Newsjournal of the Society for Industrial and Applied Mathematics sinews.siam.org

siam news

Volume 48/ Number 10
December 2015

Cardiovascular Blood Flow Simulation: *From Computation to Clinic*

By Alison L. Marsden

Cardiovascular blood flow simulations offer non-invasive means to quantify hemodynamics in the heart and major blood vessels for patients with cardiovascular disease. This data is not readily available from standard clinical measurements, yet it can offer key insights into disease progression and subsequent physiologic response, and thus aid in clinical decision-making. In much the same way that simulations have impacted aeronautical design, they now bring — for the first time — quantitative, predictive tools to surgical and treatment planning for a range of cardiovascular diseases in children and adults.

Simulations are performed in a multistep process involving a rich and diverse array of mathematical techniques. The process generally starts with analysis of medical imaging data and proceeds through model construction, meshing, solution of the governing equations, boundary condition assignments, data assimilation and error propagation, and statistical correlation with clinical outcomes. A wide variation of mathematical and computational disciplines must be integrated throughout this modeling process. Simulations are already showing an impact in the clinical setting, and have the potential to improve outcomes for both children and adults affected by a multitude of diseases.

Patient-specific cardiovascular simulations typically begin with acquisition and processing of medical imaging data. Computed tomography (CT) or magnetic resonance imaging (MRI) is generally segmented using 2D or 3D level set, thresholding, or region-growing algorithms, which often necessitate manual intervention. Recent efforts to improve automated segmentation algorithms have focused on machine-learning algorithms, including deep learning and shape analysis. These improvements are crucial to enabling high-throughput processing of models for large patient cohorts in clinical studies. The segmented data allows for the construction of a 3D anatomic model that represents a region of interest of a particular patient's vascular anatomy. Model construction requires care to ensure that boolean and smoothing operations maintain fidelity to the original image data.

See **Blood Flow Simulation** *on page 4*

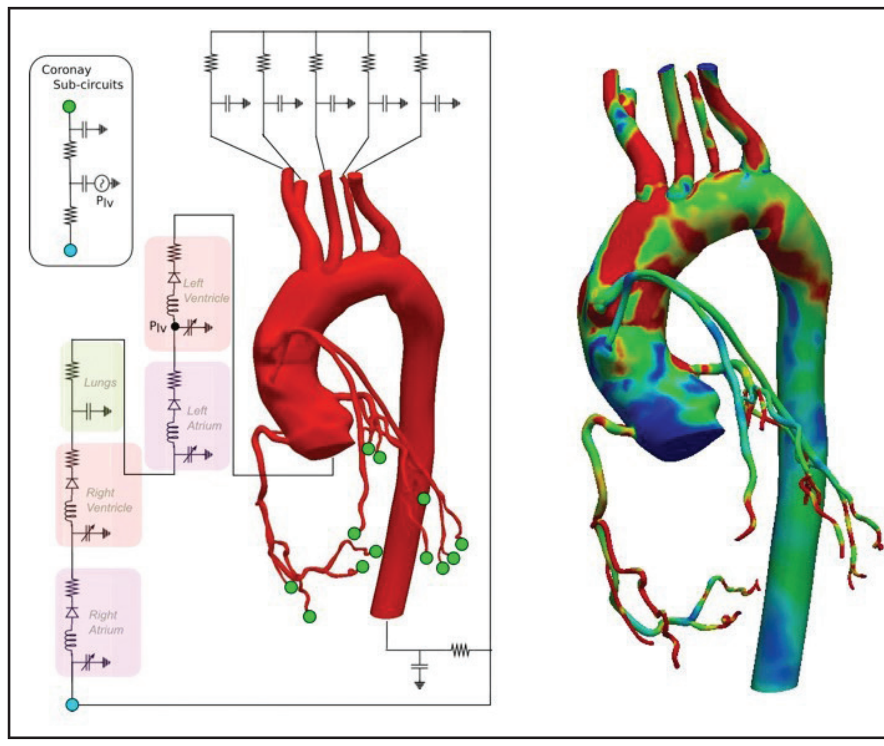

Figure 1. *Patient-specific model and coupled system of boundary condition equations governing cardiovascular physiology (left) and simulated wall shear stress acting on vessel walls for coronary artery bypass graft surgery.*

Computational Plate Tectonics and the Geological Record in the Continents

By Louis Moresi

Earth scientists recently celebrated the fifty-year anniversary of the theory of plate tectonics. The notion that the Earth's surface is composed of a small number of slowly but continually-moving 'rigid' plates floating on a convecting, fluid interior is now firmly established as the foundational concept of the discipline. And in the last decade, it has become routinely observable thanks to space geodesy (see Figure 1). If the plates can be considered rigid, then they are merely boundary conditions on a global circulation problem.

The theory of plate tectonics is actually a kinematic description of plate motion that describes how the plates move, but it does not tell us why they move as they do. Neither does it explain how and why new boundaries form or show what happens in the continental regions where deformation is more diffuse. We don't know how or when plate tectonics began, or why plate motions are only observed on Earth and not on other planets or moons in the solar system. Addressing these questions requires a fully-dynamic theory of plate motion and constitutive behaviour.

The contours of the strain rate in Figure 1 show some regions where plate boundaries are relatively diffuse, meaning that the plates are not rigid there. Most of these regions occur in the continents; particularly obvious is the regional deformation associated with the collision of India and Eurasia which produced the Himalayan mountain belt (see Figure 2). The realization that the plates are not rigid is the first step towards addressing one of the most enduring and significant challenges facing the Earth sciences: the development of a coupled model of deep circulation, plate motions, and continental deformation.

