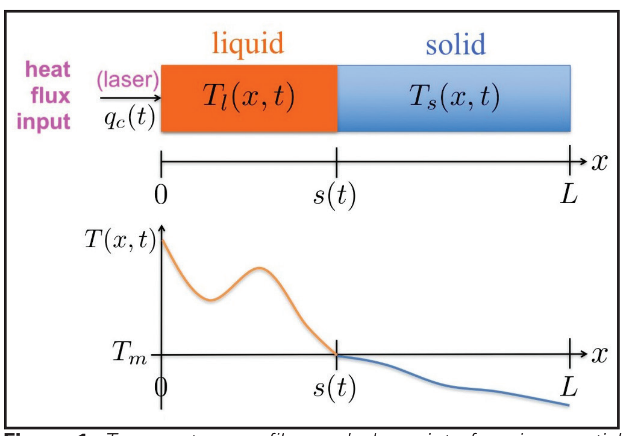

Figure 1. *Temperature profiles and phase interface in a partial differential equation-ordinary differential equation (PDE-ODE) system involving a liquid, a solid, and rightward melting with the aid of heat flux applied by a laser on the left boundary. Figure courtesy of Shumon Koga.*

PDE Control on Moving Domains

Classical control theory devised for ordinary differential equations (ODEs) requires remarkable sophistication in the design of feedback laws for nonlinear systems. Feedback synthesis for PDEs poses even greater challenges, namely in transitioning from the finite to infinite system dimension. The greatest achievements in nonlinear ODE control occurred in the 1980s and 90s, whereas PDE control has blossomed during the last two decades.

Not all physical systems are modeled by ODEs of a fixed order or PDEs on fixed domains. Some important applications—including traffic, opinion dynamics, and climate science—involve processes whose dimensions or domains depend on the size of the process state. For instance, the state vector dimension can increase with the size of the state. Or a higher temperature in its PDE spatial domain may cause the domain to grow, as with melting ocean ice.

Classical control techniques are unequipped to deal with such dimension-varying dynamics. In fact, these possibilities have rarely even occurred to the control research community, which has been preoccupied in recent years with already-difficult nonlinear, infinite-dimensional, stochastic, and hybrid phenomena in fixed dimension.

Among the simplest and most elegant problems with the state's dimension that varies with the state's size are those involving a connected ODE and PDE, so that the PDE's state acts as an input to the ODE, whose state thus represents the PDE's boundary location. Such PDE-ODE systems may involve either parabolic or hyperbolic PDEs.

Control of the Stefan System (Parabolic)

An example of a *parabolic* PDE-ODE system in which the ODE state represents the PDE's boundary location is the so-called *Stefan system*. Developed and analytically solved by Slovenian-Austrian physicist Josef Stefan (of Stefan-Boltzmann fame) in the late 1800s, the system models melting and freezing.

Researchers have recently used the Stefan system to model numerous other physical phenomena, including additive manufacturing with both polymers and metals; growth of neuronal axons; tumor proliferation; cancer treatment via cryosurgeries; spread of invasive species in ecology; lithium-ion batteries; domain walls in ferroelectric thin films; and information propagation in social networks.

Stefan's model gives rise to several control and state estimation problems; here we focus on one that is both simple and difficult. The goal is to regulate the liquid-solid interface position $s(t)$ to a setpoint $s_r > 0$. This is shown in Figure 1, where $T_s(x,t)$ and $T_l(x,t)$ respectively represent the spatiotemporal temperatures in the solid and liquid. Heat PDEs govern the temperatures and a scalar ODE—whose inputs are the heat fluxes at the PDEs' boundaries—governs the interface position.

Using the backstepping approach for PDE-ODE systems [3], we design and implement a feedback law $q_c(s, T_l, T_s)$ by employing a laser to apply a heat flux to the liquid. This backstepping feedback is proportional to the error between the measured thermal energy and the thermal energy at the melting/freezing point, plus the interface tracking error $s - s_r$. The backstepping approach entails construction of a Volterra transformation of the temperature state and a Lyapunov functional based on the transformed temperature state.

This control law achieves global stabilization for all initial conditions where the liquid temperature is above melting and the solid temperature is below freezing; both temperatures remain in these states for all time. In physical terms, this means that no solid islands form within the liquid and no pools of liquid form within the solid. The maximum principle for the heat equation establishes this result [1-2].[1]

Control of Moving Shock in Congested Traffic

The analog to the Stefan system's parabolic PDE phenomenon is the hyperbolic PDE phenomenon that arises in traffic. This originates with a moving shock that delineates the free traffic (upstream of shock) from the congested traffic (downstream from shock), as seen in Figure 2. The hyperbolic nonlinear Lighthill-Whitham-Richards PDE, which acts as a simple delay for small deviations, models the traffic flow. A scalar ODE governs the shock motion, and the traffic densities of the congested and free traffic at the shock location form the ODE's inputs. This ODE represents the Rankine-Hugoniot jump condition that is common in compressible gas models.

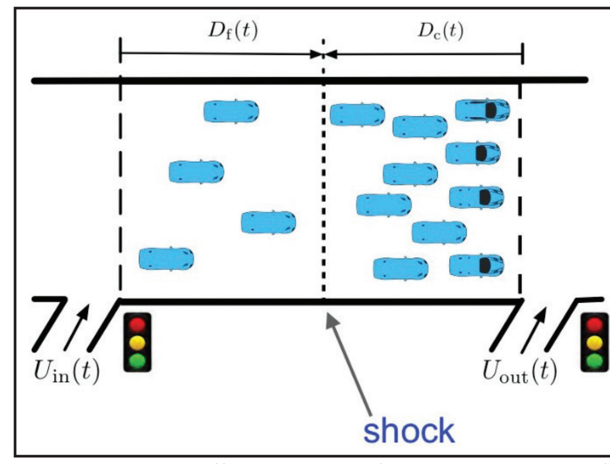

Figure 2. *Free traffic (upstream/left) and congested traffic (downstream/right) are separated by shock, depicted as a sharp increase in density. Modulating the durations of the red and green lights on the on-ramps regulate the shock location to a desired position. Figure courtesy of Huan Yu.*

Researchers again use the PDE backstepping design to devise a feedback law that regulates the moving shock's position to a setpoint. Without this type of control law to arrest the shock at a desired location on the freeway, congested traffic would continue to propagate upstream until it consumes the entire road. The feedback law is implemented via "ramp metering," which involves modulation of the red and green lights on the freeway on-ramps around steady durations that correspond to the desired location of the shock.

Analyzing the PDE-ODE system with the feedback law once again employs a backstepping/Volterra transformation of the traffic density PDE's state, along with a resulting Lyapunov functional. Like with the Stefan system, stability occurs in the H_1 Sobolev norm. However, while stability for the Stefan system holds for all physically meaningful initial conditions, it only remains true locally—for small deviations of the density field around its equilibrium profile—for the traffic problem.

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Miroslav Krstic is a distinguished professor of mechanical and aerospace engineering at the University of California, San Diego. He is a coauthor of two books with SIAM (one of which received the International Federation of Automatic Control (IFAC) Chestnut Textbook Award) and has written 11 other books on control theory. Krstic is a Fellow of SIAM, the Institute of Electrical and Electronics Engineers, the American Society of Mechanical Engineers (ASME), IFAC, and three other societies. He is the recipient of ASME's Rufus Oldenburger Medal, IFAC's Nonlinear Control Systems Award, the American Automatic Control Council's John R. Ragazzini Education Award, and several other accolades.

