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Dynamics and the Dark Matter Mystery

By Donald G. Saari

Dark matter is a fascinating, frustrating scientific mystery. Astronomers claim that much of it forms halos surrounding galaxies, yet "no one has ever seen this material or been able to study it" [1]. Hence, anticipation accompanied delivery of the "Alpha Magnetic Spectrometer - 02" to the International Space Station in May 2011. Although a goal was to discover this elusive stuff, nothing conclusive has been found [1]. Dark matter supposedly explains gravitational effects, which suggests the merit of analyzing colliding galaxies because gravitational dragging should distort those halos. However, such behavior was not detected [3]; what happened was consistent without the supposed presence of dark matter. A recently-concluded, highly-sensitive and anticipated "Large Underground Xenon" experiment [8] failed to detect a single trace of dark matter. With these and other consistently negative findings, why should we believe this material exists?

The search for dark matter relies upon circumstantial evidence. All of the astronomers and astrophysicists I have consulted with agree: The most compelling argument, as described in the press, is that galaxies would spin apart if dark matter did not exist, which is contrary to observations. In other words, *dark matter is the difference between a mathematical prediction* (mass needed to keep a galaxy from dissipating) *and the known amount of mass*.

Because dissipation qualifies as dynamics, I investigated it [6-7]. Spoiler alert: Newtonian dynamics do not support the dissipation assertion, nor do they require dark matter and halos. But whether dark matter exists is an empirical issue that mathematics cannot resolve. Something might be found eventually, but what follows compromises, if not eliminates, a standard argument for the existence of massive amounts of this mysterious material.

Computing Mass

Intuition about the computation of mass comes from swinging a weight where "a fast swing plus a weak string can equal a broken window" [7]. To determine the Sun's mass, M_S, planets are the rotating objects and the string's strength comes from M_S and the planet's distance from the Sun, *r*. The only unknown in Newton's two-body equation is M_S. So, with nearly circular orbits (the scalar $r'' \approx 0$), it follows that

$$M_S = \frac{rv^2}{G}, \qquad (1)$$

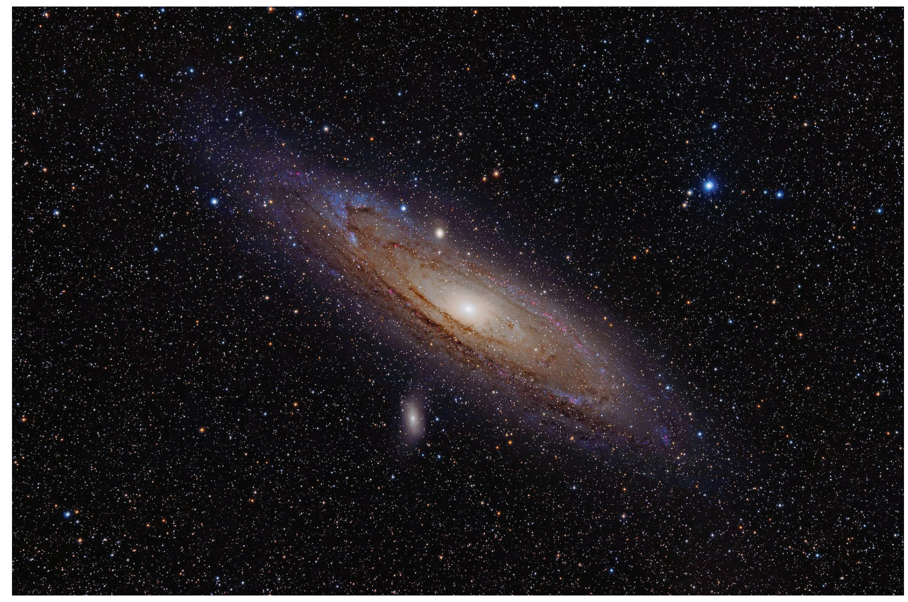

Figure 1. *Image of Earth's nearest galaxy, the Andromeda, with trailing stars. Photo credit: Wikimedia Commons.*

where *G* is the gravitational constant and *v* is the rotational velocity. To illustrate this with our home planet, $r = 92.96$ million miles and $v = 2\pi r/(\text{one year})$.

(1) also identifies the dissipation concern: if M_S is much smaller than in (1) for *r* and *v*, the two-body system cannot be stable; i.e., the $r'' \approx 0$ assumption is false. Using the spinning object analogy, a much smaller M_S value represents a "weak string," thus encouraging an escaping planet.

Unfortunately, general properties of billion-body Newtonian systems are unknown, so astronomers developed creative approximations to study galactic systems. Intuition for a standard approach comes from star-soup

See **Dark Matter** *on page 3*

Bridging Continuum and Molecular Models in a Beating Heart Simulation

By Takumi Washio

Numerical continuum modeling of muscle offers a very interesting research topic. In typical continuum materials, the strain uniquely determines the stress. However, this rule does not apply to muscles undergoing contraction. The actomyosin complexes in muscle [1] constantly change their conformations during the contraction phase of events, such as attachment, dissociation, and power strokes of the lever arm (see Figure 1a). Furthermore, the transition rates depend on the strain of the lever arm, which is affected by the continuum muscle contraction.

In computer simulations of a beating heart, modeling these molecular behaviors is necessary to correctly reproduce the muscle contraction. The contractile force in cardiac cells rises when the sarcoplasmic reticulum (SR) releases Ca^{2+} ions, and decreases when these ions are sequestered back into the SR. In many earlier studies, the temporal change of contractile force under a given Ca^{2+} transient was computed by a system of ordinary differential equations (ODEs). However, ODEs cannot easily model the stochastic and cooperative behaviors of actomyosin complexes. For example, in a healthy beating heart, the left ventricular pressure (LVP) (see Figure 1b, black line) falls to almost zero at the end-systole (or end of contraction), but nearly 10% of the peak Ca^{2+} concentration remains in the cytosol, that is, within heart cells (see Figure 1b, red line). Furthermore, the LVP falls much more rapidly than the Ca^{2+} concentration. These quick relaxation properties of cardiac muscle are assumed to originate from the cooperative behavior between the neighboring actomyosin complexes and the stochastic power-stroke, strain-dependent mechanism of the myosin lever arms. Unless we correctly model these molecular properties, we fail to reproduce the quick relaxation of the cardiac muscle. The consequence is insufficient blood-filling into the ventricular cavity during the diastolic phase.

Multiscale Model

Failure to successfully simulate a beating heart with existing ODE models has motivated our method to directly mimic individual molecules in our beating heart model. To realize this idea, we couple macroscopic continuum dynamics by the finite element method (FEM) with microscopic molecular dynamics by the Monte Carlo (MC) method. These two approaches differ on both spatial and temporal scales. In our approach [2], we embed the sarcomere model of actomyosin complexes into each tetrahedral element of the FEM (see Figure 1c) along the fiber orientation. Here we assume that a single sarcomere force represents the contractile tension generated by all cardiac cells in the element. Usually we set the time step as $\Delta T = 1$ ms in the FEM analysis, and subdivide this value into a finer time step $\Delta t = 10\mu s$ for the MC analysis.

Coupling of Molecules and Continuum

In our approach, the macroscopic active stress tensor $\boldsymbol{S}_{act}$ in the finite element time interval $\left[T, T+\Delta T\right]$ is implicitly determined, ensuring compatibility between the molecular and continuum virtual works, as shown in Figure 2 (on page 4). To account for the state transitions of the actomyosin complexes during this time interval, we relate the strain rates on three scales (actomyosin complex, sar-

See **Heart Simulation** *on page 4*

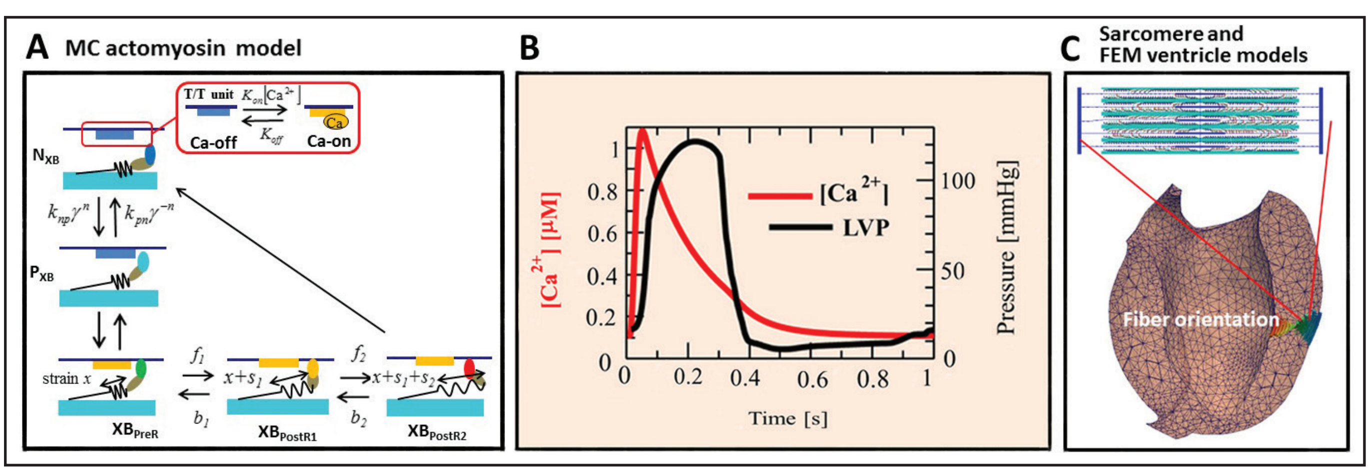

Figure 1. *Multiscale modeling.* **1a.** *MC model of the actomyosin complex. The contraction force is contributed by three attached states* $(XB_{PreR},\ XB_{PostR1},\ and\ XB_{PostR2})$. *The transitions between* N_{XB} *and* P_{XB} *are influenced by the states of the* $T\,/\,T$ *unit above the myosin head through the coefficients* K_{np}, K_{pn} *and the states of the neighboring myosins through the cooperative factors* γ^{n}, γ^{-n} $(\gamma = 40)$. **1b.** *Transients of the averaged* Ca^{2+} *concentration over the ventricle (red line) and the left ventricular pressure (LVP) (black line).* **1c.** *Sarcomere model composed of actomyosin complexes and FEM ventricle model showing the twisted fiber orientations along the transmural line. Figure credit: Takumi Washio.*

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Obituaries

By Sven Leyffer

The applied mathematics community lost a giant when mathematician Roger Fletcher passed away in June 2016 while hiking in his beloved Scottish Highlands. A professor in the Department of Mathematics at the University of Dundee, he was known both for his contributions to the field of optimization and his humble and approachable manner.

Roger began his work in optimization at the dawn of nonlinear programming. Having completed his undergraduate degree at the University of Cambridge on a state scholarship, he then pursued his Ph.D. at Leeds University. At the time, Leeds had just established one of the first computing labs in the U.K. While at Leeds, Roger first met Mike Powell, which started a lifelong competitive friendship. Mike had come to Leeds to present a seminar on derivative-free optimization, but changed his mind and chose to instead talk about a recent technical report from Argonne National Laboratory by Bill Davidon. As it happened, Roger had been given that same report by his advisor, Colin Reeves. When Mike gave his seminar, he found that Roger already knew about Davidon's then-new method and even had a working code. The two joined forces to write Roger's first paper, which appeared in the *Computer Journal* in 1963 [6], on what was later known as the Davidon-Fletcher-Powell (DFP) method.

The DFP paper was not the only hugely influential paper to come out of Roger's time at Leeds. Following a suggestion by Reeves, Roger investigated the use of his line search to extend the conjugate gradient method to nonlinear functions. The result was the Fletcher-Reeves method [7]. While neither of these two methods are widely used today, they represent a transformational moment in nonlinear programming. Roger modestly attributed his first two papers to his coauthors. "I had two huge ideas given to me by people," he said. He described his time at Leeds as "probably the happiest period of [my] life." Many years later, while a professor at Dundee, he would create a similarly happy atmosphere for his students and visitors.

Roger and Mike remained competitive friends throughout their careers, and Roger once recounted a story about when they went hiking in the Scottish Highlands. As Roger was slightly younger, he was leaving Mike behind, a situation that did not sit well with Mike's competitive nature. So Mike cleverly asked, "Roger, tell me about the proof of the conjugate gradient method" – and deftly managed to catch up with an out-of-breath Roger.

Roger emphasized the use of applications to drive his research. He believed that applications and numerical work help us understand a problem's challenges and an algorithm's limitations. During his time at Leeds, Roger explored molecular dynamics calculations that required the solution of an unconstrained optimization problem; these applications directly motivated his work on the DFP and conjugate-gradient methods. Roger later worked closely with the School of Chemical Engineering at the University of Edinburgh. He believed that the problems people want to solve should ultimately drive applied mathematics research, and valued simple examples to expose a method's limitations. In 2005, he and Yuhong Dai developed a small example demonstrating that the Barzilai-Borwein method can fail for box-constrained problems [2].

The second foundation of Roger's research philosophy was software, as he believed that software validates theory and is simultaneously a guide to good methods. He wrote a powerful and robust LP solver and later `bqpd` [4], a `Fortran77` package for solving indefinite QPs under degeneracy. These solvers supported both single- and double-precision arithmetic, because numerical difficulties manifested themselves first in the single-precision version. His solver shows some ingenious object-orientesque coding in `Fortran77` (even though I am sure Roger never knew anything about object-oriented programming or `C++`)! The QP solver relies on a matrix algebra "class" that implements the factorization of the basis matrix. Roger provided both dense and sparse instantiations of this "class" and opened the possibility for other classes – for example, for people wishing to exploit the structure of their problem.