Developing a global circulation model for the solid Earth is a grand challenge problem. Rock rheology, the manner in which rocks deform under tectonic stress,

See **Plate Tectonics** *on page 3*

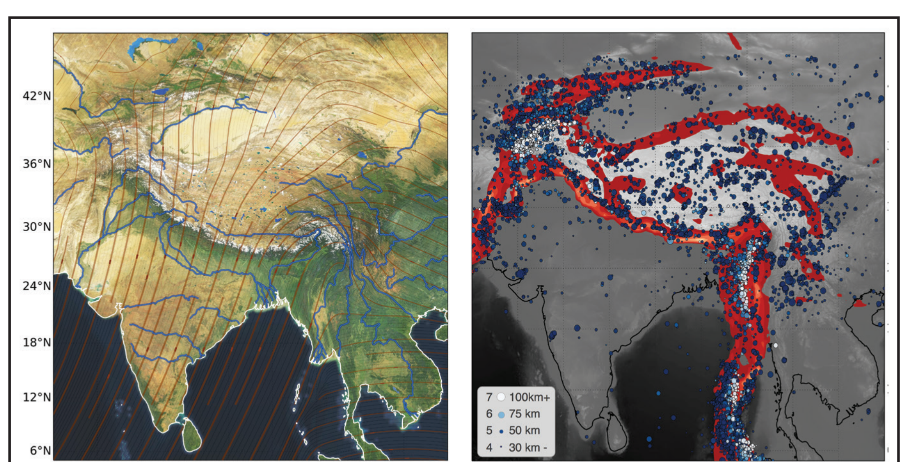

Figure 2. *One of the most dramatic departures from plate-like deformation on Earth occurred where the Indian subcontinent collided with the Eurasian continent. The map on the left is a satellite image with the flow lines from the plate motion vector field drawn in red. On the right is the same region showing 50 years of earthquake data for events larger than magnitude 4.5, colored by depth and superimposed on the strain rate.*

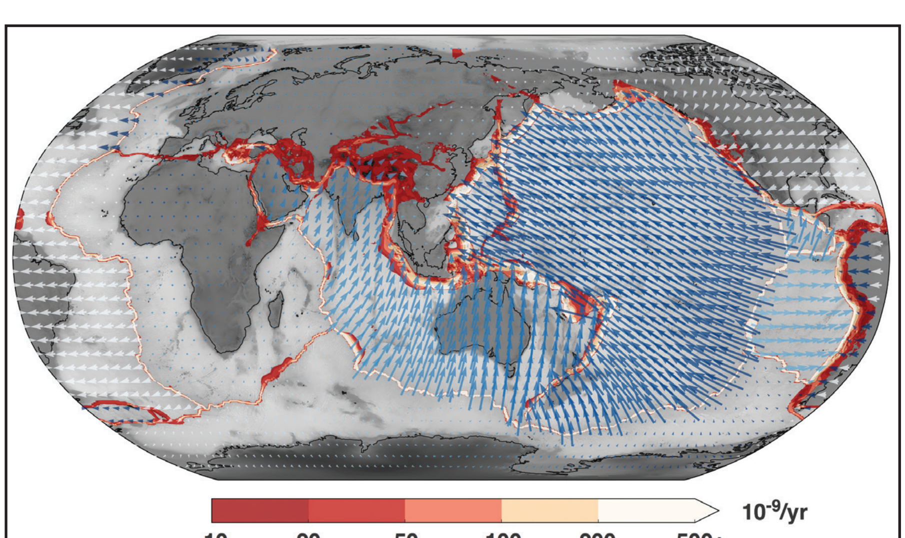

Figure 1. *A map of surface velocities shows that the surface motions are organised into a strikingly simple pattern of surface "plates" that are almost rigid bodies. The surface strain rate–coloured contours—is concentrated at the plate boundaries. The map also displays the second invariant of the strain-rate, which is vanishingly small in the plate interiors and large at the plate boundaries. The arrows are colored by their angle to 'North' as a means of distinguishing the different plates. The scale is such that the longest vector represents 10cm/yr.*

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siam news
Volume 48/ Number 10/ December 2015

DMS Questions its Impact as Innovation Engine

LETTER TO THE EDITOR

In *DMS Mathematical Sciences Research Institutes Update* (*SIAM News* October 2015) Michael Vogelius, NSF Mathematical Sciences Division Director, defends the decision to eliminate the Institute for Mathematics and its Applications (IMA) and the Mathematical Biosciences Institute (MBI), while preserving the Institute for Computational and Experimental Research in Mathematics (ICERM), the Institute for Pure and Applied Mathematics (IPAM), and the Mathematical Sciences Research Institute (MSRI), following review of noncompetitive renewal proposals by the DMS' Institute Management Team. Of the five institutes under consideration, all those serving wholly or in part the interests of the pure mathematics community are to be fully funded, while those principally supporting the applied mathematics community are to be shut down. Dr. Vogelius does suggest that MBI could continue receiving partial funding from DMS if it can find, in effect, matching funds from the National Institutes of Health (NIH) or the NSF Directorate for Biological Sciences (DBS). By weakening its investment in applied mathematical research, Dr. Vogelius weakens the case for support of the Division of Mathematical Sciences as a whole.