[1] http://a2c2.org/awards/o-hugo-schuck-best-paper-award

Laura Bassi: A Trailblazer for Women in Science

Laura Bassi and Science in 18th Century Europe: The Extraordinary Life and Role of Italy's Pioneering Female Professor. *By Monique Frize. Springer, New York, NY, July 2013. 216 pages, $39.99.*

BOOK REVIEW
By Ernest Davis

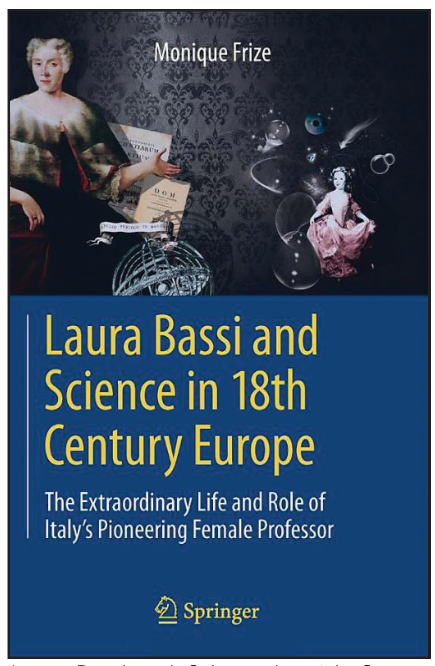
In 1732, much excitement surrounded a doctoral thesis defense by a brilliant 20-year-old prodigy at the University of Bologna. An enormous crowd—including many of the leading figures in Bologna and the surrounding areas, two cardinals, and an archbishop—attended the event. After a successful defense, the candidate received the symbols of the degree—a book, a ring, a silver crown of laurels, and an ermine mantle—and an appointment as lecturer, with an annual stipend of 500 lire. Commemorative medals were struck in silver and pewter, and three volumes of poetry were published in her honor.

In *her* honor; that was the astonishing part. The candidate was Laura Bassi, the second woman ever (after Elena Piscopia in 1678) to earn a Ph.D. and an overall trailblazer for women in science and higher education. Bassi subsequently became the first woman appointed as a university professor and the first female member of a scientific academy (she was ultimately a member of 14 academies). Her life, accomplishments, social context, and scientific setting are the subject of a fascinating biography entitled *Laura Bassi and Science in 18th Century Europe* by Monique Frize, herself a distinguished bioengineer at the University of Ottawa.

Italy, particularly Bologna, was centuries ahead of the rest of the world in recognizing female scientists. Germany first awarded a Ph.D. to a woman in 1787, followed by the U.S. in 1877 and France in 1903 (Marie Curie). The U.S. appointed its first female college professor in 1871; Britain did so in 1904, France in 1906 (Curie again), and Germany in 1923. The U.S.-based National Academy of Sciences admitted its inaugural female member in 1925, trailed by the Royal Society in Britain in 1945 and France's Académie des Sciences in 1979.

A decades-long debate on the proper role and education of women persisted in late 17th- and early 18th-century Italian intellectual circles. Polemics were written and public discussions held on the topic. At one end were extreme misogynists, who believed that (i) women were intellectually and morally inferior, (ii) their education beyond household duties was futile, and (iii) fathers and husbands should confine daughters and wives to their proper sphere. At the other end were people (predominantly female) who argued that properly-educated women were equal or superior to men in all respects.[1] Conventional wisdom (at least among males) took a middle ground and concluded that women were mostly inferior to men. One might educate them or not, as deemed appropriate, but should certainly keep expectations realistic. However, a small number of "exceptional" women were presumed to be equal to men; these women were celebrated and even elevated to a certain degree. Advocates of this point of view enjoyed making lists of exceptional women throughout history.

From this standpoint, Laura Bassi deserved a place on these lists. Her father was a lawyer; he was neither aristocratic nor rich but somewhat well-connected. Bassi was educated at home, where she learned Latin, French, Greek, mathematics, Aristotelian and Cartesian philosophy, and Newtonian physics (later in life she also learned English). Her remarkable intelligence, abilities, and extremely impressive persona became widely known in and beyond Bologna. When she was ready, her doctoral defense took place, with all the attendant pomp and circumstance.



Laura Bassi and Science in 18th Century Europe: The Extraordinary Life and Role of Italy's Pioneering Female Professor. By Monique Frize. Courtesy of Springer.

From the city's perspective, this was a celebration of the fact that a daughter of Bologna had emerged as an exceptional woman. Bassi's defense was actually a public relations stunt on behalf of the city and university, both of which had declined in status from their former greatness. Then again, what a society chooses to celebrate reflects—if not its actual values—at least the values to which it aspires.

Yet even after the excitement of her doctoral defense, the cards were stacked against Bassi actually pursuing a career in science. Despite her salaried appointment, she was not allowed to lecture at the university. Instead, she was expected to dedicate herself to literature—writing verse for public occasions and such—as literature was supposedly more suitable than science for feminine talent. Any interactions with male colleagues inevitably raised eyebrows.

But Bassi played her cards patiently and ably. She also had some powerful supporters, particularly Pope Benedict XIV. Bassi married scientist Giuseppe Veratti in 1738, which made it possible for her to participate in otherwise-male scientific gatherings (this disappointed those who felt that exceptional women should devote themselves to higher things, rather than personal relationships). Though she was not allowed to lecture at the university, she and Veratti taught students at their own home. 18th-century laboratory equipment was expensive, but Bassi and Veratti gradually built up one of the best laboratories in Italy.

In 1745, Benedict XIV created an elite group of 24 scientists at Bologna called the Bennedetina, after himself. Bassi persuaded him to add her as a 25th member, which established her position as a scientist and allowed her to focus on scientific research and teaching. She corresponded with the scientific savants of Italy and beyond, including the young Alessandro Volta. Bassi's fame spread rapidly throughout Europe; Voltaire wrote her a flattering letter and poets penned poems in her praise. She is believed to have had between nine and 12 children, five of whom survived infancy.

In 1776, Bassi was appointed to the chair of experimental physics at Bologna, a position that finally permitted her to teach public classes at the university. Her husband was selected as her teaching assistant. This arrangement continued until her death in 1778.

Major gaps exist in our knowledge of Bassi's actual scientific work. She published few articles and no books. Between 1746 and 1777, she presented 31 dissertations describing her research at Bologna, but most of her manuscripts—which were deposited with the university—have been lost; only the titles remain. Yet the enduring records and evidence of her correspondence prove that Bassi was a leading figure in the emerging study of electricity. She also conducted work in hydrodynamics, flames, and the regeneration of salamander body parts, and played a role in the victory of Newtonian over Cartesian physics.

In the decades after Bassi's death, the position of women in Italian universities deteriorated. The popes who succeeded Benedict XIV were not supportive of female education. In the wake of Napoleon's conquest, Italian universities—and Bologna in particular—were modernized and reformed with inimical changes for women. Between 1803 and 1874, the nation's universities were largely closed to women, with a partial exception for medical training. Bassi and the other Italian female scientists of her time—mathematician Maria Gaetana Agnesi, artist and anatomist Anna Morandi Manzolini, and physicist Cristina Roccati—were in some ways a false dawn. Nonetheless, their dedication to science and courage in breaking the glass ceiling of their time are important historical milestones.