Throughout his career, Roger distrusted textbooks. While working towards his Ph.D., he implemented the steepest descent method, which was then the current method of choice. It failed to solve his problem, and Roger grew doubtful of things written in books:

> I read in a couple of books (Householder's book [9], I think it was; another book, Hildebrand [8] perhaps). They seemed to suggest that steepest descent was a very good method. So I tried it, and it generated reams and reams of paper, punched paper tape output as the iterations progressed, and didn't make a lot of progress.[1]

However, Roger was just as suspicious of his own opinion, and not above changing his own mind. When he refereed a paper by the young Dai on the Barzilai-Borwein method, he initially rejected the idea as useless. Luckily, Dai persisted; eventually Roger not only changed his mind but also coauthored a number of papers with him [1-3].

This self-doubt and suspicion enabled Roger to stay fresh and produce groundbreaking results, even late in his career. When I last met him, he was excited about his recent work on an augmented Lagrangian method for nonnegative QP. He was using a clever transformation of variables that also allowed him to store a single vector of size n that combines the primal and dual variables, thereby exploiting their natural complementarity.

Roger was widely-recognized in the mathematics community. He won the George B. Dantzig Prize with Stephen M. Robinson in 1997 and shared the Lagrange Prize in Continuous Optimization with Philippe Toint and myself in 2006, awarded jointly by SIAM and the Mathematical Optimization Society. Roger was a fellow of the Royal Society of Edinburgh, the Royal Society of London, and SIAM. Despite these accolades, he remained humble and approachable throughout his career, and never lost the sheer joy of solving problems and making discoveries (he acknowledged that his discovery of filter methods [5] made him "tingle when [he] thought about it").

Roger had a great, deadpan sense of humor (if a somewhat limited reservoir of jokes). On one occasion, he complimented me and said, "Nice pullover, is it new?" This confused me, given Roger's lack of fashion sense and the fact that the pullover was quite old. The mystery was solved when I took the pullover off and discovered a gaping hole in its sleeve.

Roger Fletcher, 1939-2016, pictured here in his beloved Scottish Highlands. Image courtesy of Sven Leyffer.

Roger was what Americans would call a no-nonsense applied mathematician who believed in simple arguments and proofs. At the University of Dundee he fostered a happy environment for his many Ph.D. students and visitors. Roger selflessly provided guidance to his students, passing on to a new generation of researchers the luck and good ideas he felt he was given. He will be missed.

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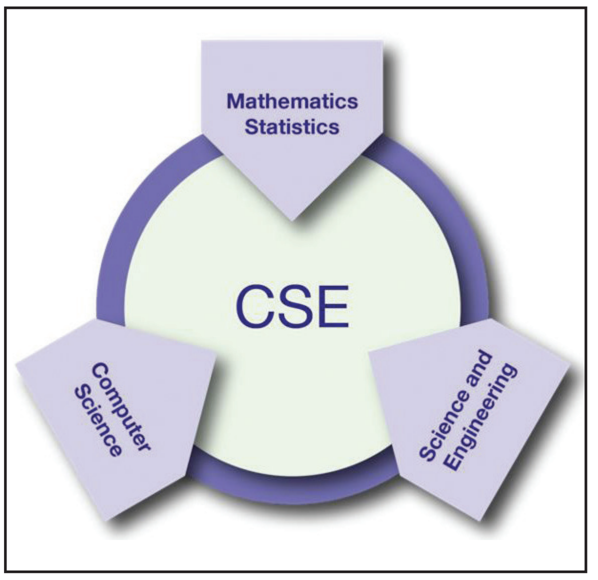
New Report on Research and Education in Computational Science and Engineering

By Ulrich Rüde, Karen Willcox, Lois Curfman McInnes, and Hans De Sterck

Over the past two decades, computational science and engineering (CSE) has become an increasingly important part of research in academia, industry, and laboratories. Mathematics-based advanced computing is now a prevalent means of discovery and innovation in essentially all areas of science, engineering, technology, and society, and the CSE community is at the core of this transformation. SIAM has been a driving force in this development by hosting the Activity Group on Computational Science and Engineering (SIAG/CSE), organizing the biennial flagship SIAM Conference on CSE, and publishing the *SIAM Journal on Scientific Computing* – one of the top journals in the field. A 2001 report, *Graduate Education in Computational Science and Engineering* by the SIAM Working Group on CSE Education [2], has helped to define the role and scope of CSE during the past two decades. However, a combination of disruptive developments—including the architectural complexity of extreme-scale computing, the planet's ongoing data revolution, and the penetration of mathematically-based CSE methodology into more and more fields—is currently redefining CSE's reach.

While CSE is rooted in the mathematical and statistical sciences, computer science, the physical sciences, and engineering, today it increasingly pursues its own unique research agenda. The field is now widely recognized as an essential cornerstone that drives scientific and technological progress in conjunction with theory and experiment. Scientific experimentation and theory, the classical paradigms of the scientific method, both strive to describe the physical world. However, high-fidelity predictive capabilities can often be realized only by numerical computation. CSE's overarching goal of achieving truly *predictive* scientific capabilities is its distinguishing factor. It accomplishes this through advances that combine modeling, numerical analysis, algorithms, simulation, big data analytics, high performance computing, and scientific software. The development of predictive capabilities lies at the core of CSE as a new discipline in its own right and has already impacted a number of disciplines, including but not limited to simulation-based design in the automotive industry, simulation-based decisions in computational medicine, and simulation-based predictions of global climate. It is also set to catalyze fundamental changes in



CSE is at the intersection of mathematics and statistics, computer science, and core disciplines from the sciences and engineering. This combination gives rise to a new field whose character is different from its original constituents. Image credit: [1].

See **Computational Science** *on page 5*

Dark Matter

Continued from page 1

type pictures of galaxies, with bodies pulling others along (as in Figure 1, on page 1). This star-soup appearance suggests approximating actual *N*-body systems with a continuum where, if $M(r)$ is the galaxy's mass up to a star at distance *r* (from the galaxy's center) and *v* is its rotational velocity [2], then

$$M(r)=\frac{rv^2}{G}. \qquad (2)$$

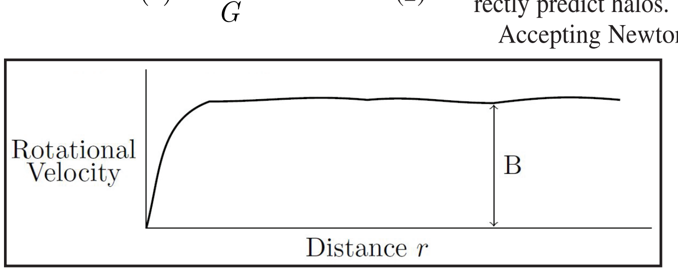


Figure 2. *Spiral galaxy's rotational velocity curve (RVC). Image credit: Donald G. Saari.*

The $M(r)$ values depend on *v*, the rotational velocity of a star at distance *r*. Here, Vera Rubin's stunning contributions [4] become relevant. Contrary to expectations, she showed that the rotational velocity curve (RVC) of spiral galaxies behaves as in Figure 2; it increases almost *linearly* near the galactic center to essentially flatten out with $v \approx B$.

Substituting $v \approx B$ into (2) predicts that

$$M(r)\approx Dr,\quad m(r)=M'(r)\approx D,\quad \text{where } D=\frac{B^2}{G}, \qquad (3)$$

which significantly exceeds in mass every entity known to exist! Where is the mass? If (2) is correct, and the known $M(r)$ is significantly smaller than in (3), one of the following must be true: (**1**) The galaxy is dissipating (contrary to observations), (**2**) Newton's laws are incorrect, or (**3**) Massive amounts of unobserved matter exist. The first two options are not palatable, which leaves the third and a search for dark matter – the difference between mathematical predictions and the known mass. The discrepancy is substantial for large *r* values, which explains the conjectured halos surrounding galaxies.

Dynamics

Everything depends on whether (2) holds for Newtonian systems of *N* discrete bodies (e.g., stars, planets, etc.). It does not! The fact that (2) is identical to the two-body equation (1) offers a clue. Independent of its derivation, the two-body equation (2) approximation is inappropriate for galaxies as it contradicts those pictures of stars pulling other stars along – a dynamic not admitted by (2). But Newton's equations require strong near-body interactions where faster-moving stars (e.g., body 1 in Figure 3) drag along slower ones (body 2, which then drags body 3, etc.), as in pictures of galaxies. So, a star's Newtonian rotational velocity is the $M(r)$ gravitational effect *plus* dragging terms; these larger *v* values exaggerate $M(r)$ values of (2). As dragging is more pronounced at larger distances, expect this error to incorrectly predict halos.

Accepting Newton's equations requires accepting that (2) exaggerates $M(r)$ values. But are the incorrect values "close enough" for practical purposes? To explore this concern, I applied (2) to analytic billion-body solutions [6] with properties similar to those motivating (2). My solutions with $m(r) \le \frac{1}{r}$ have $M(r) \le \ln(r)$. But the values of (2) *exceed* $M(r) \approx Dr$ (see (3)), proving that (2) can yield exponentially exaggerated predictions! No solution has halos, yet (2) incorrectly predicts massive ones! These egregious errors manifest differences between systems of discrete bodies and approximations; actual systems involve dragging effects, while continuum approximations ignore this crucial dynamic.

Angular Momentum

To exploit Rubin's seminal contributions, the rotational velocities suggest using the system's angular momentum $\sum_{j=1}^{N} m_j \mathbf{r}_j \times \mathbf{v}_j = \mathbf{c}$ (**c** is a constant of integration). In the simpler coplanar setting (for exposition), this is

$$\sum_{j=1}^{N} m_j r_j v_j = c, \qquad (4)$$

where r_j is the $\mathbf{r}_j$ length and, here, v_j is the rotational velocity.

There exists $S(t)$ [5] where the j^{th} body's contribution to the angular momentum about the axis of rotation is Sr_j; i.e., $c=\sum m_j r_j (Sr_j)$. Should each body's rotational velocity be Sr_j, these rotational terms would represent a rigid body rotation, which does not happen. Instead, a star's rotation relative to the system is $\omega_j = v_j - Sr_j$.

To depict ω_j, start with the angular momentum line (AML) $y = Sr$, which identifies a body's contribution to the system's angular momentum (see Figure 4). In Figure 4, ω_j is the vertical difference between the RVC and the AML. If $\omega_j > 0$ (the RVC is above the AML), the star is a "leader" and rotates faster than the system. If $\omega_j < 0$, (the RVC is below the AML), the star is a "laggard" and falls behind the system's rotation. These differences are related with the following interesting equality (substitute $v_j = Sr_j + \omega_j$ into (4)):

$$\sum_{\text{Leader}} m_j r_j \omega_j = \sum_{\text{Laggard}} m_j r_j\,|\omega_j|. \qquad (5)$$

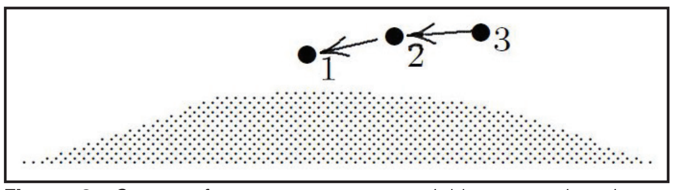


Figure 3. *Center of mass versus near-neighbor attraction. Image credit: Donald G. Saari.*

As ω_j values define AML-RVC differences, $W=\sum m_j \omega_j^2$ measures the AML positioning. If, for instance, $W=0$, then $\omega_j = 0$ forces the RVC to lie on the AML. Similarly, small *W* values require the RVC to be "close" to the AML. Estimates on *W* values involve standard galactic stability assumptions: the galaxy's moments of inertia and kinetic energy are nearly constant. With two-body systems, these conditions require that the velocity emphasize rotations. The same conclusion [5, 7] holds for *N*-body systems; they require a small *W* value, forcing the RVC to be close (defined by *W*) to the AML.

And so, with small $m_j \omega_j^2$ values, large masses must have small ω_j values, forcing the RVC to approach the AML. This is precisely what we observe! Near the galactic center with its heavier masses, the RVC is nearly a straight line (see Figure 2). So, dynamics explain this initial, linear growth where the RVC hugs the AML (see Figure 4).

For large distances, Figure 4 requires $\omega_j \approx Sr$; i.e., $m_j \omega_j^2$ nearly equals $S^2 m_j r^2$. Thus, small $m_j \omega_j^2$ values require $m(r) \le A/r^2$, which is compatible with known mass levels but significantly contradicts $m(r) \approx D$ assertions in (3) and the existence of massive halos. Indeed, $m(r) \approx D$, and small *W* values require $\omega_j \le \frac{A}{r}$, so the RVC approaches the linear AML, contradicting observations. Similarly with (5), as the large laggard region distances have $|\omega_j|$ values asymptotically approaching Sr_j, the summation eventually has $\sum_{\text{Laggard}} m_j r_j^2$ sizes; (5) indicates that $m(r) \le A / r^2$.