The DMS has a $225M annual budget for 2015. Dr. Vogelius' statement justifies the DMS' existence in part because it "promotes interdisciplinary connections across all fields of science, engineering, and technology" and because its activities "are essential components of the innovation engine that drives the nation's economy in the 21st century."

Dr. Vogelius' statement also mentions that recent budget pressures have reduced the funding rate from rates "in the low 30s" circa 2012 to 26.8% in 2014. But funding rates for proposals submitted to the NIH and the DBS are even smaller: 24% at DBS[1] and from 8-20% at NIH.[2] The suggestion that MBI might find matching funds from these sources appears either naïve or disingenuous.

If Congress, through the Government Accountability Office, were to investigate the actual impact of DMS as an "innovation engine," it seems more likely that elimination of MSRI, ICERM, or IPAM would be called for. Or, perhaps, elimination of the entire Division of Mathematical Sciences. By pursuing a policy of retrenchment and weakening its investment in applied mathematics, Dr. Vogelius undermines the basis for supporting the entire division.

— Peter J. Thomas, associate professor in the Department of Mathematics, Applied Mathematics and Statistics at Case Western Reserve University.

1 http://www.nsf.gov/dir/index.jsp?org=BIO
2 http://report.nih.gov/success_rates/

Regaining Control in our Electric Grid

By Sean Meyn

The power grid in the U.S. and many regions of the world is implementing new technologies in an effort to realize the "smart grid" vision. Smart meters and a smarter grid will likely lead to more efficient use of our infrastructure. In addition, increased renewable energy integration has the potential to provide power at low cost. This optimism may be justified, but only if experts in control theory play a leading role.

Within the next decade it is expected that renewable energy will be ubiquitous, exposing the grid to levels of volatility it has never experienced before. As consumers install more solar panels and energy storage devices, dynamic models of the grid will require revision.

Presented with so many changes, it is an exciting and daunting time to be in charge of the grid. But the challenges faced by tomorrow's grid operator are manageable, as long as we keep in mind a basic lesson of engineering: *our models of the grid and of human behavior are only approximations of reality.*

Volatility from Renewables

Figure 1 shows power from wind generation in the Bonneville Power Administration (BPA) region in the Pacific Northwest during the first days of 2015. The vertical axis is measured in gigawatts. The first day of the year was completely calm, with virtually no energy from wind, yet the maximum power on January 5 is similar to the output of four typical nuclear reactors. In addition to this fluctuation in wind energy, the sun also brings volatility: California's rush to increase solar energy penetration may mean that the net load[1] will be near zero during lunchtime on sunny days. This is great news, in the sense that these energy sources are clean, domestic, and renewable. The question, however, is, how do we deal with this massive disturbance to the grid?

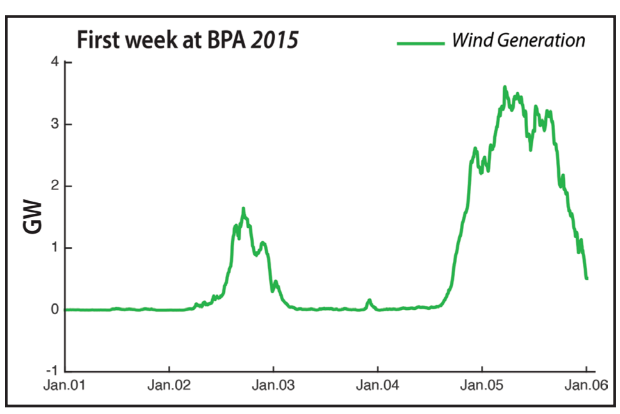

Figure 1. *Wind generation during a typical week at BPA.*

One of several proposed resources is batteries. Southern California Edison (SCE), which supplies electricity to much of Southern California, recently announced the "largest battery in the world." The SCE battery is a 6,300 square-foot facility capable of storing 32 MWh (megawatt-hours) of energy. This is not a lot. It would take one hundred times this amount of storage to address the ramps seen on January 4 and 5 at BPA. In addition to their enormous investment cost and size, batteries do not "store for free." They have a limited lifetime, and waste energy as they charge and discharge.

Consumers in the Loop

Fred Schweppe's vision of a grid in which primary control would be augmented by the action of loads ramping power consumption up and down in response to local measurements inspired dreams of a better grid among academics [5]. He and many others have also argued for real-time prices to consumers as a mechanism for real-time control, putting consumers in the loop and introducing new dynamics. Both market analysis [4] and control considerations cast doubt on this approach to regulating the grid.

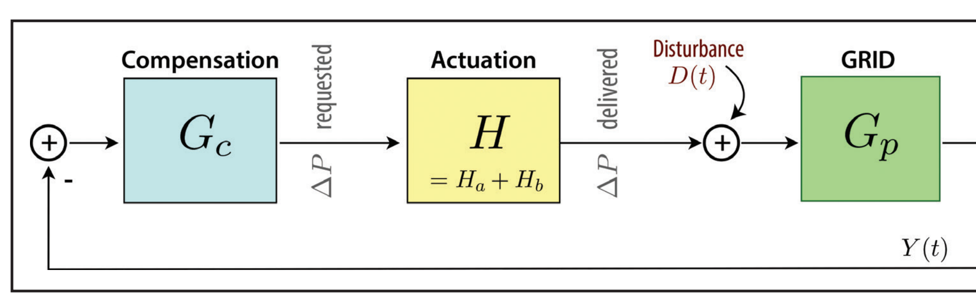

Figure 2. *Power grid control loop.*

This begs a multitude of questions. Do we expect consumers in Seattle to track the entirety or a portion of BPA wind generation? Where most of the loads are on/off devices, how can consumers be expected to track continuous regulation signals? Will uncertain consumer response, and delayed response, lead to an unstable feedback loop? What effect will this have on water heaters and refrigerators that are ramping up and down to service the grid? To answer these questions, we need to look more closely at the control problem faced by today's grid operator.