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

[1] Notable Italian mathematician Maria Gaetana Agnesi wrote a tract on the subject when she was 11 years old. Giovanni Antonio Volpi, a misogynist who was apparently open-minded, published both this and another feminist essay as supplements to his own treatise in 1729.

A Perspective on Diversity and Inclusion in Computing

By Elizabeth Bautista

When I first began my current career 20 years ago, I was both a minority and the only female on a team of eight male staff members. As a recent graduate with knowledge of the then-new Linux operating system entering an environment that had relied upon Solaris for years, my skills were dismissed by colleagues who often told me that I really did not know Unix. As much as I tried to convince them otherwise—that Linux is like Unix and my skills were transferable—my coworkers treated me as if I had no experience. While I had not previously worked in a high-performance computing (HPC) environment, I had prior experience as a system administrator in a distributed setting. Within three months I had learned Solaris and was outperforming my peers, creating innovative processes and updating standard operating procedures throughout the data center. A year later, I overheard the team leader tell a colleague that he was happy *he* was able to teach *me* in a short amount of time. I felt marginalized that he was claiming ownership of my accomplishments and minimizing my efforts.

As a Filipino woman in a male-dominated industry, I had no role models at the lab, at other National Laboratories, or even in the media. Present demographics of HPC facilities in National Laboratories will likely find no Filipino women in the science, technology, engineering, and mathematics (STEM) areas. I often wondered if all Filipinas were nurses, accountants, or caregivers, rather than scientists. I felt isolated in STEM; aside from human resources staff, I had no one to consult about career trajectories or navigation of the National Laboratory system. As the only female in a shared 24/7 space, I experienced implicit bias that made me doubt myself and question the appropriateness of assertion when stating my needs. For example, I was teased for working hard when I asked staff members to move a conversation elsewhere so that I could concentrate in my workspace. They had no idea that I *always* had to work harder to prove myself and the value of my efforts in pursuit of a level of recognition comparable to their own. How else was I going to get ahead?

I am currently part of a management team of 12, and while the team is 50 percent female I am the only minority female. A 2014 study by the National Center for Women & Information Technology[1] indicates that while women make up 26 percent of the computing workforce, Asian women specifically comprise only five percent (there was no demographic specifically for Filipino women, so they were likely incorporated in the Asian category). A 2014 Google study of the diversity gap in Silicon Valley[2] reported that women account for only 18 percent of the tech industry. While the field has seen progress over the last two decades, situations have become more complex. Given the statistics, are things really any different now than when I was beginning my career?

CAREERS IN MATHEMATICAL SCIENCES

To answer that question, we must first define diversity. Merriam-Webster defines diversity as both "the condition of having or being composed of differing elements," and "the *inclusion* of different types of people (such as people of different races or cultures) in a group or organization." In the workplace, creation of a diverse and inclusive environment must be more than an organization's mission statement, more than words on a strategic plan, and more than a yearly requirement of 40 hours of diversity-related activities.

[1] http://www.ncwit.org/sites/default/files/resources/btn_02282014web.pdf

[2] https://i0.wp.com/blog.leeandlow.com/wp-content/uploads/2015/03/Diversity_In_Tech-lg.jpg?ssl=1

Elizabeth Bautista (far right) shares ideas on notifications for environmental data with colleagues at Lawrence Berkeley National Laboratory. Photo courtesy of City College of San Francisco Career Services.

While I believe that many organizations have workforce diversity, such an atmosphere does not automatically translate into an inclusive culture. Cultivating inclusivity can be straightforward: change hiring processes, vary recruitment tactics, widen the candidate pool, alter interview procedures, modify the definition of minimum qualifications, etc. Diversity implementation begins with a hiring manager's commitment to cast a wide net that includes as many people as possible—especially from unlikely sources—and hire the best candidate regardless of his/her demographic.

Inclusion is an important aspect of an organization's culture. It is implicit in a company's operation, the managers' daily practices, and the staff's individuality — all guided by an overarching set of core values aligned with an institution's mission. Being inclusionary is the conscious decision to accept and respect other people's differences and take action to nurture an equal experience for everyone. It is not *treating* everybody the same way, but rather *creating* an environment where everyone experiences equal treatment. Inclusion can be as simple as remembering to bring a gluten-free pastry for a staff member with Celiac disease when purchasing donuts for colleagues. Conversely, it can be as difficult as advocating for your female minority employee by not allowing your senior privileged-class leadership to interrupt her or ignore her contributions. A 2014 *Business Insider* article entitled "13 Subtle Ways Women Are Treated Differently At Work" states that "if women are assertive, it can be seen as aggressive…whatever women do at work, they have to do it nicely."[3] In my experience, this continues to hold true.

Inclusion is having the maturity to engage in professional communication. Conversations can include admitting your need for an explanation when something is unclear. For example, at one point I did not understand the difference between vegan and vegetarian. So I asked a vegan co-worker to explain it to me. Now I recognize that food "choices" are not simply a choice, but rather an informed effort to minimize health or environmental impacts. This information subsequently helps me make thoughtful selections when my group shares a meal. Positive exchanges like this one, which incorporate patience and an open mind, can lead to much clearer work-related interactions. For example, allowing non-native English speaking employees to take their time when describing the advantages of an out-of-the-box solution—rather than requesting that they limit their explanation to five minutes—will give those employees confidence that they are being heard.

In my opinion, more resources are available today than ever before to help improve diversity in the workplace. Companies hire specific individuals—like diversity program managers, for example—to focus on diversity efforts. Staff members can volunteer to participate in programs like unconscious bias training or diversity education. Organizations create and maintain employee resource groups or implement policies surrounding supplier diversity. Employees can also watch a six-step inclusion video and partake in accompanying facilitator-based discussions. Those who complete such trainings are recognized for their initiatives.

In spite of these advancements, we still have a long way to go. From a manager's standpoint, diversity *and* inclusion training *should* be a periodic requirement, like ergonomics refreshers that occur every two to three years. Companies cannot assume that promoting someone to the managerial level automatically provides them with the necessary skills to foster a diverse and inclusive environment for staff. Yet managers are supposed to be liable for their own actions, as well as those of their direct reports. To maintain accountability and ultimately become better allies, they must speak up upon witnessing discrimination, bias, or microaggression in a psychologically-safe environment. These skill sets do not come naturally; they require practice and must be integrated into an organization's culture. Only then will every employee be capable of recognizing personal biases, commit to an awareness of things that trigger such behaviors, and work to maintain a safe space in which to address them. For example, when an employee asks a male colleague clarifying questions about a female coworker's presentation, other colleagues should be able to quickly point out this prejudice without confrontation.

Ultimately, while we can treat diversity like a checkbox item, promoting inclusivity and practicing accountability are important to diversify the workforce and ensure that we are all allies. Inclusion and accountability separate organizations that practice these behaviors for compliance from those that work to truly create environments in which staff can thrive.

[3] https://www.businessinsider.com/subtle-ways-women-treated-differently-work-2014-6

Elizabeth Bautista is manager of the Operations Technology Group at Lawrence Berkeley National Laboratory's National Energy Research Scientific Computing Center. She advocates for women and minorities to pursue science, technology, engineering, and mathematics, and supports practical, hands-on training as part of the next generation of professional education.