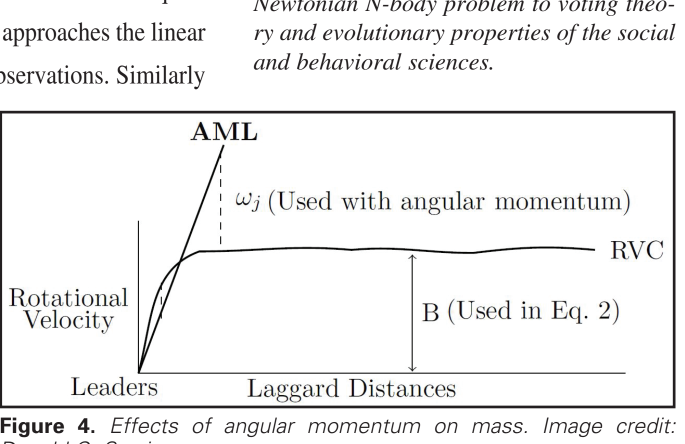


Figure 4. *Effects of angular momentum on mass. Image credit: Donald G. Saari.*

Thus, Newtonian dynamics dismiss (2) and (3). One reason for this is that two-body approximations of Newtonian systems in (2) use the RVC *height* (see Figure 4). The variable for actual Newtonian *systems* is the RVC-AML *difference*; for example, analysis of *N*-body systems differs significantly from that of its parts or approximations in (2). This casts doubt about a standard argument claiming massive amounts of dark matter.

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Donald G. Saari is a distinguished professor and director of the Institute for Mathematical Behavioral Sciences at the University of California, Irvine. His research interests range from the Newtonian N-body problem to voting theory and evolutionary properties of the social and behavioral sciences.

Heart Simulation

Continued from page 1

comere, and continuum). In the FEM analysis, the second Piola-Kirchhoff stress tensor represents the stress under contractile tension T_f:

$$S_{act} = \frac{T_f}{\lambda} \boldsymbol{f} \otimes \boldsymbol{f} = \sum_{i,j} \frac{T_f}{\lambda} f_i f_j \boldsymbol{e}_i \otimes \boldsymbol{e}_j, \tag{1}$$

where the unit vector $\boldsymbol{f} = \sum_{i=1}^{3} f_i \boldsymbol{e}_i$ denotes the fiber orientation at the material point $\boldsymbol{X}$, and λ denotes the stretch along the fiber orientation $\boldsymbol{f}$, given by

$$\lambda = \left\| \frac{\partial \boldsymbol{x}}{\partial \boldsymbol{X}} \boldsymbol{f} \right\| = \sqrt{\sum_{i,j,k=1}^{3} \frac{\partial x_k}{\partial X_i} \frac{\partial x_k}{\partial X_j} f_i f_j}.$$

The insertion of λ into the denominator of (1) is justified by the infinitesimal relationship $T_f \delta\lambda = \boldsymbol{S}_{act} \cdot \delta \boldsymbol{E}$, where $\boldsymbol{E}$ is the strain is a function of the initial strain at the attachment (x_{init}) under the thermal fluctuation, the power stroke from the latest attachment from t_A to $T + k\Delta t ({}^{T+k\Delta t}x_{PS})$, and the length change due to the filament sliding:

$$\begin{aligned} {}^{T+k\Delta t}x\left(im, is\right) &= x_{init} + {}^{T+k\Delta t}x_{PS} \\ &+ \frac{SL_0}{2} \left\{ \int_{\min\left(t_A, T\right)}^{T} {}^{t}\dot{\lambda}\, dt + {}^{T+\Delta T}\dot{\lambda} \right. \\ &\left. \times \left(T + k\Delta t - \max\left(t_A, T\right)\right)\right\}. \end{aligned} \tag{2}$$

Here, $SL_0 / 2$ is the unloaded half-sarcomere length that relates the muscle stretch rate along the fiber orientation $(\dot{\lambda})$ to the shortening velocity of the sarcomere $(-SL_0\dot{\lambda} / 2)$.

The working stroke size s increments x_{PS} during the forward transition from the pre-power stroke to the post-stroke state, and decrements x_{PS} in the reversal stroke from the post-stroke to the pre-stroke state. The rate constants of the forward (f) and backward (b) transi-

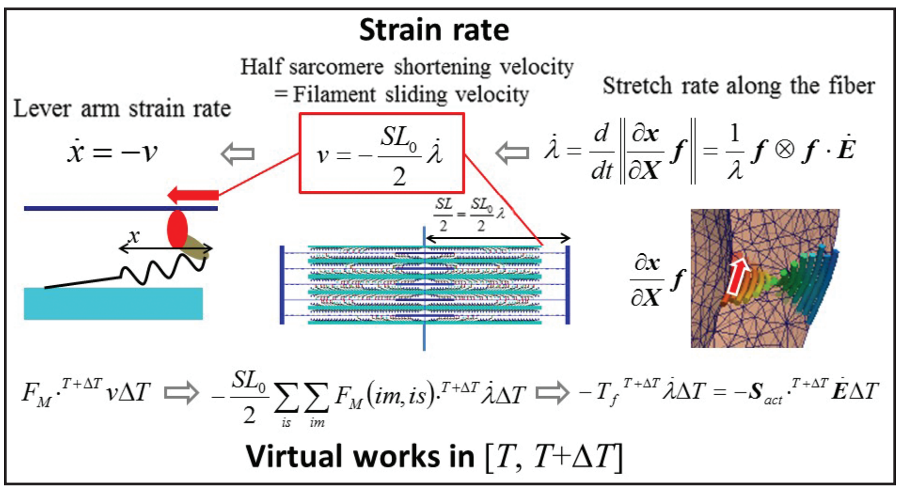

Figure 2. *Strain rates in the model (top) and the virtual works (bottom) on the three scales: the actomoysin complex, the sarcomere, and the continuum. Figure credit: Takumi Washio.*

Green-Lagrange strain tensor. The contractile tension T_f is computed by summing up the molecular forces produced by the actomyosin complexes and arranged along the actin filaments in the sarcomere model:

$$T_f = \frac{R_S}{SA_0} \frac{2}{ns} \sum_{is=1}^{ns} \sum_{im=1}^{nm} F_M(im, is).$$

Here, $SA_0 \left(= 1000\,\mathrm{nm}^2\right)$ is the cross-sectional area of a single actin filament; R_S denotes the volume ratio of the sarcomere $(= 0.5)$; $nm (= 38)$ is the number of myosin molecules surrounding the binding sites, arranged along one of the two spirals in the actin filament; and ns is the number of actin filament samples in the sarcomere model. The force generated by an individual myosin molecule is given by

$$\begin{aligned} F_M\left(im, is\right) &= \frac{\Delta t}{\Delta T} \\ &\times \sum_{k=1}^{nt} \delta_{A,k}\left(im, is\right) k_M {}^{T+k\Delta t}x\left(im, is\right), \end{aligned}$$

where the FEM time step interval $\left[T, T+\Delta T\right]$ is subdivided into nt MC time steps. $\delta_{A,k}$ takes 1 in the attached case and 0 in the detached case for $k = 1, \cdots, nt$, while k_M denotes the spring constant of the myosin lever arm and ${}^{T+k\Delta t}x$ is the strain of the myosin lever arm at time $T + k\Delta t$. This

tions between the pre and post-stroke states are determined as follows, with the relationship given by the statistical equilibrium:

$$\frac{f\left(x\right)}{b\left(x\right)} = \exp \times \left(- \frac{E_{Post} - E_{Pre} + k_M\left(\left(x+s\right)^2 - x^2\right)/2}{kT} \right), \tag{3}$$

where k and T denote the Boltzmann constant and the temperature respectively, and E_{Pre} and E_{Post} are the free energies of the myosin head in the respective pre and post-stroke states. The difference $E_{Post} - E_{Pre}$ corresponds to the partial transfer of the chemical energy obtained by ATP hydrolysis to the mechanical stress energy generated by the strain increment s. At the current FEM step in $\left[T, T+\Delta T\right]$, the filament sliding contribution (third term on the right-hand side of (2)) is computed by implicitly assuming the stretch rate $\dot{\lambda}$ at $T + \Delta T$. Through this implicit scheme, we can correctly incorporate the temporal stiffness into the Jacobian matrix and stabilize the Newton-Raphson (NR) iteration in the FEM analysis within a reasonable time step ΔT. Note that the NR steps iteratively reuse the computational results obtained in the

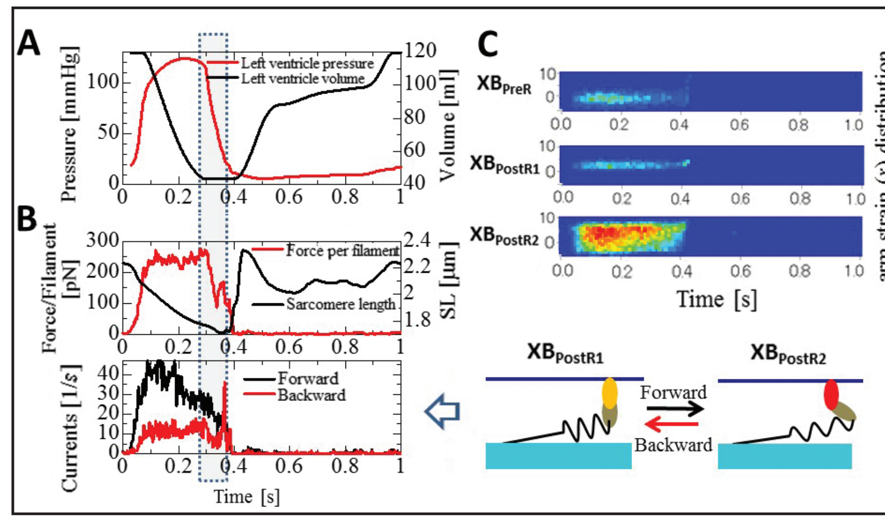

Figure 3. *Simulation results of a beating heart.* **3a.** *Time transients of the left ventricular pressure and volume.* **3b.** *Sarcomere force and length, and the currents of the forward and backward transitions.* **3c.** *Stain distributions in the lever arms of the sarcomere model embedded in the inner layer. Figure credit: Takumi Washio.*

MC steps, in which $\dot{\lambda}$ at T, not at $T + \Delta T$, is referred to compute the strain x of (2).

Beating Heart Simulation Results

Figure 3b shows the behavior of the sarcomere model embedded in the inner layer of the left ventricular free wall. At the end-systolic phase, or end of contraction (range surrounded by the broken lines in Figures 3a and 3b), the relative current of the backward to forward transitions increases as the sarcomere shortening decelerates and the sarcomere contraction finally ends. A quick stretch immediately follows the increased frequency of backward transitions. In cooperation with neighboring myosin molecules, these backward transitions swiftly reduce the blood pressure (see Figure 3a, red line), facilitating the quick filling of blood into the left ventricle (see Figure 3a, black line). Figure 3c presents the contours of the arm strain distribution. In the post-stroke state $(\mathrm{XB_{PostR2}})$, the center of the distribution shifts to larger strains towards the end-systolic phase. Such a distribution shift has a major impact on balancing the frequencies of the forward and backward transitions determined by (3).

We are currently developing more detailed molecular models under the post-K supercomputer project.[1] This study will provide insights into the molecular-level mechanisms that control the state transitions, which are necessary for linking various mutants of contractile proteins with heart failures.

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Takumi Washio has worked at the Computational Biomechanics Laboratory School of Frontier Sciences at the University of Tokyo since 2004. He has engaged in development of the multiscale and multi-physics heart simulator. In 2015, his group started a company, UT-Heart Inc., to contribute to medical and clinical communities by applying their heart simulator.

[1] This work is supported in part by MEXT as Strategic Programs for Innovative Research Field 1 Supercomputational Life Science and a social and scientific priority issue (integrated computational life science to support personalized and preventive medicine), to be tackled using a post-K computer.

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Preparing Graduates for Careers in the Mathematical Sciences

NSF Programs Offer Unique Real-World Experience

By Sue Minkoff, William Menasco, Fadil Santosa, Stephen Pankavich, and Richard Laugesen

The National Science Foundation's Enriched Doctoral Training Program (EDT) endeavors to broaden career prospects for Ph.D. graduates in the mathematical sciences. The EDT projects are meant to foster collaboration between academia and business, industry, government, or non-profit spheres, thus preparing student participants to enter the workplace. In the November issue of *SIAM News*, the authors detailed the 2015 EDT projects at the University of Texas at Dallas and Princeton University. Here, they describe both the 2016 projects and a precursor award funded in 2014.

EDT: Experiential Diversity in Graduate Education

The State University of New York at Buffalo. Principal Investigator: William Menasco. Co-Principal Investigators: Bernard Badzioch, David Hemmer, Joseph Hundley, and John Ringland.

The State University of New York at Buffalo (SUNY at Buffalo) Department of Mathematics' project is entitled "Experiential Diversity in Graduate Education" (EDGE@UB). Led by William Menasco, a mathematics professor and director of graduate studies, the initiative is a collaboration between industry and academic partners. Mathematics doctoral students in EDGE@UB participate in a yearlong training program that culminates in a summer internship where students work on site with the industry partners. The EDT grant is expected to fund half a dozen students each year in two cohorts. The grant funds the training, release time from the students' spring teaching assistant duties, and the internship itself. Students are interviewed for participation in the project and paired with industry partners in the fall. During the winter session, the interns will participate in a math boot camp that introduces them to the specific mathematical tools they will implement throughout the summer months. In the spring, the students (and their faculty mentors) will use the time they would have otherwise spent as teaching assistants to begin site visits with the industry partners. And the students become full-time interns at the external partner organizations during the summer.