Grid Control Loop

Figure 2 shows the grid from the viewpoint of a typical *balancing authority* (BA), where grid operators are in charge of main-

See **Electric Grid** *on page 6*

1 Power demand minus renewable generation

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Plate Tectonics

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is very nonlinear and history-dependent because it represents processes that occur at a much smaller temporal and spatial scale than plate motions. Such processes include the mechanics of faults formation and the manner in which they slip via the accumulated effect of thousands of small earthquakes (see Figure 2 on page 1), combined with the effects of grain-scale deformation, metamorphism, and melting.

Another aspect of the grand challenge is determining how to find and use observations which can constrain the many additional degrees of freedom required by large-scale, dynamic circulation models. Appreciating the scale of this challenge requires recognition of the fundamental difference between the geological record of the ocean floor (the plates) and the geological record of the continental crust. The oceanic crust is part of the 3D, deep circulation pattern of the solid Earth, with an overturn time of around 100 million years, comparable to the median age of the oceanic plates. The continental crust is buoyant enough to escape large-scale recycling and much more widely-distributed in age (ranging up to over three billion years).

Consider the Himalayan mountain belt, which is the result of subduction zone congestion by the buoyant and deformable continental crust. The continental collision results in the dramatic topography of the region as the crust is shortened and thickened (see Figure 3, and view an accompanying movie at sinews.siam.org). Examining the stratigraphy, cooling history, and metamorphism of the rocks allows one to infer the history of the uplifted surface, which is recorded by rocks in crumpled and overturned units. It is also indirectly recorded in the sedimentary record as rivers and glaciers carry material away from the mountain belts and into sedimentary basins.

In sedimentary basins, accumulated detritus from the landscape stacks up, burying older material and creating a stratigraphic record of the topographic erosion. The difficulty in inverting this record to reveal the history of geological deformation is that the transport of eroded sediment can occur over long distances, is heavily dependent on the history of the topography, can be quite variable in time and space, is sensitive to very small-scale processes, and is coupled to the large-scale deformation. For example, the lengthy, tortuous pathways that the major rivers draining the Himalayas have to take to reach the ocean are clearly influenced by the topography rising and translating beneath the streams and rivers as they cut their channels.

While global circulation models are needed to bring the power of plate tectonic theory to the continental geological record, making these models meaningful will require embedding models which can reproduce observable aspects of the continental record.

Solving a simplified system of equations is necessary to model the flow in the mantle and the plates' response. A typical template for this problem uses the Stokes equation for an incompressible fluid (or nearly so) driven by thermal buoyancy due to planetary cooling and deep radioactive decay:

$$\nabla \cdot \tau - \nabla p = g p \hat{z} \qquad (1)$$

$$\nabla \cdot \mathbf{u} = 0 \qquad (2)$$

$$\frac{DT}{Dt} = \nabla(\kappa \nabla T) + Q \qquad (3)$$

Silicate rocks deform in the same way as extremely high-viscosity fluids on geological timescales, which eliminates the need to consider the effects of inertia and rotation. However, a significant complexity arises from the rheology, which is strongly dependent on deformation history and composition.

$$\frac{\tau_{ij}}{\eta} + \frac{\dot{\tau}_{ij}}{\mu} + \Lambda_{ijkl}\tau_{kl} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \qquad (4)$$

The second term (red) in the constitutive law (4) is the effect of viscoelasticity, and the third term (blue) represents the effects of faulting and other forms of material failure as a non-isotropic and strain-dependent plasticity. Neglecting elastic stresses is common at the large length and time scale of these models, but plate boundaries are represented through the plasticity term and these are central to the formulation.

The most successful algorithms for dealing with the elliptic Stokes equation and the history-dependent rheology are hybrids with an Eulerian mesh suitable to build an efficient, parallel, multigrid solver for (1) and Lagrangian particles embedded in the fluid which record the stress and strain history required for (4). In the Underworld code [8], the particle properties map to the mesh via a finite element quadrature rule that must be constructed on-the-fly for the distribution of particles found in each element at every timestep.

$$\frac{Dh}{Dt} = \nabla(\kappa(h)\nabla h) - KA^m |h|^n + \dot{h}_{\text{basement}} \qquad (5)$$

$$A = \int_{\xi,\,\text{upstream}} \alpha(\xi)\, d\xi \qquad (6)$$

It is only necessary to consider those processes contributing to erosion, sediment transport, and deposition that are important at scales of hundreds of kilometers and hundreds of thousands to millions of years. Consider the changing height of a simple surface described by $h(x(t), y(t))$ with the simplified description outlined in (5). The time derivative of the surface height is computed as a balance between local, nonlinear, diffusion-like terms (red) and non-local terms related to the integrated upstream area for any point (6). Such terms occur because, for example, the available energy of a river in eroding the basement is expected to relate to both the local slope and the total amount of water in the river. To know how much sediment a river is carrying, the net erosion rate upstream must be known for every point along the river. Figure 4 illustrates the network that can be constructed from downhill flow pathway for a discrete set of points representing the surface and how integrating (5) produces a tree-like collection of pathways which cut into the surface. Such pathways form narrow, localised channels that can be very stable. However, where deposition occurs (when the energy of the flow decreases in a flatter region, for example) then the reverse is true: flows tend to diverge and multiple pathways across low-relief surfaces develop. It is much harder to apply the ordered traversal of a tree that is diverging in this way. A promising approach in this case, which is also efficient for domain-decomposed parallel computation, is to use repeated applications of the adjacency matrix of the downhill-directed graph corresponding to the flow network. Such approaches are needed when the surface is not modeled in isolation but as part of a large computation, such as the one shown in Figure 3.