The Difficulties of Addressing Interdisciplinary Challenges at the Foundations of Data Science (Part I of II)

By Michael W. Mahoney

The Transdisciplinary Research in Principles of Data Science (TRIPODS) program is an effort funded by the National Science Foundation (NSF) to establish the foundations of data science. It aims to unite the statistics, mathematics, and theoretical computer science research communities (three areas central to the foundations of data) to build the theoretical foundations that will enable continued data-driven discovery and breakthroughs in the natural and social sciences, engineering, and beyond.

The size and scope of its interdisciplinarity make TRIPODS an unusual endeavor. The program's first phase consists of $17.7 million in funding for 12 Phase I institutes.[1] After an initial three-year effort (currently in progress), a longer second phase will consist of a smaller number of larger, full-scale Phase II institutes. Additionally, a related TRIPODS+X program is designed to expand the scope of the original TRIPODS Phase I projects to involve interactions with researchers from domain "X," where "X" is astronomy, genetics, materials science, neuroscience, the social sciences, or any one of a wide range of other data-driven disciplines. Spurred by the success of TRIPODS and the excitement of using it as a model to fund interdisciplinary research more generally, the NSF recently announced the creation of a second parallel TRIPODS Phase I–Phase II program; this new cohort also includes electrical engineering.

I am the director and principal investigator (PI) of the new University of California, Berkeley Foundations of Data Analysis (FODA) Institute,[2] one of the 12 original TRIPODS Phase I institutes. I work with my co-PIs—Peter Bartlett, Michael Jordan, Fernando Perez, Bin Yu, and Uros Seljak (with TRIPODS+X)—to make transformational advances in the interdisciplinary foundations of data science, incorporating both teaching and research. We collaborate with a range of campus partners—such as the Berkeley Institute for Data Science (BIDS), Simons Institute for the Theory of Computing, Real-time Intelligent Secure Explainable (RISE) Lab, and Lawrence Berkeley National Laboratory—that address other complementary aspects of data science. Beyond simply proving theorems, we are interested in how the foundations interact synergistically with increasingly data-driven domain sciences. For me, these efforts follow a long line of previous work, including the Workshop on Algorithms for Modern Massive Data Sets (MMDS) meetings [1, 3] and the 2016 Park City Mathematics Institute summer school on "The Mathematics of Data" [2].

The TRIPODS program is both timely and important. Every field needs foundations to understand *when* and *why* methods work as they do, but the three areas that TRIPODS identifies as being closest to the foundations of data science have very different foundational principles. Much data science education and training is currently limited to teaching tools (Python routines, etc.), rather than an inherent understanding of foundational principles. While foundational research may result in plainer graphics and be less immediately applicable than work in other more applied areas, failing to invest in foundational questions will lead to fields that are less intellectually rich and have hollower shells. In such scenarios, deeper connections between superficially-different methods applied in very diverse areas will not be recognized, understood, or exploited.

Furthermore, the TRIPODS program is relevant and impressive as a model for funding cross-cutting research more generally. The interdisciplinary challenges in orchestrating fruitful interactions between foundational computer scientists, statisticians, and applied mathematicians will be mirrored—probably much more so—when considering social, behavioral, and economic challenges associated with large-scale computing platforms; ethical and responsible uses of data; machine learning for materials science or biomedical science; or any more outward-facing complications important to data science.

In both this article and part II, which will appear in the October issue of *SIAM News*, I discuss my experiences with several of these challenges.

Community Background

Beyond facing difficult technical questions about the foundations of data, building cross-cutting platforms between different disciplines and conducting truly interdisciplinary research is *very* arduous. Funding mechanisms, hiring processes, and contrasting disciplinary cultures all conspire against this. If the goal is to bridge the gap between disparate research communities, then understanding the communities' backgrounds helps us identify the following three key classes of challenges that arise in such efforts.

Structural Challenge

TRIPODS stems in part from a phenomenon, a sort of "structural chasm," that can cause interdisciplinary work to "fall between the cracks." Scientists conducting research that cuts across traditional community disciplines are familiar with the effects of this occurrence. If one has a proposal that sits squarely between the NSF's Division of Mathematical Sciences (DMS)—which funds mathematics and statistics research—and its Directorate for Computer and Information Science and Engineering (CISE)—which funds computer science research—then the individual must decide where to submit the proposal. Upon sending it to the DMS, reviewers might decide that while the proposal contains great ideas and may have high impact, it isn't quite within the scope of the department and could be better suited for CISE. Reviewers at CISE may react the same way, deeming the proposal more appropriate for the DMS. On a related note, although universities are great at putting together interdisciplinary teams, they are much less adept at hiring interdisciplinary people. This sort of *structural challenge*, whereby newly-forming areas do not conform well to existing administrative silos, is perhaps the most obvious type of issue that arises in interdisciplinary efforts.

Justification Challenge

Motivated by this predicament and prompted by the NSF, Petros Drineas

See **Data Science** *on page 11*

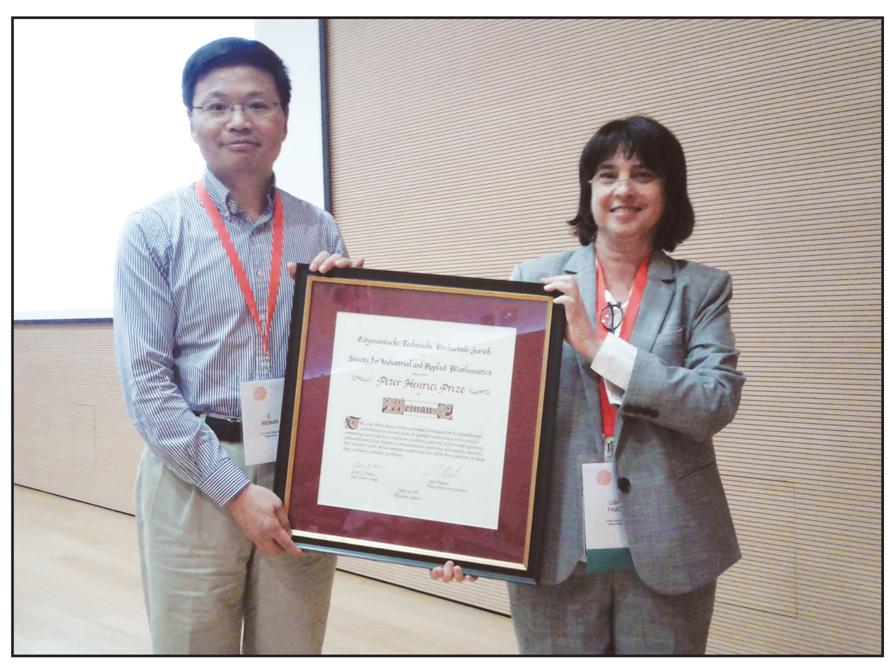
[1] https://nsf-tripods.org/institutes/
[2] https://foda.berkeley.edu/

Photos from ICIAM 2019

SIAM President Lisa Fauci (left) presents the 2019 John von Neumann Lecture prize—SIAM's highest honor and flagship lecture—to Margaret Wright of New York University at the 9th International Congress on Industrial and Applied Mathematics, which took place in Valencia, Spain, this July. Wright was recognized for her pioneering contributions to the numerical solution of optimization problems, and to the subject's exposition. Her corresponding talk was entitled "A Hungarian Feast of Applied Mathematics." SIAM photo.