CAREERS IN MATHEMATICAL SCIENCES

In addition to the student benefits, there are several possible perks for faculty. For instance, faculty mentors can develop a better understanding of the mathematics used in industry, gain exposure to new research problems that may impact their own work, and learn about industrial culture and possible career trajectories for mathematics students outside of academia. Each industry partner has a specific proposed problem suitable for EDGE@UB students. The partners and tentative problems are as follows: **(1)** IBM Buffalo Innovation Center: training of Watson; **(2)** M&T Bank: understanding behavior of homeowners with home equity lines of credit; **(3)** MOOG: improving understanding of the mathematics governing the mechanics of ball screws; **(4)** SecureRF Corporation: testing security protocols based on braid groups and finite fields; and **(5)** SUNY at Buffalo's School of Management: understanding the relationship between stochastic optimization and network outages.

EDT: Math-to-Industry Boot Camp

University of Minnesota Twin Cities. Principal Investigator: Fadil Santosa. Co-Principal Investigators: Daniel Spirn and Carlos Tolmasky.

The Institute for Mathematics and its Applications (IMA) ran its first Math-to-Industry Boot Camp in June-July 2016. The boot camp is designed to enhance the training of mathematics doctoral students by providing them with skills and experiences that are valuable when seeking positions in industry and business. Over 120 students from across the country applied, 32 of whom were selected.

The six-week camp started with the basics of programming and utilized MATLAB, Java, and C. The second week focused on data analysis, basic statistics, and machine learning, while the third week introduced mathematical modeling, both probabilistic and deterministic. In addition to the lectures given during the first three weeks, students had hands-on sessions with COMSOL (a multi-physics solver) and the statistical package R, and worked in small groups on instructor-provided problems. During training, students acquired soft skills in teamwork, project management, meeting organization, and effective presentation techniques. They also participated in a session on resume preparation and the use of LinkedIn. In addition, mathematicians from local industries were invited to talk to students about their career trajectories, followed by Q&A sessions with the students.

During the last three weeks, students worked in teams on two projects. The first set of projects were open-ended, with the goal of having students produce a non-mathematical report and present to a group of hypothetical engineers. Industry practitioners posed the second set of projects, and each team had 10 days to determine the best possible solution and present their results. The proposers were available throughout the period as mentors, and students utilized many of the tools introduced at the beginning of camp while searching for solutions. Though the projects came from different sectors of industry, many involved data analytics. Former IMA postdoctoral fellows proposed two projects in particular:

(1) Dr. Marina Brockway, co-founder of VivaQuant, a start-up based in Minneapolis, MN, asked her team to develop algorithms that detect anomalies in electrocardiograms.

(2) Dr. Jesse Berwald, a data scientist at Target Corporation, proposed a project involving the unique identification of individuals based on various digital footprints.

See **Preparing Graduates** *on page 7*

Computational Science

Continued from page 3

many more areas of technical, economic, societal, and political decision processes.

A new report, titled *Research and Education in Computational Science and Engineering* [1], analyzes the current status of CSE and the aforementioned new developments. The report, available in preprint form and on the SIAG/CSE wiki page,[1] summarizes the status of CSE as an emerging discipline and presents the field's trends and challenges in research and education for the next decade. The report is based on the outcomes of a 2014 workshop sponsored by SIAM and the European Exascale Software Initiative, a minisymposium and a panel discussion held during the 2015 SIAM Conference on CSE, as well as feedback from the CSE community collected over the past two years. Despite CSE's fundamental importance, the report finds that many current institutional structures do not adequately reflect the needs of the discipline. Examples of barriers preventing CSE advancement include a dearth of appropriate interdisciplinary structures at universities and funding institutions, lack of recognition for the important role of scientific software, and institutional challenges in creating suitable educational programs. The new report elaborates on these arguments in detail and reveals the following central findings:

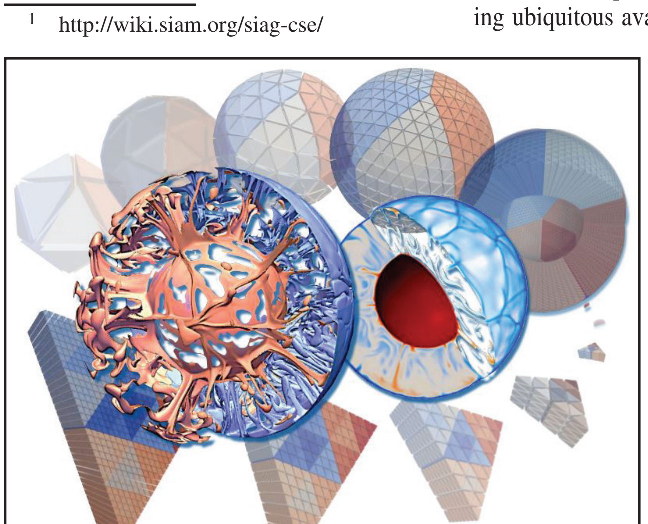
1. CSE has matured to a discipline in its own right.

2. Computational algorithms lie at the core of CSE progress, and scientific software, which codifies and organizes algorithmic models of reality, is the primary means of encapsulating CSE research to enable advances in scientific and engineering understanding.

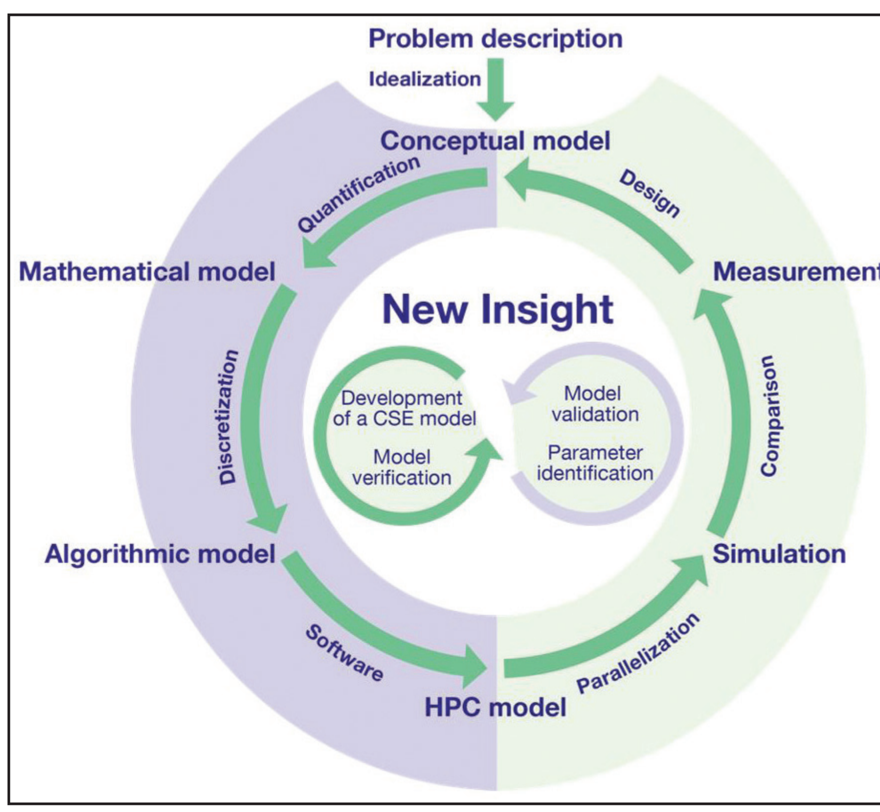
3. CSE methods and techniques are essential to capitalize on the rapidly-growing ubiquitous availability of scientific and technological data.

The report also highlights a number of specific CSE "success stories" – application examples in which CSE research is significantly impacting the real world. These accounts emphasize both the long-term payoff of investment in fundamental CSE research and the criticality of sustaining that investment to leverage current and future opportunities—as articulated in the report's recommendations—for CSE research and education over the next decade.

[1] http://wiki.siam.org/siag-cse/



This image, featured on the cover of the 2016 Research and Education in Computational Science and Engineering report, illustrates Earth mantle convection, the planet-wide creeping flow of the Earth's mantle on time scales of millions of years. The computational mesh is generated from an icosahedron that is hierarchically refined 12 times to reach a global resolution of one km, resulting in a finite-element mesh with more than one trillion (10^{12}) degrees of freedom. Petascale class machines and highly efficient, parallel multigrid methods are required to solve the resulting equations in a timestepping procedure. The image first appeared in the 2014 DFG mathematics calendar and is an outcome of the DFG project TerraNeo (led by Hans-Peter Bunge, Ulrich Rüde, and Barbara Wohlmuth) in the Priority Programme 1648 Software for Exascale Computing.



The CSE pipeline, from physical problem to model and algorithms to efficient implementation in simulation software, with verification and validation driven by data. The pipeline is actually a loop that requires multiple feedbacks. Image credit: [1]

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Ulrich Rüde heads the chair for simulation at the University of Erlangen-Nürnberg and is leader of the Parallel Algorithms Project at the Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS) in Toulouse. He served as editor-in-chief of the SIAM Journal on Scientific Computing from 2005-2010, and is a SIAM Fellow. Karen Willcox is a professor of aeronautics and astronautics and co-director of the Center for Computational Engineering at the Massachusetts Institute of Technology. Lois Curfman McInnes is a senior computational scientist in the Mathematics and Computer Science Division of Argonne National Laboratory. She co-chaired the 2015 SIAM Conference on CSE and is serving as chair of SIAG/CSE from 2015-16. Hans De Sterck is a professor of computational and applied mathematics in the School of Mathematical Sciences at Monash University in Melbourne, Australia. He co-chaired the 2015 SIAM Conference on CSE and currently serves as a section editor for the SIAM Journal on Scientific Computing.

Collectively, the authors served as the 2013-2014 officers of SIAG/CSE.

Applied Mathematics and Political Crises

BOOK REVIEW

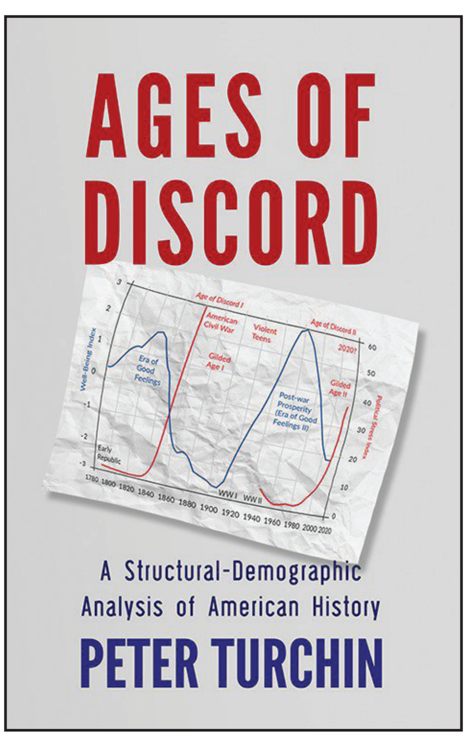
By Richard H. Burkhart

Ages of Discord: A Structural-Demographic Analysis of American History. *By Peter Turchin. Beresta Books, Chaplin, CT, September 2016. 274 pages, $35.00.*

Lately, U.S. politics seems to be coming apart at the seams. Why is this happening? And can anything as abstract as mathematics be at all useful for understanding something as messy as politics gone off the rails? Especially when there is not much history of mathematical prowess from professional historians?

Peter Turchin, an exemplary interdisciplinary professor and scholar, has set out to remedy this scarcity of mathematical history using classic applied mathematics and solid historical data, and none too soon. His latest book, *Ages of Discord: A Structural-Demographic Analysis of American History*, is a warning shot across the bow of the U.S. ship of state – that dangerous shoals and storms lie dead ahead, with huge swells already rocking the boat. Turchin's "Political Stress Index" has been growing exponentially, so much so that he likens our current situation to that of the U.S. just before the Civil War, or to France prior to the French Revolution.

Turchin is a founder of what he calls "cliodynamics," or the application of mathematical modeling, especially dynamical systems, to the study of history (Clio is the Greek muse of history). To this he brings a strong background in population biology, as well as historical studies and anthropology. I highly recommend his classic work of popular history, *War and Peace and War: The Rise and Fall of Empires* (2006). This book is based on his more technical *Historical Dynamics: Why States Rise and Fall* (2003), which discusses the strengths and limitations of a variety of mathematical models as they apply to specific historical periods. These periods are drawn from the Roman Empire, Chinese dynasties, and European history, concentrating on agrarian empires and regimes prior to 1900.



Ages of Discord: A Structural-Demographic Analysis of American History. By Peter Turchin. Courtesy of Beresta Books.

Turchin's newest book adapts and updates these earlier studies, applying them to the history of the U.S. from the Revolutionary War to the present. The cover of the book shows a wonderful chart, with a blue curve displaying the rise and fall of two narrow "Eras of Good Feelings" (1810-1840 and 1940-1970), alternating with a red curve for his Political Stress Index, which rises exponentially as consensus politics gives way to escalating inequality.