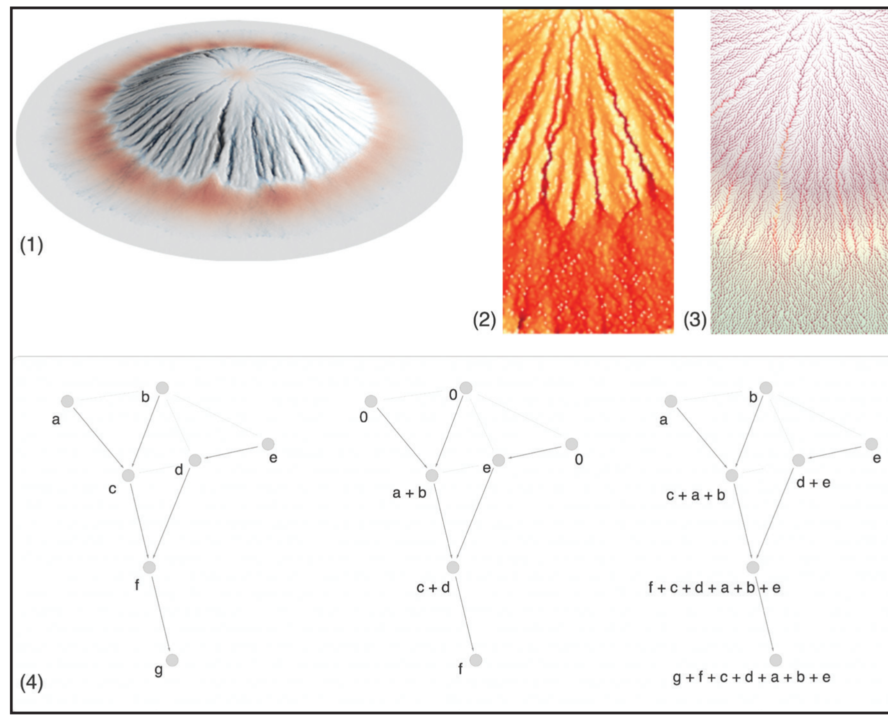

Figure 4. *Idealised erosion, transport and deposition models are based on computing height changes which depend on local slope, those dependent on long-range transport processes by rivers or glaciers, and motions due to large-scale tectonics. Long-range transport by rivers requires knowledge of information integrated from the entire upstream catchment of every point. Erosion tends to localise, whereas deposition has the opposite characteristic (1, 2). Upstream integrals can be calculated very efficiently with an appropriately-ordered traversal of the graph of downhill connectivity of the surface (3, 4). Parallel algorithms based on arbitrary spatial decompositions of the domain disrupt this efficient ordering.*

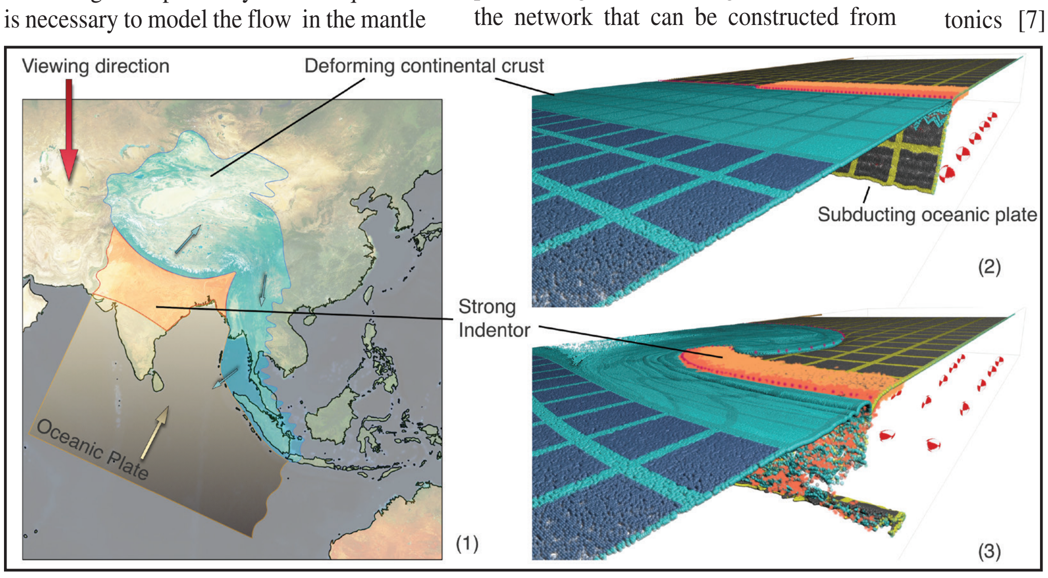

Figure 3. *A low-angle view of a numerical model of continental collision using the Underworld particle-in-cell finite element code. The map (1) interprets the model in terms of the India-Eurasia collision. In the simulation, the Indian indentor heads towards the viewer and crumples the crust into a mountain belt in the foreground. In the background, the crust escapes away from the viewer pulled by the subduction zone. Snapshots from the movie: (2) pre-collision and (3) late in the collision.*

Acknowledgments: The maps were produced using the cartopy plotting package (Met Office, 2010) with data from the following sources: Global topography and bathymetry from ETOPO1 [1], plate motions and strain rates from the global strain rate project [5], and satellite images from Mapbox (mapbox.com). Seismic data was obtained using the obspy package [2].