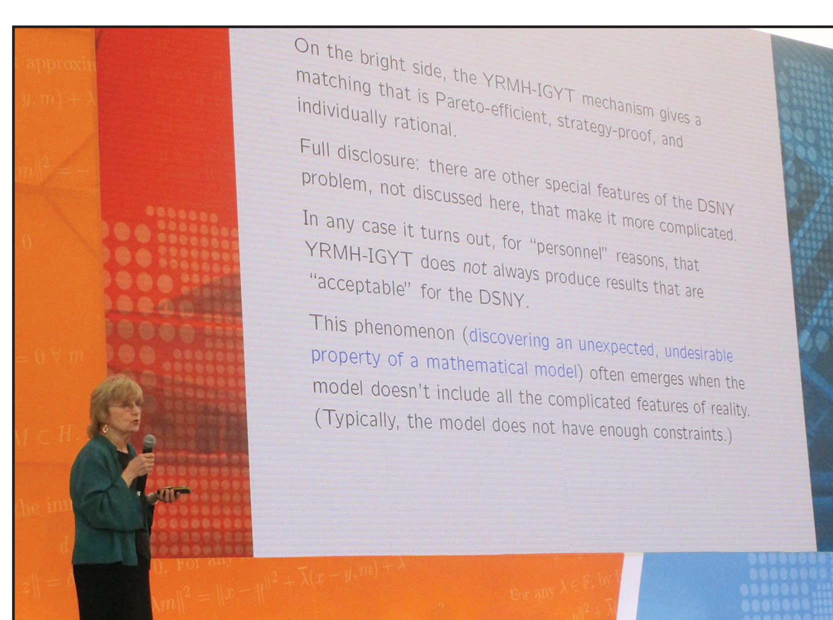
SIAM President Lisa Fauci (right) and Association of Women in Mathematics (AWM) President Ami E. Radunskaya (left) present Catherine Sulem of the University of Toronto with the 2019 AWM-SIAM Sonia Kovalevsky Lecture prize at the 9th International Congress on Industrial and Applied Mathematics, held in Valencia, Spain, this July. Sulem was acknowleged for her contributions to nonlinear analysis and partial differential equations (PDEs), specializing in the topic of singularity development in solutions of the nonlinear Schrödinger equation, on the problem of free surface water waves, and on Hamiltonian PDEs. Sulem's associated lecture was titled "The Dynamics of Ocean Waves." SIAM photo.

SIAM President Lisa Fauci (left) awards Maria J. Esteban of the Université Paris-Dauphine with the 2019 SIAM Prize for Distinguished Service to the Profession at the 9th International Congress on Industrial and Applied Mathematics, which took place this July in Valencia, Spain. Esteban was recognized for her outstanding contributions towards uniting the mathematics communities in France, Europe, and the rest of the world, and for helping to bridge the gaps between theoretical mathematics and applications, including those in industry. SIAM photo.



Weinan E (left) of Princeton University accepts the 2019 Peter Henrici Prize from SIAM President Lisa Fauci at the 9th International Congress on Industrial and Applied Mathematics, held this July in Valencia, Spain. The award is given jointly by SIAM and ETH Zürich, and noted E's breakthrough contributions in various fields of applied mathematics and scientific computing, particularly nonlinear stochastic (partial) differential equations, computational fluid dynamics, computational chemistry, and machine learning. E spoke to conference attendees about "Machine Learning: Mathematical Theory and Scientific Applications" in his corresponding prize lecture. SIAM photo.

Members of the SIAM Class of 2019 Fellows were recognized at the 9th International Congress on Industrial and Applied Mathematics, which was held in Valencia, Spain, this July. From left: Stephen Jonathan Chapman (University of Oxford), José Antonio Carrillo de la Plata (Imperial College London), Juan C. Meza (University of California Merced), Jill C. Pipher (Brown University), Fariba Fahroo (Air Force Research Laboratory), Gitta Kutyniok (Technische Universität Berlin), Wolfgang A. Dahmen (University of South Carolina), and Froilán Dopico (Universidad Carlos III de Madrid). SIAM photo.



Margaret Wright of New York University, recipient of the 2019 John von Neumann Lecture, delivers a talk called "A Hungarian Feast of Applied Mathematics" on July 16th during the 9th International Congress on Industrial and Applied Mathematics, which took place in Valencia, Spain. SIAM photo.

View information on all 2019 major SIAM prize recipients at
http://www.siam.org/Prizes-Recognition/Major-Prizes-Lectures.

A full list of the 2019 Fellows is available at
http://www.siam.org/Prizes-Recognition/Fellows-Program.

Trends in Combinatorial Analysis: Complex Data, Machine Learning, and High-Performance Computing

By Ariful Azad, Bora Uçar, and Alex Pothen

Discrete algorithms and combinatorial analysis were well represented at the 2019 SIAM Conference on Computational Science and Engineering (CSE19), which took place earlier this year in Spokane, Wash. Over 15 talks—dispersed among five minisymposia—covered topics ranging from graph algorithms and machine learning to scientific computing. Like many other communities in applied mathematics and computational science, the SIAM Activity Group on Applied and Computational Discrete Algorithms (SIAG/ACDA)—founded this spring—is innovating techniques to learn from large-scale combinatorial data. Challenges that accompany learning from data include increasing data volumes and complexity, the need for novel algorithms, and efficient employment of high-performance computing resources. Researchers at CSE19 presented ongoing work that addressed these challenges and captured the following four trends.

Scientific Data and Combinatorial Representation

Several presenters spoke about combinatorial models they have developed to represent scientific datasets, and algorithms they have designed for efficient solution of the aforementioned problems. Possible application areas include astrophysics, biology, agriculture, and neuroscience. In some cases, researchers used complex networks to model the data. For example, Ariful Azad (Indiana University Bloomington) utilized correlated brain segments, as measured by functional magnetic resonance imaging (fMRI), to create a brain connectivity network. Ananth Kalyanaraman (Washington State University) analyzed agricultural phenomics data via persistent homology techniques. And Francesca Arrigo (University of Strathclyde) modeled complex datasets as multilayer networks, where different layers of each network capture various features or modalities. Overall, members of SIAG/ACDA are actively finding innovative ways to model increasingly complex scientific and business datasets.

Algorithmic Innovation

After representing data with a sound mathematical model, the next step often involves developing algorithms to solve problems of scientific interest. New scientific and business challenges lead to the creation of novel, efficient algorithms in the SIAG/ACDA community. For example, Arrigo also discussed an eigenvector-based centrality measure in multilayer networks capable of calculating centrality in a network with several different types of interactions among various entities. Syed M. Ferdous (Purdue University) described the design of parallel approximation algorithms for computing edge covers using the primal dual linear programming framework, with applications to semi-supervised classification.