Turchin identifies three factors, the key functions of his "structural-demographic theory," which often lead to civil war or state collapse. The first and foremost is competition and conflict among a rising population of elites, the second is a declining real wage for an expanding population of workers, and the third, though less prevalent, is state financial collapse. We can view these factors as an empirically-verified version of Thomas Robert Malthus' classical population theory, but one that identifies vital feedback loops that produce approximate cycles of rise and fall over a century or two, rather than a more or less permanent Malthusian nightmare of poverty for the masses. The Political Stress Index is simply the product of these three factors, which Turchin calls "Elite Mobilization Potential," "Mass Mobilization Potential," and "State Fiscal Distress."

Turchin's elite population equation is given by a standard first order differential equation (think exponential growth), except that there is an added term involving the wage rate, a term which will send the elite rate of growth into negative territory after a time delay and sufficient fall in the wage rate. The wage rate depends primarily on the gross domestic product (GDP) per capita (a measure of productivity) and the historical supply/demand ratio for labor, and uses a nonlinear product and power formula. Turchin is very careful to explain the equations in detail and to minimize the number of parameters. He starts with simplified equations and concepts before moving into the complexities required to match the historical data. The result is some of the best popular exposition of applied mathematics that I have ever encountered.

Turchin is equally good at the "human interest" level, describing all the historical datasets he was able to locate. These datasets include not just population statistics, GDP, average wages, and national debt, but everything from a surprising history of legal salaries to average male heights, labor battles, Senate filibusters, largest fortunes, immigration expansion and contraction, age at first marriage, and much more. In every case, he seeks multiple datasets to estimate each independent variable or parameter.

Though remarkably successful at illuminating societal discord, Turchin's analysis obscures the underlying drivers of economic growth or contraction that derive from technologies, resources, and ecosystems. Our new technologies for exploiting fossil fuels have propelled the spectacular growth of the last two centuries compared to the modest growth of land-based empires, thus exposing us to the possibility of greater economic and political collapse. Already returns to investment in fossil fuels are falling while the costs of climate change and other environmental damage are rising, threatening economic contraction ahead and accelerating the factors of discord that Turchin identifies.

Ironically, a successful mathematical analysis that includes such broader variables has been around for over 40 years; namely, the famous *Limits to Growth* scenarios of the early 1970s by Dennis Meadows, Donella Meadows, Jørgen Randers, and William Behrens III. At that time, the mathematical technique was called "system dynamics" ("nonlinear dynamical systems" in today's lingo), and was well beyond the comprehension of economists, let alone historians. It uses five major variables—population, food supply, resources, industrial output,

See **Political Crises** *on page 7*

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FALL 2017 SEMESTER WORKSHOPS

These workshops are affiliated with ICERM's Fall 2017 semester program *Mathematical and Computational Challenges in Radar and Seismic Reconstruction* running September 6 through December 8, 2017.

SEPTEMBER 25 – 29, 2017
Waves and Imaging in Random Media
Wave propagation and imaging in complex media is an interdisciplinary area in applied mathematics, with roots in hyperbolic partial differential equations, probability theory, statistics, optimization, and numerical analysis. It has a wide range of applications, including not only radar and seismic reconstruction but also many others, such as laser beam propagation through clouds, light propagation through the atmosphere in astronomy, secure communications in scattering media, medical imaging, and nondestructive testing of materials. ***Organizers***: *J. Garnier, University Paris Diderot; K. Ren, University of Texas - Austin; C. Tsogka, University of Crete.*

OCTOBER 16 – 20, 2017
Mathematical and Computational Aspects of Radar Imaging
This workshop will bring together mathematicians and radar practitioners to address a variety of issues at the forefront of mathematical and computational research in radar imaging. Some of the topics planned include shadow analysis and exploitation, interferometry, polarimetry, micro-Doppler analysis, through-the-wall imaging, noise radar, compressive sensing, inverse synthetic-aperture radar, moving target identification, quantum radar, multi-sensor radar systems, waveform design, synthetic-aperture radiometry, passive sensing, tracking, automatic target recognition, over-the-horizon radar, ground-penetrating radar, and Fourier integral operators in radar imaging. ***Organizers***: *M. Cheney, Colorado State University; A. Doerry, Sandia National Laboratories; E. Mokole, U.S. Naval Research Laboratory (Ret); F. Robey, MIT Lincoln Laboratory.*

NOVEMBER 6 – 10, 2017
Recent Advances in Seismic Modeling and Inversion: From Analysis to Applications
This workshop will bring together academic and industrial researchers with the goal of addressing some of the key challenges in the analysis of seismic inverse problems, with emphases on reconstruction, big data and fast algorithms. We aim to facilitate interactions among scientists addressing all aspects of this problem, from analysts addressing such questions as stability and uniqueness through geophysicists developing new acquisition systems and applying cutting-edge ideas to field data sets. The workshop will place particular emphasis on fast algorithms that address the unique big data requirements of seismic imaging from the reservoir to whole-Earth scale. ***Organizers***: *Vladimir Druskin, Schlumberger Doll Research; Maarten de Hoop, Rice University; Alison Malcolm, Memorial University of Newfoundland; Alexander Mamanov, University of Houston; Lexing Ying, Stanford University.*

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Preparing Graduates

Continued from page 5

More information about these and the other projects can be found on the IMA site.[1]

EDT: Front Range Applied Mathematics Exchanges and Workshops

Colorado School of Mines and the University of Wyoming. Principal Investigators: Stephen Pankavich and Gregory Lyng. Co-Principal Investigators: Barbara Moskal and Myron Allen.

The Front Range Applied Mathematics Exchanges and WORKshops (FRAMEWORK) program is a collaborative project between the Department of Mathematics at the University of Wyoming (UW) and the Department of Applied Mathematics and Statistics at the Colorado School of Mines (CSM). It is designed to broaden and enhance the training of doctoral candidates in the mathematical sciences by providing students with skills and experiences that are crucial for obtaining positions within business, industrial, and national laboratory settings. In order to achieve these goals, the project focuses on four key elements. First, students will participate in summer internships at national research institutions, including Los Alamos National Laboratory, Sandia National Laboratories, the United States Geological Survey, the National Renewable Energy Laboratory, and the National Center for Atmospheric Research, as well as at industrial partners such as Neptune and Company, the Western Research Institute, and the numerous technology companies located at the Wyoming Technology Business Center. These internships will introduce current Ph.D. students to real-world applications and cultivate awareness of the communication, budgeting, and project management skills necessary within professional settings. Secondly, the project will feature annual end-of-summer workshops to enhance incoming Ph.D. students' success in the first-year curriculum and showcase the previous cohort's internship experiences. To further integrate and advance student development, UW and CSM have begun an innovative course-sharing program; by sharing delivery of required first-year graduate courses, the two departments will increase their capacity to offer advanced topics courses for Ph.D. candidates and support the preparation of interns. Finally, the two institutions plan to target the recruitment of baccalaureate students at nondoctoral institutions and those supporting historically underrepresented groups along the Colorado Front Range in order to enhance the diversity of the Ph.D. pipeline within the region.

MCTP: PI4: Program for Interdisciplinary and Industrial Internships at Illinois

University of Illinois at Urbana-Champaign. Principal Investigator: Yuliy Baryshnikov. Co-Principal Investigators: Lee DeVille and Richard Laugesen.

Funded in 2014, the Mentoring Through Critical Transition Points in the Mathematical Sciences (MCTP) Program predates the EDT Program but provides similar training to students and postdoctoral researchers in the mathematical sciences.

Students working on team-building exercises during the Institute for Mathematics and its Applications Math-to-Industry Boot Camp. Photo credit: Rebecca Malkovic.

The employment bottleneck is particularly severe in academic mathematics, while at the same time scientific and engineering fields increasingly need researchers with strong mathematical and quantitative backgrounds. These trends create an opportunity for the development of truly interdisciplinary mathematicians – those who obtain Ph.D.s in core mathematical fields, but whose careers take place outside of an academic mathematics department. The Program for Interdisciplinary and Industrial Internships at the University of Illinois at Urbana-Champaign,[2] supported by the NSF's MCTP award, responds to this opportunity by connecting Ph.D. students from all areas of mathematics with internships in scientific labs, government labs, and industrial research groups. Program components include academic-year topics courses (e.g., "Top Ten Algorithms"); a Computational Mathematics Bootcamp to begin the summer; working groups for beginning students on exploratory topics, such as "topologically constrained problems of statistical physics;" and summer internship placements for 10-12 Ph.D. students. Past projects have included a logic student analyzing patterns in functional MRI data, a number theorist modeling ant colonies, a differential equations student working in agricultural data analytics, and a topologist developing tools for augmented reality and virtual meetings. The funding from NSF has successfully catalyzed relationships with companies and government labs, and the internship program will continue to thrive beyond the grant-funded period.

A fourth-year Ph.D. student at the Colorado School of Mines presents a seminar about her summer internship research at Los Alamos National Laboratory to incoming Ph.D. students. Photo credit: Stephen Pankavich.

Sue Minkoff is a professor in the Department of Mathematical Sciences and an affiliated professor in the Departments of Geosciences and Science/Mathematics Education at the University of Texas at Dallas. She started the Careers in Mathematical Sciences Column for SIAM News in 2010. This article (her 24th column), marks the end of her time as column editor. William Menasco (menasco@buffalo.edu) is a professor of mathematics at The State University of New York at Buffalo. Fadil Santosa is a professor of mathematics at the University of Minnesota and director of the Institute for Mathematics and its Applications. Stephen Pankavich is an assistant professor in the Department of Applied Mathematics and Statistics at the Colorado School of Mines, where he has been instrumental in recruiting and advising new Ph.D. students and increasing the proportion of women and minorities enrolled within the Ph.D. program to over 60% of the graduate population. He has also served as the treasurer for the SIAM Central States Section since 2014. Richard Laugesen has taught at the University of Illinois at Urbana-Champaign since 1997, where his research focuses on partial differential equations and spectral theory. As director of Graduate Studies, he promotes mathematical careers in industry and government and works toward a future in which more women and minority students will pursue graduate-level mathematics.

[1] https://www.ima.umn.edu/2015-2016/SW6.20-7.29.16

[2] https://pi4.math.illinois.edu

Political Crises

Continued from page 6

and pollution—and projects graphs of these variables into the future, based on scenarios for impending parameter values. The "business as usual" scenario (using the best current estimates for the parameters) has held up remarkably well according to a recent study by Graham Turner (Melbourne Sustainable Society Institute, University of Melbourne).[1] I would love to see Turchin's work extended along these lines, or vice versa.

Peter Turchin concludes *Ages of Discord* by asking, "Will we be capable of taking collective action to avoid the worst of the impending structural-demographic crisis?" *Limits to Growth* suggests that the crisis is actually much deeper. Applied mathematicians have much to contribute.

Richard H. Burkhart received his Ph.D. in mathematics at Dartmouth College in 1976. He then taught at the University of North Carolina at Wilmington before moving back to his home territory, Seattle, where he worked for Boeing in scientific and engineering computing and algorithm development for 21 years. He took early retirement to become a full time activist and independent researcher, especially in areas of democracy and economics.

[1] http://sustainable.unimelb.edu.au/sites/default/files/docs/MSSI-ResearchPaper-4_Turner_2014.pdf

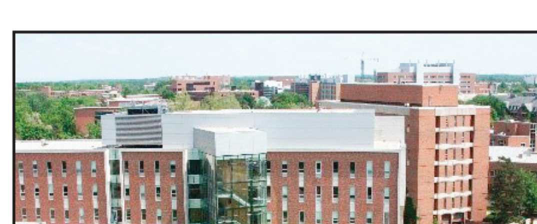
PSM
PROFESSIONAL SCIENCE MASTER'S

Master of Science in Industrial Mathematics (MSIM) at Michigan State University

This is a two-year degree program blossomed since the late 90s. The MSIM students learn not only standard mathematical and statistical tools to strengthen data analytics skills, but also basic concepts of business and engineering with project management and industrial communication skills at workplace. Major successes of the program are strong connections with local companies and excellent graduate placement.

https://math.msu.edu/msim/

- One of the oldest Professional Science Master's (PSM) programs in the United States.
- Continued industrial sponsorship and spring-term industrial projects since late 90s.
- Successfully preparing students for job placements for 17 years.



From Archimedes and Euclid to Hamilton and Poincaré

MATHEMATICAL CURIOSITIES

By Mark Levi

Symplectic maps of $\mathbb{R}^{2n}$ are basic objects of Hamiltonian mechanics, and the time t map of a Hamiltonian system's position-momentum pair is symplectic. Symplectic maps of $\mathbb{R}^2$ are the area-preserving ones.

I recently realized that the Archimedian law of the lever amounts to an area-preservation property of a simple map of $\mathbb{R}^2$, as described next. Afterwards, I will reference an analogy between the Archimedian lever on the one hand and Hamiltonian mechanics on the other.

Figure 1 shows a seesaw in equilibrium, pressed at both ends. Archimedes' law of the lever gives the condition for the equilibrium, $fl = FL$, i.e.,

$$F = \frac{l}{L} f.$$

Furthermore, $S = \frac{L}{l} s$, according to Euclid. To summarize, we have the "Euclid-Archimedes map," $(s,f) \mapsto (S,F)$, given by

$$\begin{cases} S = \lambda s \\ F = \dfrac{1}{\lambda} f, \end{cases} \qquad (1)$$

where $\lambda = L/l$. This map is clearly area-preserving, but for a reason deeper than the explicit form (1). Indeed, let us cyclically move the two fingers in Figure 1 so that the positions and the forces return to their original values. We end up doing zero work:

$$\oint f\,ds + \oint (-F)\,dS = 0. \qquad (2)$$

The minus sign is due to the fact that the right finger presses with force $-F$. During the cyclic motion, the point (s,f) describes a closed curve γ in the plane, while the point $(S,F) = \varphi(s,f)$ describes the image curve $\varphi(\gamma)$. Therefore, the zero-work condition (2) amounts to the equality of areas inside γ and $\varphi(\gamma)$. Incidentally, (2) is a compact way of saying that the lever is not a perpetual motion machine.