Further Reading

Many of the papers which first described the theory of plate tectonics are extremely accessible. Wilson's 1963 paper [11] on continental drift and Heirtzler's 1968 paper [4] on sea-floor spreading bracket the period of major discoveries.

A review of computational plate tectonics [7] is written for a broad audience and describes the methods discussed here with examples. Applications of adaptive mesh refinement to a solid Earth global circulation model with emergent plate boundaries are described in [10]. More background on Figure 3 and the movie can be found in [9].

To learn more about the large-scale interaction between mantle circulation and the surface processes of erosion, sediment transport, and deposition, see [3].

References

[1] Amante, C. & Eakins, B.W. (2009). ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. *NOAA Technical Memorandum NESDIS NGDC-24*. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M.

[2] Beyreuther, M., Barsch, R., Krischer, L., Megies, T., Behr, Y., & Wassermann, J. (2010). ObsPy: A Python Toolbox for Seismology. *Seismological Research Letters, 81*(3), 530–533. doi:10.1785/gssrl.81.3.530.

[3] Braun, J. (2010). The many surface expressions of mantle dynamics. *Nature Geoscience, 3*(12), 825–833. doi:10.1038/ngeo1020.

[4] Heirtzler, J. R. (1968). Sea-Floor Spreading, *Scientific American*, *219*(6), 60–70.

[5] Kreemer, C., Holt, W. E., & Haines, A. J. (2003). An integrated global model of present-day plate motions and plate boundary deformation, *Geophysical Journal International, 154*, 8–34.

[6] Met Office. (2010-2015). Cartopy: a cartographic python library with a matplotlib interface, Exeter, Devon. http://scitools.org.uk/cartopy.

[7] Moresi, L. N., Gurnis, M., Zhong, S., & Zhong, S. J. (2000). Plate tectonics and convection in the Earth's mantle: Toward a numerical simulation, *Computing in Science & Engineering, 2*(22). http://dx.doi.org/10.1109/5992.841793.

[8] Moresi, L. N., Quenette, S., Lemiale, V., Mériaux, C., Appelbe, B., & Muhlhaus, H. B. (2007). Computational approaches to studying non-linear dynamics of the crust and mantle. *Physics of the Earth and Planetary Interiors, 163*(1-4), 69–82. doi:10.1016/j.pepi.2007.06.009.

[9] Moresi, L. N., Betts, P. G., Miller, M. S., & Cayley R. A. (2014). Dynamics of continental accretion. *Nature, 508*(7495), 245–248. doi:10.1038/nature13033.

[10] Stadler, G., Gurnis, M., Burstedde, C., Wilcox, L. C., Alisic, L., & Ghattas, O. (2010). The Dynamics of Plate Tectonics and Mantle Flow: From Local to Global Scales. *Science, 329*(5995), 1033–1038.

[11] Wilson, J. T. (1963). Continental drift. *Scientific American, 208*(4), 86–100.

Louis Moresi is a professor of geophysics at the University of Melbourne in Australia. He is interested in understanding the evolution of the deep Earth over geological time, and how this evolution is recorded in the superficial geological record. To read about the computational models that drive his work, visit his webpages at www.moresi.info. He is also a strong supporter of open source code and literate programming. (The source code for the maps in this article is available in the form of ipython / jupyter notebooks on his website).

Blood Flow Simulation

Continued from page 1

Patient-specific simulations usually require time-dependent solutions of the partial differential equations (PDEs) governing blood flow, the Navier-Stokes equations, and complex geometries, which commonly require parallel, high-performance computing. Recent advances in simulation methodologies have increased efficiency and enabled heightened physiologic realism. Yet the addition of fluid structure interaction (FSI) to model vessel wall deformation makes simulations more challenging and computationally expensive. Finite volume or finite element methods with appropriate boundary and initial conditions allow the governing equations to be solved numerically. The cardiovascular community widely uses finite element methods with unstructured meshes due to complex geometries and FSI. Much of the recent work has employed stabilized (streamline-upwind/Petrov–Galerkin, or SUPG) methods with linear finite elements, but higher-order spectral elements, unstructured finite volume methods, and immersed boundary techniques offer attractive alternatives.

Since only a portion of a patient's anatomy can be included in the 3D model — both due to computational expense and limits of image resolution — boundary conditions must be applied at inlets and outlets of the model to accurately represent the vascular network outside of the 3D domain. The choice of boundary conditions is of paramount importance in cardiovascular simulations, as conditions upstream and downstream of the 3D model greatly influence the local flow dynamics. The current state-of-the-art cardiovascular simulations implicitly couple the Navier-Stokes equations in the 3D domain with reduced-order models of circulatory physiology, forming a closed loop system. Electrical circuits, in which flow is analogous to electric current and pressure drop is analogous to voltage, offer a convenient analogy. Organ compartments, including the heart, systemic, and pulmonary circulations, are constructed from circuit elements, resulting in a system of ordinary differential equations (ODEs). Solution of this coupled PDE/ODE system poses numerical challenges. These challenges include flow reversal at the outlets, the need for specialized pre-conditioners for the linear system of equations, and ill conditioning arising from the dominance of a few eigenvalues coming from the coupled boundaries [4].