Machine Learning

Many presenters at CSE19 focused on machine learning methods and algorithms. In fact, a minisymposium entitled "The Intersection of Graph Algorithms and Machine Learning" featured several talks on clustering and learning from discrete datasets and networks. For instance, Nesreen Ahmed (Intel Research Labs) introduced an algorithm that learns useful graph representations from diverse datasets. Azad spoke about his group's search for a consensus clustering among segmented brain fMRI images (see Figure 1). Several other researchers addressed the application of deep neural networks to the solution of challenging problems in data analytics.

High-performance Computing

With ever-increasing amounts of data and the availability of parallel computers, parallel algorithms and high-performance computing are trending themes in high-end data analytics that involve the SIAG/ACDA community. A two-part minisymposium at CSE19 entitled "Graph and Combinatorial Algorithms for Enabling Exascale Applications" was dedicated to massively-parallel graph and combinatorial algorithms. Arif Khan (Pacific Northwest National Laboratory) exhibited a parallel approximation algorithm to solve a data privacy problem called adaptive anonymity for a terabyte-scale healthcare dataset on a computer at Lawrence Berkeley National Laboratory's National Energy Research Scientific Computing Center. Mostofa Patwary (NVIDIA) demonstrated a scalable clustering algorithm called BD-CATS that can cluster 1.4 trillion cosmological particles using 100,000 cores on a Cray supercomputer. Speakers across various minisymposia introduced parallel combinatorial algorithms for multicore processors, graphics processing units, distributed supercomputers, and cloud infrastructures.

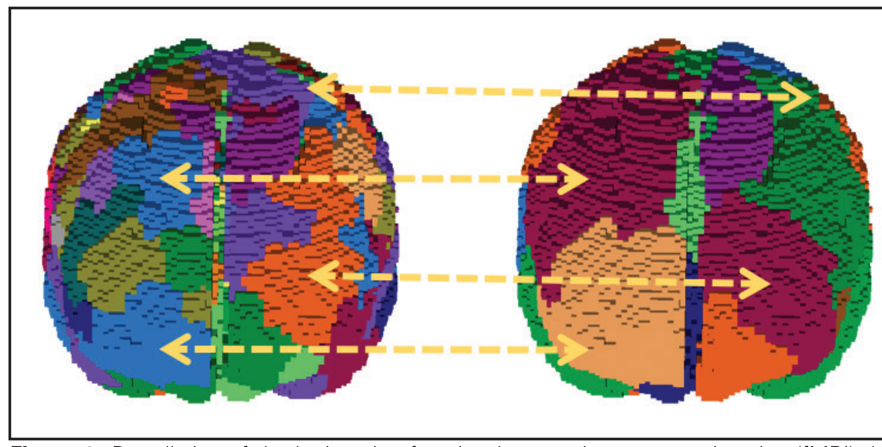


Figure 1. *Parcellation of the brain using functional magnetic resonance imaging (fMRI) data and a clustering algorithm. The left side depcits large communities and the right side depicts small communities. Figure courtesy of Ariful Azad.*

See **Combinatorial Analysis** *on page 12*

Prize Spotlight: 2019 SIAM Conference on Financial Mathematics & Engineering

Daniel Lacker (Columbia University) and Mykhaylo Shkolnikov (Princeton University) are dual recipients of the 2019 SIAM Activity Group on Financial Mathematics and Engineering Early Career Prize. The duo were honored during the 2019 SIAM Conference on Financial Mathematics & Engineering, which took place in early June at the University of Toronto in Ontario, Canada. The award recognizes Lacker for his remarkable contributions to the probabilistic theory of mean field games and its applications to mathematical finance. Shkolnikov was commended for his major contributions to the study of large systems of competing particles and corresponding applications to rank-based models in stochastic portfolio theory.

Alvaro Cartea of the University of Oxford (far left), invited speaker at the 2019 SIAM Conference on Financial Mathematics & Engineering, and Sebastian Jaimungal of the University of Toronto (far right), organizing committee co-chair, pose with SIAM Activity Group on Financial Mathematics and Engineering Early Career Prize winners Mykhaylo Shkolnikov of Princeton University (second from left) and Daniel Lacker of Columbia University (second from right). SIAM photo.

Update to the SIAM Journal on Financial Mathematics

SIAM is pleased to announce the addition of a new section for the *SIAM Journal on Financial Mathematics* (*SIFIN*). Along with full-length research articles, authors can now submit "Short Communications" with a maximum length of 10 pages. The journal intends fast review and speedy publication for Short Communications papers.

To submit, select "Short communications" as the manuscript type on the online submission form.[1] For more information, please visit the *SIFIN* Instructions for Authors page.[2]

SIFIN addresses theoretical developments in financial mathematics as well as breakthroughs in the computational challenges they encompass. The journal provides a common platform for scholars interested in the mathematical theory of finance, and practitioners interested in rigorous treatments of the scientific computational issues related to implementation. On the theoretical side, *SIFIN* publishes articles with demonstrable mathematical developments motivated by models of modern finance. On the computational side, it introduces new methods and algorithms representing significant improvements on the existing state of affairs of modern numerical implementations of applied financial mathematics.

[1] https://sifin.siam.org/cgi-bin/main.plex
[2] https://www.siam.org/Publications/Journals/SIAM-Journal-on-Financial-Mathematics-SIFIN/Instructions-for-Authors

Spinning Out

While riding a bike in a straight line, I suddenly squeeze the rear brake. This locks the rear wheel and keeps the front wheel rolling freely. Will I continue in a straight line until the bike stops? *Let us assume that I keep the front wheel straight at all times* (so, strictly speaking, I should have training wheels to avoid falling over).

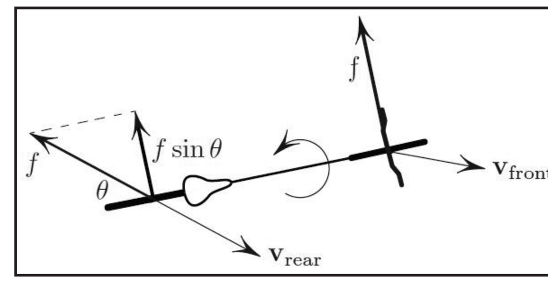


Figure 2. *If both wheels slip, the perpendicular component of friction is greater on the front wheel, causing a spinout.*

It seems quite natural to argue that the *friction on the locked rear wheel will hold the rear of the bike backwards and act as a stabilizer*, ensuring that the bike continues going straight. Interestingly, this argument is wrong; the bike will actually spin out.

Where is the mistake in the no-spinout argument? It comes from ignoring the front wheel and thus missing the fact that the front wheel acts as a destabilizer. This destabilization beats the stabilizing effect of the rear wheel. Indeed, the front wheel's velocity aligns with the bike frame, assuming that no slipping occurs. The front wheel therefore acts like an arrow's fin, and our "arrow" is initially moving backwards (see Figure 1). This arrow will consequently turn around and the fin/front will follow the rear, resulting in a complete spinout. Regardless of the rear wheel's trajectory (and we do not address its shape here), the front wheel tracks the rear wheel due to the no-sideslip assumption. In our "proof" of stability, we got it exactly backwards (pun intended): it is the *front* wheel and not the rear wheel that acts as a stabilizer.

MATHEMATICAL CURIOSITIES
By Mark Levi

So far we have assumed that the front wheel holds its grip on the road, i.e., that no slippage occurs. But what if the front wheel sideslips (as could happen when riding on ice)? The key is to observe that the frictional force acting on a sideslipping wheel in the absence of rolling friction is *perpendicular to the direction of rolling* (see Figure 2). Indeed, the projection of the frictional force in the direction of rolling vanishes by assumption, and the force is hence purely perpendicular to the wheel's direction (i.e., aligned with the wheel's axle).