If the board can flex, as in Figure 2, then the map $(s,f) \mapsto (S,F)$ is no longer given by (1), but is still area-preserving; the above proof applies without change.

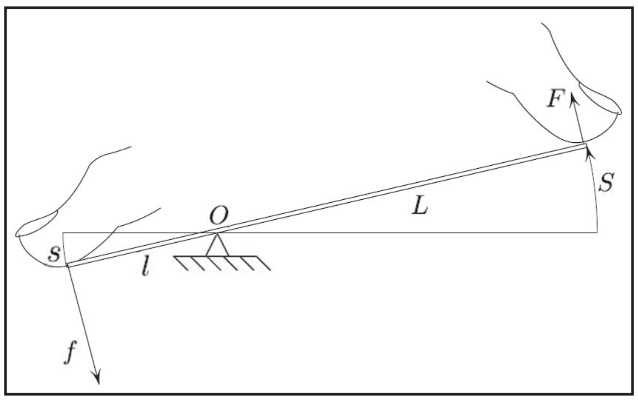


Figure 1. *The left finger pushes with force f; the right finger is being pushed with force F.*

Seesaw and Hamiltonian Dynamics

Remarkably, the Hamiltonian flow is symplectic for the same reason that the "seesaw map" φ is area-preserving.[1] To make sense of the last sentence, I must specify the analogy between the seesaw in Figure 2 on the one hand and a Hamiltonian system on the other. The following explanation outlines this analogy (a full discussion can be found in [1]). Consider a mechanical system with the Lagrangian L, depending on generalized position and velocity. Let us fix two points $(0,q)$ and (T,Q) in time-space and define the action

$$A(q,Q) = \int_0^T L(r(t), \dot{r}(t))\,dt,$$

with the integration occurring over the minimizer $r(t)$ of the integral subject to $r(0) = q$, $r(T) = Q$ (we assume this minimizer is unique and depends smoothly on q, Q). For any (admissible) T, the momenta p, P at times $t = 0$ and $t = T$ are given by

$$P = A_Q(q,Q), \quad p = -A_q(q,Q). \qquad (3)$$

This can be taken as the definition of the momentum, or related (in a one-line calculation) to the more standard definition, as explained on page 261 of [1].

Returning now to the seesaw of Figure 2, let $U(s,S)$ be the potential energy; then

$$F = U_S(s,S), \quad f = -U_s(s,S). \qquad (4)$$

A comparison between (3) and (4) shows that the action and the momenta $(A,\ p,\ P)$ are close analogs of the potential energy and the forces $(U,\ f,\ F)$. The proof of the symplectic character of the time T map $(q,p) \mapsto (Q,P)$ for arbitrary T becomes a verbatim copy of the area preservation's proof of the "seesaw map" $(s,f) \mapsto (S,F)$.

A Paradox

If the spring in Figure 2 dissipates energy under deformations, then (2) becomes

$$\oint f\,ds + \oint (-F)\,dS = W > 0, \qquad (5)$$

where W is the heat dissipated in the spring x; (5) suggests that the area decreased by W. However, the map $\varphi := (s,f) \mapsto (S,F)$ depends only on the static properties of the spring and thus *must* be area-preserving; there is no difference between a dissipating and a non-dissipating spring in a static state. Resolution of this paradox is left as a puzzle for interested readers and may (or may not) be discussed in the next column.

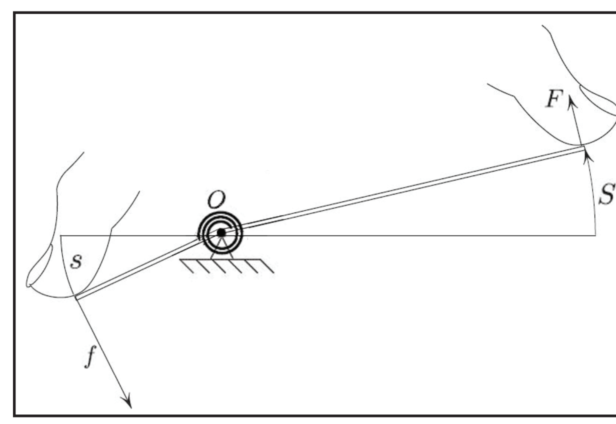


Figure 2. *The hinge at O has a spring trying to keep the board straight.*

All figures are provided by the author.

Acknowledgments: The work from which these columns are drawn is partially supported by NSF grant DMS-9704554.

References

[1] Levi, M. (2014). *Classical Mechanics with Calculus of Variations and Optimal Control: an Intuitive Introduction.* Student Mathematical Library, vol. 69. American Mathematical Society.

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

[1] Or symplectic, if we allow more than one degree of freedom to move the endpoints.

New Developments Regarding SIAM's Prize Program

By James Crowley

SIAM is in the process of standardizing prize nomination procedures. This is motivated by numerous requests from prize selection committees who have had to deal with a bewildering array of submissions. Submitted nominations currently range from two to five nomination letters, which are anywhere between two and 10 pages long, per individual. Committees may be bombarded with 50 emails supporting the nomination of one person, and none for the other nominees. Arguing that the quality of the nomination, rather than the volume of the package, should determine the winner, committee chairs have requested a more standard set of rules.

Additionally, SIAM has seen an increasing number of activity group (SIAG) prizes, which are administered by SIAM staff and thus warrant special software to facilitate the submission and review process. The software is more rigid regarding what it will accept, further necessitating the need to streamline the submission process.

SIAM is currently testing the newly-implemented software system, which was used to manage nominations for a subset of prizes this year. The system will be refined for next year's prize submissions, based on the results.

SIAM thanks everyone who submitted a nomination this year for their time, effort, and patience.

Furthermore, the SIAM Council, which oversees the prize program headed by the Vice President at Large (currently Ilse Ipsen), approved further changes to the program. These changes will go into effect on January 1, 2017.

SIAM has also moved away from prize selection committees deliberating at the table and simply picking a prize winner, for good reason. While this practice was not uncommon many years ago, it has been discouraged in recent years to ensure a fair system that avoids an "old boy's network," if you will, or an exclusive clique choosing from a narrow group of individuals. The system hence evolved into a process that considers only formal nominations that conform to the call for nominations.

However, it became clear that the prize selection committee must consider a reasonable number of nominations for such a system to be successful. This realization resulted in the SIAM Council's stipulation of a three-nomination minimum for consideration by the prize committee.

Furthermore, since a lack of nominations indicates insufficient interest in a prize, repeated failure to reach the three-nomination minimum can result in the prize's discontinuation.

Jim Crowley is the executive director of SIAM.

Gene Golub g2s3 2017
SIAM Summer School

May 29-June 9, 2017
Akademie Berlin-Schmöckwitz
Germany

Data Sparse Approximations and Algorithms

The summer school will be held in conjunction with the 2017 SIAM Activity Group in Linear Algebra (SIAG/LA) International Summer School on Numerical Linear Algebra and is intended for Master and PhD students in mathematics and related programs.

The lecturers are

- Bernhard G. Bodmann, University of Houston, USA
- Lars Grasedyck, RWTH Aachen, Germany
- Serge Gratton, CERFACS, France

Application Deadline: February 1, 2017
More information posted at
http://www.siam.org/students/g2s3/

Got a Problem?

SIAM is seeking problem ideas for national high school math modeling competition

In 2016, more than 5,000 high school students in the U.S. participated in and submitted solutions to an open-ended, realistic, math-modeling problem presented to them in the M^3 Challenge, an Internet-based applied math contest that occurs annually in February/March. The contest, which is organized by SIAM, poses a problem that students, working independently in teams of 3–5, must solve in just 14 hours.

Over the years, students have tackled timely issues such as making school lunches healthy, implementing recycling guidelines, persistent drought, the census, the stimulus package and job creation, energy independence, Social Security solvency, and choosing stocks for maximum gain. Coming up with great problem ideas year after year is not easy, and that's where we're hoping you can help.

Required problem characteristics

- Be accessible to 11th and 12th graders
- Be suitable for solution in 14 hours
- Provide the possibility for significant mathematical modeling
- Be of current interest and involve interdisciplinary problem solving and critical thinking skills
- Have enough data available for a variety of approaches and depth of solutions
- Be broken into a few parts with some parts easier than others so that all teams can make some progress
- Identify references to help students get started

Format your problem statement idea like previous Challenge problems, which can be found at *m3challenge.siam.org/resources/sample-problems*.

Problem structure

Within the problem statement, there should be three questions for teams to answer:

- Question One: The warm up — Every serious team can answer.
- Question Two: The guts — Framed so that every team can have some success and many teams can cover it well.
- Question Three: The discriminator — Many teams can do something, while only a few will have exceptional results.

We are open to any topic!

Of particular interest are problems based on timely, relevant, hot-button issues facing the U.S. and the rest of the world.

- Problems selected to be used as "the" Challenge problem receive a $1,000 honoraria.
- Problems found suitable to add to the M^3 problem reserve bank receive $150; an additional $150 will be paid if it is used as a sample or resource on the Challenge website.

Previous problem titles

2006: Solving the Social Security Stalemate

2007: Beat the Street!

2008: Energy Independence Meets the Law of Unintended Consequences

2009: $787 Billion: Will the Stimulus Act Stimulate the Economy?

2010: Making Sense of the 2010 Census

2011: Colorado River Water: Good to the Last Acre-Foot

2012: All Aboard: Can High Speed Rail Get Back on Track?

2013: Waste Not, Want Not: Putting Recyclables in Their Place

2014: Lunch Crunch: Can Nutritious be Affordable and Delicious?

2015: STEM Sells: What is Higher Education Really Worth?

2016: Share and (Car) Share Alike: Modeling New Approaches to Mobility

See a video that shows ten years of Challenges in five minutes! Go to Youtube and Search on "M3 Challenge 10th Anniversary"

SUBMIT your problem idea at m3challenge.siam.org/challenge/suggest-problems

To submit new ideas or get additional information, contact:

Michelle Montgomery
Project Director, Moody's Mega Math Challenge
SIAM – Society for Industrial and Applied Mathematics
3600 Market Street, 6th Floor, Philadelphia, PA 19104 USA
montgomery@siam.org / M3Challenge@siam.org

The National Association of Secondary School Principals placed this program on the NASSP National Advisory List of Student Contests and Activities since 2010.

Funded by The Moody's Foundation

m3challenge.siam.org

Organized by siam Society for Industrial and Applied Mathematics

Geometric Design: Visualization and Representation

SIAG/GD Offers a Forum for Evolving Research in the Field

By Gudrun Albrecht, Daniel Gonsor, Stephen Mann, and Thomas J. Peters

Due to dramatic progress in computer technology over the last sixty years, visualization of three-dimensional (3D) geometrical objects has become an essential part of many applications in fields such as the automotive and airplane industries, architecture, medicine, mechanical engineering, and the advertising sector. Geometric design—based mainly on geometry, applied mathematics, and computer science—provides curve and surface representations and associated algorithms.

SIAM's biennial conference on geometric design, organized by the Activity Group on Geometric Design (SIAG/GD), remains a top forum for staying abreast of evolving research in the field. The conference fosters connections between academia and industry, educating academics of the problems facing industry and allowing the two sectors to exchange information about the latest mathematical developments in curves and surfaces. In the earliest days, the conference focused on Bézier and B-spline curves, (mostly tensor product) surfaces, and algorithms for working with such representations. Over the decades, the topics discussed at the conference expanded to include new research, such as triangular Bézier patches, *n*-sided surface patches, general dimensionality, blossoming, multiresolution techniques leading to wavelets, subdivision surfaces, and isogeometric analysis. The best of these methods have been adopted by industry and appear in many commercial products today.

It is important to distinguish between the two basic methods for curve and surface representation, namely the representation by *implicit* versus *parametric* equations. For example, a surface in 3D xyz-space may be described by one (implicit) equation of the form $f(x,y,z)=0$ or by three (parametric) equations of the form $x=x(u,v)$, $y=y(u,v)$, $z=z(u,v)$ with the parameters u,v.

The *implicit* representation is well-suited for solid modeling, a special form of geometric modeling where a solid is a bounded, closed set of points in 3D Euclidean space. Many solid modeling systems are based on quadric primitives like planes, spheres, cylinders, and cones, i.e., their 3D objects are composed by quadric surfaces, or parts thereof. Quadric surfaces also find applications in image processing, and have been generalized to super-quadrics in the context of computer graphics.

Parametric representations of curves and surfaces are well-suited for the control of position and tangency on a curve or surface, as well as for the computation of curvature at curve or surface points. Therefore, they see wide implementation in geometric design. Parametric representations almost exclusively utilize blending functions that rely on both pure polynomials and their rational generalizations. The especially well-behaved Bernstein polynomials and B-spline basis functions are commonly used to signify the polynomials yielding the Bernstein-Bézier and the B-spline representations of curves and surfaces respectively; rational B-splines are commonly referred to as Non-Uniform Rational B-Splines (NURBS) [8]. Due to the useful geometrical relation between the curve itself and the control polygon, Bézier and B-spline curves are easy to handle and represent the standard for curve representation in the current commercial computer aided design (CAD) systems.