There is rising interest in clinical data assimilation and uncertainty quantification in cardiovascular simulations. Because physicians are unlikely to trust simulations for clinical use unless they are accompanied by confidence intervals on model predictions, models must account for myriad sources of uncertainty. These include noise in image data, measurement errors associated with cardiac catheterization, phase contrast MRI, and natural physiologic variation. One must first perform parameter estimation in the presence of uncertainty to assimilate clinical data into models. Propagation to model outputs and uncertainty quantification for model outputs happens next. Bayesian approaches are particularly attractive for this purpose, including multi-level Monte Carlo methods and compressed sensing [5]. Application of optimization to design surgical geometries and devices, including derivative free-pattern search methods incorporating surrogates, has proven to be particularly effective and efficient. Computational performance is of utmost importance in this context, as each function evaluation may require hours of run time on a parallel cluster, and algorithms can quickly become intractable without special care to maximize efficiency.

Clinical interest in patient-specific cardiovascular modeling is rapidly accelerating, with recent application to numerous diseases in children and adults. These diseases include congenital heart disease, coronary artery disease, Kawasaki disease, cerebral and abdominal aneurysms, and medical device design. In 2014 the FDA granted the first approval of cardiovascular simulations for routine clinical use with the introduction of fractional flow reserve by computed tomography (FFRct), created by HeartFlow, Inc. FFRct is an assessment of the functional severity of coronary artery stenosis, and clinical trial results have demonstrated excellent agreement with invasive measurements as well as a reduction in the number of invasive procedures performed on patients [1]. Current studies are examining surgical methods for coronary artery bypass graft surgery and causes of vein graft failure.

Simulations have also impacted pediatric cardiology with the introduction of novel surgical methods for single ventricle heart patients, a severe condition in which a child is born with only one functioning heart ventricle. Surgical methods for the Fontan procedure (the third stage surgery performed in single ventricle palliation) were changed based on simulation results to adopt an offset design in order to avoid flow collision, and, more recently, a "Y-graft" design that improves flow distribution. The "Y-graft" was designed and optimized via simulations before translation to clinical use at Lucile Packard Children's Hospital at Stanford University [3]. A recently-introduced concept for stage-one single ventricle surgery, called the "Assisted Bidirectional Glenn," now aims to improve outcomes in neonates by incorporating an ejector pump to increase pulmonary blood flow [2]. In this context, multiscale simulations provide a means to develop novel surgical methods, for which it may be ethically infeasible to test directly in patients.

Numerous challenges remain as tools for cardiovascular simulations mature. Among these is the ongoing challenge of validation against in vivo data, which is often hindered by ethical considerations of invasive data collection, particularly in children. Future simulations should include far more detailed models of biological and physiologic responses, such as the chemistry of blood clot formation, vascular growth and remodeling in response to changing mechanical loads, auto regulatory feedback mechanisms, and vascular mechanotransduction. These mechanisms will require specialized numerical methods capable of handling increasingly-complex multiscale problems.

Finally, because cardiovascular software development is a complex undertaking, readers might benefit from the exploration of software tools available through the open source SimVascular project,[1] which provides a complete open source pipeline from image data and patient-specific model construction to meshing, boundary condition assignment, and simulation results, and is freely available for academic purposes.

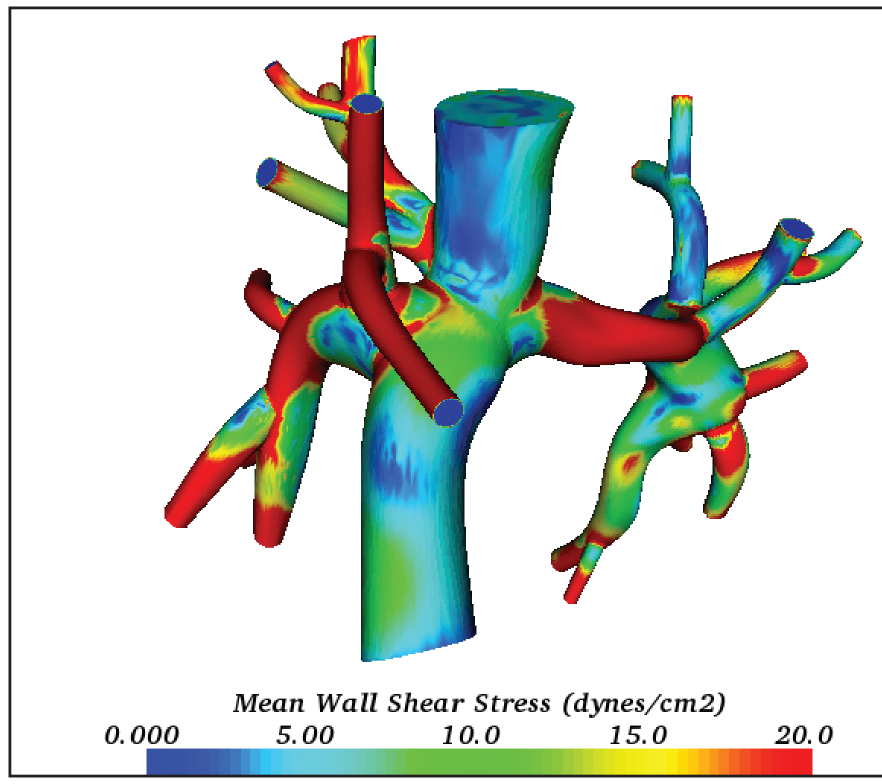

Figure 3. *Patient-specific blood flow simulation of the Fontan surgery performed to treat patients with single ventricle heart defects. Simulations can be used to predict a range of clinically-relevant parameters including flow distribution, shear stresses, oxygen delivery, and cardiac workload.*