As a result, the front friction is spent entirely on trying to spin the bike out while the rear friction is partly "wasted" on the longitudinal component; more formally (and assuming, perhaps unrealistically, that the two frictions are the same), we have

$$f > f \sin\theta.$$

The sideways frictional push on the front wheel exceeds that on the rear wheel, again resulting in a spinout.

The figures in this article were provided by the author.

Mark Levi (levi@math.psu.edu) is a professor of mathematics at the Pennsylvania State University.

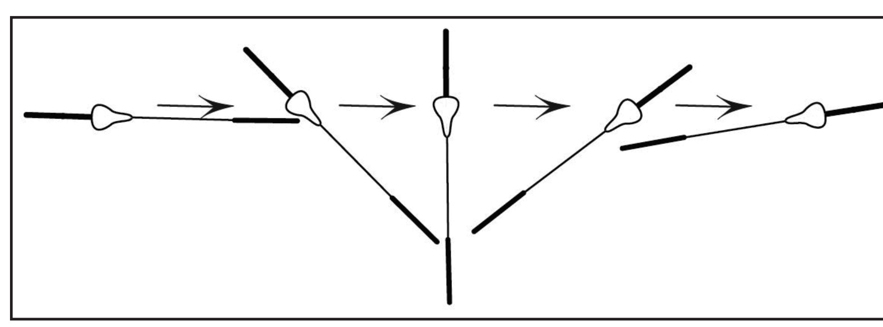


Figure 1. *The front wheel, free to spin, tracks the rear (locked) wheel.*

Data Science

Continued from page 8

(Purdue University) and Xiaoming Huo (Georgia Institute of Technology) organized an exploratory workshop on Theoretical Foundations of Data Science (TFoDS): Algorithmic, Mathematical, and Statistical[3] in April 2016. The workshop's objective was "to identify important research challenges that strengthen and broaden the mathematical, statistical, and algorithmic foundations of data science." Participants discussed potential opportunities for collaboration between the relevant communities, and investigated workforce challenges and infrastructure development. Ultimately, the meeting yielded a report that suggested the creation of a "center or institute, funded by an agency such as the NSF…that emphasizes the foundational aspects of data science."[4]

Much discussion during TFoDS addressed a *justification challenge*, whereby foundations should inform—and be informed by—very practical problems (i.e., avoid representing pure theory divorced from practice) while not having to justify existence in terms of its immediate usefulness in particular domains.

Cultural Challenge

A lot of TFoDS conversation also focused on what form the aforementioned center or interdisciplinary institute could take, or whether an institute is even the best mechanism to propel the area forward. However, there was little consensus. Unresolved questions include the following.

1. Should such an institute run short meetings or long programs?
2. What are attendance expectations? Should the institute be an "incubator" for projects that cut across the three relevant areas?
3. Would these projects be funded by "internal" proposal solicitations? Should they be virtual or physically located in one place?
4. How would one encourage long-term interactions? Should projects attempt to promote "risky" research, particularly among younger researchers?
5. How do these desires relate to the timescales for publication, recognition, and reward?

Far from being administrative issues, these questions (and the lack of straightforward answers) highlight a *cultural challenge*. Structuring interactions between different areas—given their very distinct styles and modes of interaction, in addition to the conflicting power dynamics within and between them—is an extremely complicated task.

Part II of this article, to be published in the October issue of SIAM News, will describe the broader NSF context as well as lessons for interdisciplinary and antedisciplinary balance, both for foundations of data and in a more general framework.

[3] http://www.cs.rpi.edu/TFoDS
[4] http://www.cs.rpi.edu/TFoDS/TFoDS_v5.pdf

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[1] Golub, G.H., Mahoney, M.W., Drineas, P., & Lim, L.-H. (2006, October). Bridging the gap between numerical linear algebra, theoretical computer science, and data applications. *SIAM News, 39*(8).
[2] Mahoney, M.W., Duchi, J.C., & Gilbert, A.C. (Eds.) (2018). *The Mathematics of Data. IAS/Park City Mathematics Series* (Vol. 25). Providence, RI: American Mathematical Society.
[3] Mahoney, M.W., Lim, L.-H., & Carlsson, G.E. (2008). Algorithmic and statistical challenges in modern large-scale data analysis are the focus of MMDS 2008. *SIGKDD Explor., 10*(2), 57-60.

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Professional Opportunities and Announcements

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For rates, deadlines, and ad specifications, visit ***www.siam.org/advertising****.*

*Students (and others) in search of information about careers in the mathematical sciences can click on "Careers" at the SIAM website (****www.siam.org****) or proceed directly to* ***www.siam.org/careers****.*

Balancing Motherhood with a Successful Career in STEM

Navigating a career as a professional mathematician or researcher is hard enough. But every aspect—working evenings and weekends, traveling to conferences, acquiring tenure, etc.—becomes much more difficult when one adds parenting to the mix. Three SIAM members share their insights and experiences on effectively managing these challenges.

I have a confession: for a long time, I did not really think about the fact that I am a female mathematician. Requests for sound bites about "advice for women in STEM" made me uncomfortable because I didn't really have any particular suggestions. My mother told me I could be anything I wanted when I grew up if I worked hard enough, so that's what I did — without really noticing if the people around me were boys or girls. I worked extremely hard simultaneously as a waitress, tutor, and video store clerk to support myself and pay for the last few years of my undergraduate education. I earned a fellowship to attend graduate school and landed the tenure-track academic job that I wanted, which offered a balance of both research and teaching. I had it all!

However, becoming a mother shifted my perspective and caused me to realize that it isn't totally possible to always have it all — or at least it feels that way. Balancing academia with motherhood (which eventually turned into being a single parent of two daughters) is extremely challenging for me, even though I do know deep down that I am successful at both. It helps to remember that I actually have choices, even when I feel like I don't. I can say "no" if I want to, or I can say "yes" and describe the exciting opportunities I have to my kids.

For a while, I was the only woman in my department. So when I first found out that I was pregnant, I decided not to take maternity leave and went right back to work thinking I could handle things. My choice was a stupid one that taught me to make smarter decisions. I had *no* idea how exhausting it is to have a baby and get tenure at the same time. I handed in my tenure packet the same semester my younger daughter was born. I remember rushing home countless times to nurse only to discover that dad had just given the baby a bottle because I was late and she was hungry. Those times made me feel like a total failure as a mother. But I wasn't a failure; I was just late. And when my child's eyes lit up upon seeing me, I knew I was forgiven. I also fell asleep at my desk and in departmental meetings on many occasions.

As a result, I slowly started to make choices. For example, I decided to administer in-class exams when most other professors in my department gave evening exams. I did not want to be at work from 6-8 p.m., so I found a workaround. Eventually I realized that flexibility is one of the most wonderful things about academia (given a supportive department, for which I am grateful). When my kids were sick, I could be home most of the time and work while they slept. When they had a snow day, they could sit in my class of 100 calculus students and quietly color in the front row. I was able to chaperone school field trips to the zoo or attend the 10 a.m. parent-teacher conferences. If I needed to be home by 3 p.m. to get my daughters off the bus every single day, I could make that happen and still prepare my lectures and write my papers; it just required some focused time management. Did I miss out on some things? Of course. I did not see my daughter ride a bike without training wheels for the first time because I was grading at the kitchen table. I wasn't there when my other daughter took her first steps because I was away at a conference. My daughter's letter to Santa once read, "I was good — I played so mommy could get her work done." Ouch. However, I am thankful for my decision to have a family and maintain my career because both make me happy.