Methods for visual analysis commonly used in geometric design include shaded images, various forms of reflection lines, and false coloring with curvature information. Figure 1 shows a comparative visual analysis of four methods for G^1 interpolation of 3D points and associated normals [7] by curved triangular Bézier patches.

One example of an industrial collaboration involving Bézier curves is the synchronous visualization of molecular simulations on high performance computing platforms, in which a molecule was modeled as a knot using a Bézier curve within a tubular neighborhood. Molecular perturbations within this neighborhood preserved isotopy, ensuring that no new self-intersections could occur *unless* the curve approached the boundary of the neighborhood. Since the displayed graphics were piecewise linear (PL) approximations, an additional imperative was to ensure that each PL approximation was ambient isotopic to the knot [11]. Given an initial PL knot, one can then generate an ambient isotopic Bézier curve within a user-chosen error bound

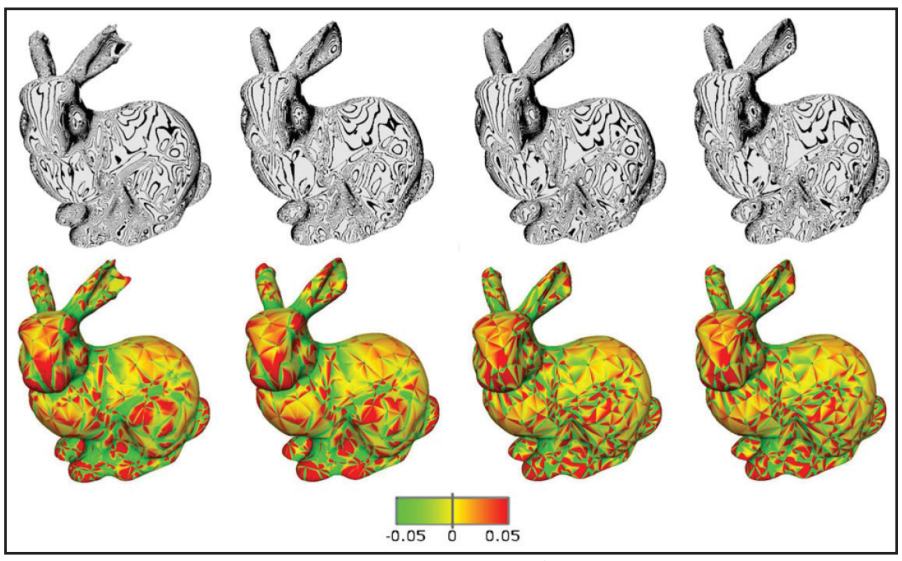


Figure 1. *Quality analysis of four piecewise triangular G^1 Bézier interpolants by highlight lines (top row) and Gaussian curvature (bottom row). Image credit: [7].*

See **Geometric Design** *on page 12*

Q&A with ONR's Reza Malek-Madani

Reza Malek-Madani is a mathematics professor at the Naval Academy and a program officer for the Applied and Computational Analysis Program at the Office of Naval Research (ONR). He recently chatted with science writer and mathematician Analee Miranda about the ONR's mission and research focus, funding opportunities and programs available for applied mathematicians, and career prospects at the ONR, among other topics.

What is the focus of your ONR program? Is your ONR portfolio directly related to your existing research?

To provide rigorous, state-of-the-art research for the benefit of the Navy and Naval Research Enterprise. Specific topics of interest to the United States Navy and the U.S. Department of Defense (DoD) require rigorous analysis with mathematics- and physics-based foundations. At the same time, the research needs to be applied to a specific Navy need. The ONR's website has details on various research needs, such as the Multi-Scale/Multi-Physics Modeling, Dynamical Systems and Oceanic and Atmospheric Modeling, and Inverse Methods thrusts.[1]

The ONR is a funding agency, much like the National Science Foundation. The program officers at the ONR manage portfolios to help advance research investigations of interest to the Navy and the Marine Corps. They are not at the ONR to carry out their own personal research, but to enable and promote research. As a professor and researcher, I work on partial differential equations – in particular, how laser beams propagate in random media. Although this work is useful to the Navy, my academic research interests are completely separate from the research that my program funds. My ONR program interests are focused on a larger group of fields, with varying applications that the Naval Science and Technology Strategy has identified. At the analytical and computational level, I'm looking for research that supports multidisciplinary applications that align with critical naval applications.

For example, work in the multiscale/multiphysics thrust is intended to provide a mathematical framework for modeling in systems that have as many as 10 to 15 scales across their spatial and temporal domains. This type of research is almost always validated by comparison with real data. Some other interests include remote sensing using first principles for geophysical fluid dynamics, which can then be compared to real data, the ground truth. The data is often collected at the various naval laboratories. I'm looking for state-of-the-art research that can add to the existing models of the terrains and bathymetries that the Navy is interested in. Another field of interest is inverse problems. This type of mathematics emphasizes modeling wave propagation when the medium's statistics are not known – it is analytical and rigorous.

When you think of SIAM, what ONR programs/projects under your management immediately stand out? What other SIAM-related fields would the ONR find interesting?

Andrew Stuart's work[2] and Chris Jones'[3] work immediately stand out. They are both current principle investigators (PIs), each of whose work has been featured in *SIAM News*. Some other applied math fields include optimization theory and data science – a fairly new program at the ONR with a particular focus on understanding the geometry of data. Machine learning tools are popular right now, as is graph theory. Our ONR division has many math-related interests.

SIAM organizes many conferences in the course of the year on a variety of topics in applied mathematics and computational science. Would you encourage your colleagues at the ONR to actively participate in these conferences?

Yes, I recently attended and ran a minisymposium at the SIAM Conference on the Mathematics of Planet Earth in Philadelphia. I also ran a minisymposium at the SIAM Conference on Applied Mathematics Education. The ONR is very active in SIAM, and ONR staff attend SIAM meetings and conferences regularly.

What kind of value do you think an applied mathematician brings that is vital to the success of ONR research that you oversee?

Rigorous modeling. In particular, modeling phenomena with error estimates, numerical simulations that are based on data, theorems, proofs, and analytical rigor.

What does an applied mathematician need to know before submitting a proposal to the ONR?

I recommend that mathematicians have a conversation with the program officer of the program they feel best fits their research. The program officers can help one determine if the proposed work is indeed the right fit for the program. The proposals will require some fundamental math development, and the mathematical

See **Reza Malek-Madani** *on page 12*

[1] http://www.onr.navy.mil/Science-Technology/Departments/Code-31/All-Programs/311-Mathematics-Computers-Research/Applied-Computational-Analysis.aspx

[2] https://sinews.siam.org/DetailsPage/tabid/900/ArtMID/2243/ArticleID/893/Default.aspx

[3] https://sinews.siam.org/DetailsPage/TabId/900/ArtMID/2243/ArticleID/1749/Lagrangian-Data-Assimilation-in-Ocean-Modeling.aspx

SIAM Celebrates Diversity in Mathematics

By Raegan Higgins, Erica Graham, and Shelby Wilson

The 20th SIAM Workshop Celebrating Diversity (WCD) took place at the 2016 SIAM Annual Meeting (AN16) in Boston, MA, this summer. Participants of the three-day workshop heard talks from 22 speakers, including postdoctoral fellows, faculty members, and industry professionals. All speakers were female and/or an underrepresented minority.

WCD began in 1996 as the "Graduate Student Focus on Diversity Workshop" when the computational and applied mathematics minority graduate students at Rice University helped lead its organization. The primary organizers—past president of SIAM Margaret Wright (New York University), Richard Tapia (Rice), and former Rice graduate students Monica Martinez, Cassandra McZeal, and Pamela Williams—put much time and effort into the day's events. The result was a spectacular and exciting workshop, with back-to-back activities from 10:30 a.m. until 10:00 p.m. The daylong event included two sessions (eight speakers) and a luncheon. Over the years, the workshop evolved into Diversity Day, extending to three days with 24 speakers. WCD, the current event, follows the same format with 24 speakers and a luncheon.

Erica Graham (Bryn Mawr College), Raegan Higgins (chair, Texas Tech University), and Sue Minkoff (University of Texas at Dallas) were the WCD committee members for AN16. The session themes ranged from fluid dynamics and image analysis to optimization and computational statistical methods. The session on applications to biological and medical sciences was very well attended.

A session entitled "Showcasing Diversity: Women in Mathematical Biology" featured three minority women mathematicians who discussed their research on mathematical problems with applications to biological and medical sciences. The talks covered a variety of pure and applied mathematical tools, from algebraic topology to numerical techniques, while the biological topics ranged from the prediction of DNA folding to species migration modeling. This session also highlighted the depth and breadth of the field of mathematical biology.

Building on the momentum that has steadily grown over the past two decades, the WCD organizers look ahead to the next 20 years with great enthusiasm. The goal has always been, and still remains, to introduce a newer generation of underrepresented researchers to the SIAM community while building connections among a diverse body of applied mathematicians at all stages of their careers. Current WCD organizers Erica Graham (chair of the WCD committee for the 2017 SIAM Annual Meeting), Raegan Higgins, and Shelby Wilson (Morehouse College) wish to expand the growing WCD community by adding to the events that already successfully embody the workshop's mission. In addition to the minisymposia and luncheon for participants and honored guests, which have become workshop staples, the organizers have begun planning a WCD kickoff mixer to coincide with the start of the 2017 SIAM Annual Meeting. We look forward to seeing you in Pittsburgh next summer!

Shelby Wilson (Morehouse College) discusses angiogenesis inhibitors during the Workshop Celebrating Diversity at the 2016 SIAM Annual Meeting. SIAM photo.

Raegan Higgins, an associate professor of mathematics at Texas Tech University, works in the area of time scales with an emphasis on oscillation criteria. She was the WCD chair for the 2016 SIAM Annual Meeting. Erica Graham is an assistant professor of mathematics at Bryn Mawr College. She works in the area of mathematical biology, with applications to endocrinology. Erica is WCD chair for the 2017 SIAM Annual Meeting. An assistant professor of mathematics at Morehouse College, Shelby Wilson works in mathematical biology with applications to the medical sciences. She will be the WCD chair for the 2018 SIAM Annual Meeting.

Professional Opportunities and Announcements

Send copy for classified advertisements and announcements to: ***marketing@siam.org****;*
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 and Jobs" at the SIAM website (***www.siam.org***) or proceed directly to* ***www.siam.org/careers****.*

California Institute of Technology

Department of Computing and Mathematical Sciences

The Department of Computing and Mathematical Sciences (CMS) at the California Institute of Technology invites applications for the position of lecturer in computing and mathematical sciences. This is a (non-tenure-track) career teaching position, with full-time teaching responsibilities. The start date for the position is September 1, 2017, and the initial term of appointment can be up to three years.

The lecturer will teach introductory computer science courses including Data Structures, Algorithms, and Software Engineering, and will work closely with the CMS faculty on instructional matters. The ability to teach intermediate-level undergraduate courses in areas such as software engineering, computing systems, or compilers is desired. The lecturer may also assist in other aspects of the undergraduate program, including curriculum development, academic advising, and monitoring research projects. The lecturer must have a track record of excellence in teaching computer science to undergraduates. In addition, the lecturer will have opportunities to participate in research projects in the department. An advanced degree in computer science or related field is desired but not required.

Please view the application instructions and apply online at **https://applications.caltech.edu/job/cmslect**.

The California Institute of Technology is an Equal Opportunity/Affirmative Action Employer. Women, minorities, veterans, and disabled persons are encouraged to apply.

Georgia Institute of Technology

School of Mathematics

The School of Mathematics at Georgia Tech is accepting applications for faculty positions at all ranks and in all areas of pure and applied mathematics and statistics. Applications by highly-qualified candidates, and especially those from groups underrepresented in the mathematical sciences, are particularly encouraged. See **www.math.gatech.edu/resources/employment** for more details and application instructions.

DEPARTMENT OF AEROSPACE ENGINEERING -
Open Rank Faculty Search College of Engineering
University of Illinois at Urbana-Champaign

The Department of Aerospace Engineering at the University of Illinois at Urbana-Champaign seeks highly qualified candidates for multiple faculty positions in all areas of aerospace engineering, with emphasis on the areas of orbital mechanics, space systems, multi-functional composites, and additive manufacturing. Preference will be given to qualified candidates working in emerging areas of aerospace engineering whose scholarly activities have high impact. Please visit **http://jobs.illinois.edu** to view the complete position announcement and application instructions. Full consideration will be given to applications received by **December 16, 2016**. Applications received after that date may be considered until the positions are filled.

The University of Illinois conducts criminal background checks on all job candidates upon acceptance of a contingent offer.

Illinois is an EEO Employer/Vet/Disabled - www.inclusiveillinois.illinois.edu and committed to a family-friendly environment (http://provost.illinois.edu/worklife/index.html).

AEROSPACE ENGINEERING
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UT DALLAS

THE UNIVERSITY OF TEXAS AT DALLAS
School of Natural Sciences and Mathematics

DEPARTMENT OF MATHEMATICAL SCIENCES

TENURE-TRACK POSITIONS IN STATISTICS AND MATHEMATICS

The Department of Mathematical Sciences within the School of Natural Sciences and Mathematics at The University of Texas at Dallas invites applications for up to four tenure-track faculty positions at the Assistant level in the following general areas:

- Statistics (up to two positions).
- Mathematics (up to two positions) with a strong preference for less represented or unrepresented areas of Mathematics within the Department.

The University of Texas at Dallas is a rapidly growing University with ambitious plans to advance in education and research. The Department of Mathematical Sciences has active research programs in several areas of Mathematics and Statistics. It has 29 tenured/tenure-track faculty, and offers the following degree programs: BA, BS, MS and PhD in Mathematics; MS and PhD in Statistics; BS and MS in Actuarial Science; MS in Bioinformatics and Computational Biology; and the Graduate Certificate in Data Science.

Candidates should have a PhD in Mathematics, Statistics or a closely related field, and a strong commitment to excellence in research and teaching. To apply, candidates should submit a letter of interest, a current curriculum vitae with a complete publication record, a detailed statement of research interests, a statement of teaching philosophy, unofficial graduate transcripts, and at least three reference letters via the online application form available at **http://jobs.utdallas.edu/postings/6837**.

Evaluation of applications will begin on November 15, 2016, and will continue until the positions are filled. For more information, contact Dr. Ali Hooshyar, Chair of the Search Committee, by email at **Ali.Hooshyar@utdallas.edu**.

The University of Texas at Dallas is an Equal Opportunity/Equal Access/Affirmative Action Employer committed to achieving a diverse and inclusive community.

丘成桐数学科学中心
Yau Mathematical Sciences Center

Yau Mathematical Sciences Center
Tsinghua University, Beijing, China

Positions:

Professorship;
Associate Professorship;
Assistant Professorship (tenure-track).

The YMSC invites applications for the above positions in the full spectrum of mathematical sciences: ranging from pure mathematics, applied PDE, computational mathematics to statistics. The current annual salary range is between 0.25-1.0 million RMB. Salary will be determined by applicants' qualification. Strong promise/track record in research and teaching are required. Completed applications must be electronically submitted, and must contain curriculum vitae, research statement, teaching statement, selected reprints and /or preprints, three reference letters on academic research and one reference letter on teaching(Reference letters must be hand signed by referees), sent electronically to

msc-recruitment@math.tsinghua.edu.cn

The review process starts in December 2016, and closes by April 30, 2017. Applicants are encouraged to submit their applications before December 31, 2016.

Reza Malek-Madani

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application should be directly tied to a Navy need. We want our PIs to be knowledgeable about applications. Indeed, information about Navy interests is available online, but the best way to figure out what the Navy is interested in is to speak with a program officer. This could be a phone call or some kind of institutional event with guest speakers from the ONR.

What is expected from a mathematician who receives ONR funding?

Publications in well-known journals, proactive communication and interaction with the program officer and any pre-stipulated deliverable such as software and reports.

What is a typical work week for you at the ONR and how has your personal research experience prepared you for this role?

I typically try to stay on top of publications that my PIs produce, read relevant journals in applied math and physics, and in general, actively engage in keeping up-to-date with existing research as it relates to my ONR program. That aspect of the position requires previous research experience. Most of the work at the ONR is management-related. Although some time is spent researching topics for the program, this is only a percentage of the time. My time at the ONR is typically taken up by administrative tasks such as reading proposals by potential PIs, balancing budgets, communicating with PIs, writing reports, etc.

Are there internships available for applied math students who are interested in Navy research?

The ONR does not have internships, but the Naval Research Laboratory (NRL) does. NRL internships are probably best for mathematics undergraduate and graduate students. Many research opportunities may also be found on our website.

What kind of positions in the ONR would be suitable for a recent grad in mathematics? What are the requirements? How would they apply?

There are no experience requirements that may prevent a new Ph.D. from holding the program officer position at the ONR. That said, I would highly recommend that new graduates first develop their research program, whether in an academic environment or a national laboratory, since entry-level research is important for a career in scientific management and administration.

Want to learn more about Navy research? There is NO better place to really understand naval science and technology (S&T) and make contacts than at the Naval Future Force Science and Technology (S&T) Expo.[4] In July 2017, we will be hosting the conference in Washington, D.C. Many high-ranking naval, academic and industry leaders will attend. The expo will feature workshops, demonstrations, and outreach events.

Want to learn more about Navy internships? USAJOBS is a great place to start. We also recommend you check out the internships sponsored by the Navy's Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) program. The ONR publishes a list of fellowship and internship opportunities for students.[5] The NRL's research opportunities for students may be found on their website.[6]

Reza Malek-Madani received his Ph.D. in applied mathematics from Brown University in 1979. Subsequently he held two postdoc positions, one as a Van Vleck Assistant Professor at the University of Wisconsin-Madison, and the other in the Department of Mechanics at the Johns Hopkins University, working in Clifford Truesdell's group. He has been a faculty member in the Department of Mathematics at the United States Naval Academy since 1983. Beginning in 2000, he has also served as the program officer in Code 311 at the Office of Naval Research.

Analee Miranda is a freelance curriculum writer and mathematician. She is a subject matter expert on the radar scattering effects of UHF/VHF/HF radar on humans. Her current research interests include discovering new medical applications of radar technology.

[4] http://www.onr.navy.mil/Conference-Event-ONR/2017-naval-expo.aspx

[5] http://www.onr.navy.mil/en/Education-Outreach/undergraduate-graduate.aspx

[6] https://www.nrl.navy.mil/careers/students/

Geometric Design

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[10]; Figure 2 shows the convergence of an iterative algorithm for the stick knot 4_1. Researchers are now extending the software to consider unresolved issues on PL knots.

Geometric design applications are also relevant for constructing suitable trajectories for computer numeric control (CNC) machining applications. Parametric polynomial *Pythagorean-Hodograph* (PH) curves introduced by Farouki and Sakkalis are important for CNC machining [9] because they have the useful property of admitting a closed form representation of their arc-length, thus permitting rational offset curves. Romani et al. generalized these curves to Algebraic-Trigonometric Pythagorean-Hodograph (ATPH) curves [12], and Albrecht et al. recently proposed the promising and general class of Pythagorean Hodograph B-Spline curves [1].

Subdivision curves and surfaces have become a popular alternative to the implicit and parametric curve and surface representations, especially in animation applications. Subdivision is a versatile tool that is both intuitive and easy to use and implement. Subdivision schemes are defined via iterative algorithms that exploit simple refinement rules to generate denser and denser point sequences, starting from an initial point set and ultimately converging to a continuous, potentially-smooth function.

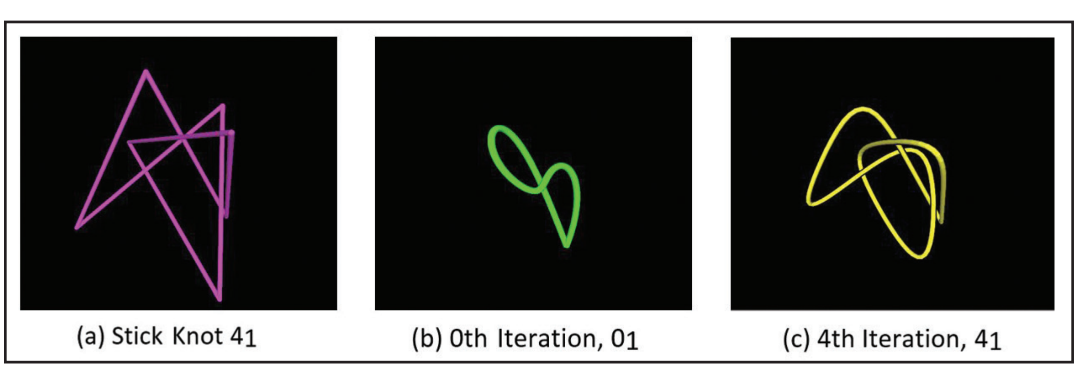

Figure 2. *Stick knot, 0th, & 4th collinear insertions. Image credit: Thomas J. Peters.*

While subdivision methods are popular in computer animation systems, their integration into CAD applications has taken much longer. The European project NIIT4CAD[1] investigated the practical integration of subdivision surfaces in a commercial CAD system [2-3, 6]. Figure 3 shows a result of Albrecht and Romani's conic and convexity-preserving subdivision method [2].

Although computer aided geometric design (CAGD) is a mature and well-developed field of mathematics, we are periodically confronted with industrial problems and situations that challenge the effectiveness of current, state-of-the-art CAGD theory and tools. Creative use of existing theory and techniques may prove adequate in such situations. Sometimes the solution to a desired property (e.g., faster and more accurate rendering of spline surfaces) may merely require diligent review of existing literature, or in rarer situations, a completely novel approach.

Additionally, new fields and applications are immersed in CAGD challenges. Foremost among these are alternative materials, including new design and manufacturing (and design-for-manufacturing) techniques, carbon fiber composite materials, and additive manufacturing with materials ranging from polymers to titanium. A slightly different perspective involves meeting existing challenges by taking advantage of new approaches such as isogeometric analysis, which, among other benefits, alleviates the prevalent problem of producing grids from existing geometrical representations to perform various analyses. This in turn leads to the issues of alternative geometrical representations designed to overcome limitations to traditional representations, such as tensor-product polynomial splines and NURBS. Generally such alternatives require a tradeoff with traditional representations. Rational Geometric Splines (RAGS) [4-5], which are designed to preserve the most important properties of the traditional spline representation without the inherent restrictive rectangular topology, offer an example of one such tradeoff. See Figure 4 for an example of RAGS modeling a surface of higher-order genus incompatible with traditional methods.

Healthy membership numbers and diversity of participating fields (academia, industry, and government) attest to both the relevance of the field and the SIAG/GD's vibrancy. The existence of other active contributing organizations, such as the Association for Computing Machinery's Symposium on Solid and Physical Modeling, Shape Modeling International, and the Symposium on Geometry Processing, demonstrates the continued relevance of geometric design.

[1] http://eurostars.unibo.it/main-project/

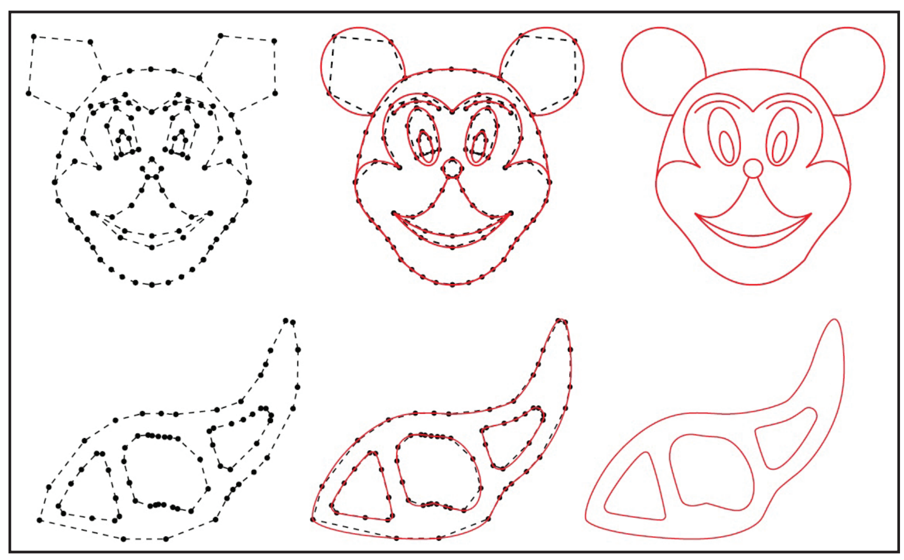

Figure 3. *Results of a subdivision method applied to real-world data. Starting polylines are visible in the left column, while the center and right columns display refined polylines obtained after seven steps of the algorithm. Data of the bottom row (bottle opener) are courtesy of the CAD company think3. Image credit: [2].*

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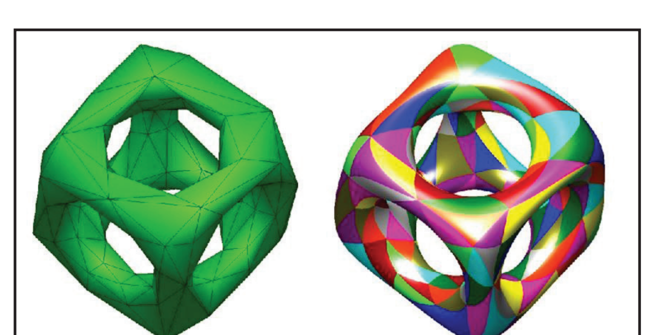

Figure 4. *An example of RAGS modeling a surface of higher-order genus. On the left is a grid, and on the right is a surface with colored patches. Image credit: [4].*

Gudrun Albrecht, professor of applied mathematics at the University of Valenciennes, France from 2002 to 2016, is currently changing affiliation to the Mathematics Department at the National University of Colombia in Medellin, Colombia. Daniel Gonsor is a member of the Applied Mathematics group of the Boeing Research & Technology organization in North Charleston, South Carolina. Stephen Mann is a professor in the Cheriton School of Computer Science and cross-appointed to the Department of Mechanical and Mechatronics Engineering at the University of Waterloo. Thomas J. Peters is a professor of computer science and engineering and a professor of mathematics at the University of Connecticut, with years of industrial experience in computer aided design and computer generated imagery.