I travel to conferences nearly once a month, which takes strategic planning. But there are perks. The first time my younger daughter ever slept through the night was in a hotel room at the 2008 SIAM Conference on Optimization in Boston, Mass. It was the night before my talk, and also (fittingly) Mother's Day! A special gift indeed. Now that my girls are in school and have their own schedules, I have to find someone to care for them while I'm away. It takes a village for me to have a career and a family.

I still don't really think of myself as a female mathematician, but I do consider myself a mother of two amazing daughters with an incredibly exciting and often challenging career. I would not say that this path is easy or right for everyone, but it is certainly possible with the appropriate strategy and lots of help. As my daughters have gotten older, they have grown to appreciate what I do; they celebrate with me when my Ph.D. students defend their theses or bring me ice cream when I am buried in paper grading. To me, the most important outcome of this is that they know they will have choices about their careers and families too.

— Kathleen Kavanagh

I always look forward to the SIAM Conference on Computational Science and Engineering. In addition to highlighting new research through various talks, it offers a chance to reconnect with familiar faces from graduate school and previous partnerships, as well as the opportunity to establish potential new collaborations. This year I brought my three-month old daughter with me to Spokane, Wash., along with our au pair to assist with her care while I attended sessions.

I knew a priori that I would need to miss parts of the conference to feed and tend to my daughter, but wanted to make this process as efficient as possible. She refuses to take a bottle, and since I regularly work from home I am able to take breaks during the day to feed her. I called the conference center ahead of time to inquire about a nursing room. When it became clear that one was not inherently available, SIAM arranged to have a conference room dedicated as a nursing space. Even so, I had to be extra diligent in looking ahead, planning which talks I wanted to attend, and deciding which were of lower priority so that I could arrange our feeding schedule accordingly.

I also made an effort to coordinate dinners—which I often use for networking purposes at conferences—with my daughter's feeding and sleeping schedules and confirm with my fellow diners that she would be welcome to join us. One plan to take an Uber to a restaurant beyond walking distance was foiled since I wanted to avoid the hassle of carrying and installing a car seat. Another dinner was spent shouting (and laughing) over bouts of fussiness, but everyone was a good sport.

Kathryn Maupin (far left) and baby Annette successfully navigated the 2019 SIAM Conference on Computational Science and Engineering, which took place earlier this year in Spokane, Wash. Photo courtesy of Brian Freno.

The main benefit of bringing our au pair to the conference was that I did not have to worry about finding a quality caregiver in Spokane or explaining my daughter's needs to a new person. Aside from the change in environment (a hotel room instead of our house), her days were largely the same as they are at home. She played and napped, and I took breaks from the conference when it was time for her to eat. As any parent can likely attest, one of the difficulties of traveling with an infant or young child is the crankiness that ensues from disruption of their routine. Since our au pair accompanied us, changes to my daughter's schedule were minimal.

While managing my daughter's feeding and care during the meeting was a logistical challenge, it was not an insurmountable one. Traveling with our au pair made the whole trip more manageable, and I will likely do it again for future conferences.

— Kathryn Maupin

The 2019 SIAM Conference on Computational Science and Engineering in Spokane, Wash., earlier this year was only the second time I was away from my 14-month-old daughter, Denver. I remembered the SIAM Child Care Grants a bit too late to take advantage, though quite honestly, the idea of embarking on nine hours of travel (each way!) from Orlando, Fla. to Spokane with my little one in tow was not exactly appealing to me. Now that Denver is old enough to drink cow's milk, leaving her at home with her dad when I attend conferences is a viable option. While she was breastfeeding, however, she accompanied me to every meeting I attended, tallying 14 flights in her first year of life.

My family's support made this possible. My parents currently live in the Denver, Colo., and Washington, D.C., areas, so I took advantage of nearly every opportunity for travel to those places since I knew I would have to turn down many trips to other locations. My parents watched Denver during the day while I attended workshops and conferences, and I traveled back to her in the evenings. Though I am grateful that I could make this work, what surprised me most was the isolation I sometimes felt. Because I wasn't able to stay in conference lodging, I finished my days with long, lonely drives back to my child while other attendees went to dinner. During the workshops and meetings themselves, I used breaks to pump milk so Denver could eat the next day instead of resting and/or networking with colleagues. After a year of this, I definitely gained a new appreciation for looser meeting agendas and frequent, scheduled breaks.

During this time, I managed to attend one meeting that was not held in D.C. or Colorado: the 13th World Congress on Computational Mechanics, which took place in New York City. My partner was able to take time off work and travel with me. We stayed in the conference hotel and I returned to our room between sessions to feed Denver. This arrangement worked for us, but again was not without drawbacks. I was obviously reliant upon my partner's ability to take vacation time, and his schedule limited the number of days I could attend the meeting. I also found it challenging to be completely engaged in conference sessions with my family so close by.

Conference travel is a large part of my life as an academic researcher. Over the past year, I learned to navigate the process while caring for an infant. While it certainly hasn't always been easy or convenient, I am very grateful that I can include motherhood in my scholarship. It is especially encouraging to see other mothers do it too and witness organizations like SIAM supporting our efforts through child care grants.

— Talea Mayo

Many SIAM conferences offer support for attendees with young children. To find out if your next conference offers child care grants, click the "Lodging & Support" tab on the conference page and select "Child Care" from the dropdown list.

Kathleen Kavanagh is a professor of mathematics at Clarkson University and the Vice President for Education at SIAM. Kathryn Maupin is a Senior Member of Technical Staff in the Optimization and Uncertainty Quantification Department at Sandia National Laboratories. Talea Mayo is an assistant professor of civil engineering at the University of Central Florida and the SIAM News liaison for the SIAM Activity Group on Geosciences.

Combinatorial Analysis

Continued from page 10

We are looking forward to more talks of this flavor at the SIAM Workshop on Combinatorial Scientific Computing, to be held in Seattle, Wash., from Feb 11-13, 2020, as well as the first SIAM Conference on Applied and Computational Discrete Algorithms in 2021. SIAG/ACDA invites new and existing SIAM members with interest in designing "algorithms in the real world" that solve application-motivated problems to join us.[1]

[1] https://www.siam.org/membership/Activity-Groups/detail/applied-and-computational-discrete-algorithms

Ariful Azad is an assistant professor of intelligent systems engineering at Indiana University Bloomington. He received his Ph.D. from Purdue University and was a Research Staff Member at Lawrence Berkeley National Laboratory. Bora Uçar is a CNRS researcher at the Laboratoire de l'Informatique du Parallélism, École normale supérieure in Lyon, France. He received his Ph.D. from Bilkent University in Ankara, Turkey, and has worked at the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique in Toulouse, France. Alex Pothen is a professor of computer science at Purdue University. He is chair of the SIAM Activity Group on Applied and Computational Discrete Algorithms.