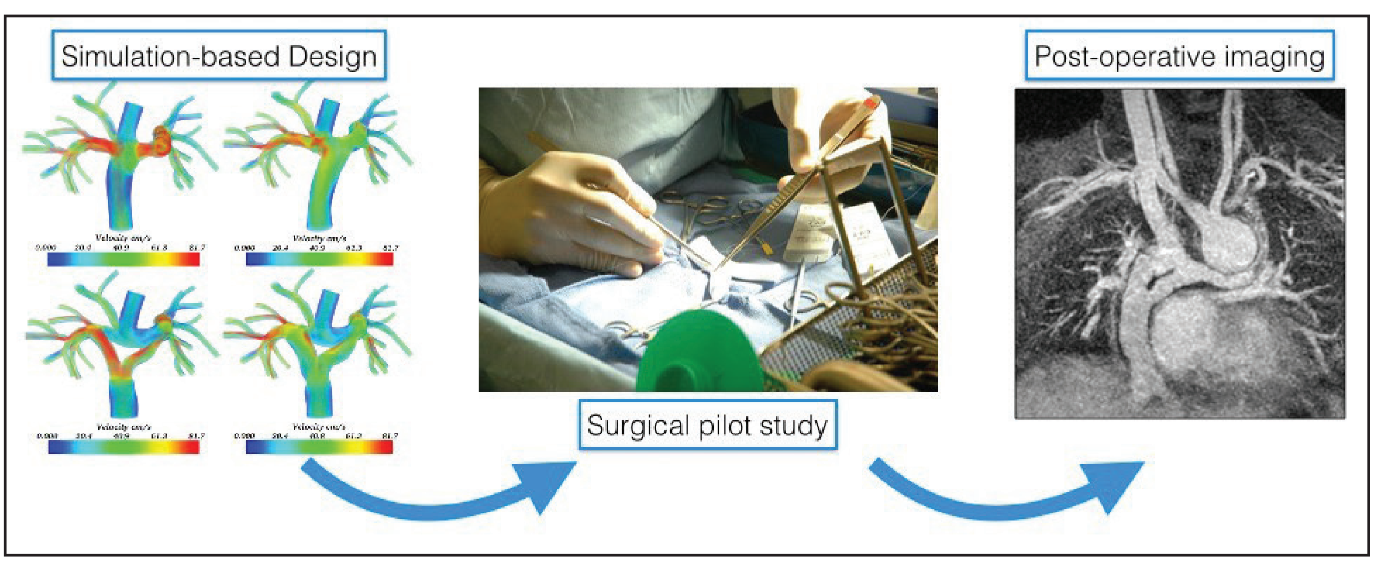

Figure 2. *Simulation-based design, clinical translation, and postoperative imaging of a novel surgical approach for the Fontan surgery to treat children born with a single ventricle heart defect.*

[1] www.simvascular.org

References

[1] Douglas, P. M., Pontone, G., Hlatky, M. A., Patel, M. R., Norgaard, B. L., Byrne, R. A.,…Rogers, C. (2015). Clinical outcomes of fractional flow reserve by computed tomographic angiography-guided diagnostic strategies vs. usual care in patients with suspected coronary artery disease: the prospective longitudinal trial of ffrct: outcome and resource impacts study. *European Heart Journal*. Advance online publication.

[2] Esmaily-Moghadam, M., Hsia, T. Y., & Marsden, A. L. (2015). The assisted bidirectional Glenn: a novel surgical approach for first-stage single-ventricle heart palliation. *The Journal of Thoracic and Cardiovascular Surgery, 149*(3), 699–705.

[3] Marsden, A. L., Bernstein, A. J., Reddy, V. M., Shadden, S., Spilker, R. L., Chan, F. P.,…Feinstein, J. A. (2009). Evaluation of a novel Y-shaped extracardiac Fontan baffle using computational fluid dynamics. *Journal of Thoracic and Cardiovascular Surgery*, *137*, 394–403.

[4] Marsden, A. L., & Esmaily-Moghadam, M. (2015). Multiscale modeling of cardiovascular flows for clinical decision support. *Applied Mechanics Reviews, 67*(3), 1–11.

[5] Schiavazzi, D. E., Arbia, G., Marsden, A. L., Baker, C., Hsia, T. Y., & Vignon-Clementel, I. E. (submitted 2015). Uncertainty quantification in virtual surgery hemodynamics predictions for single ventricle palliation. *International Journal of Numerical Methods in Biomedical Engineering*.

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Chris Budd Honored with OBE

SIAM News editorial board member Chris Budd was made Officer of the Most Excellent Order of the British Empire (OBE) for his efforts toward science and math education. Budd received the honor from Queen Elizabeth at a ceremony at Windsor Castle. He is one of the founders of "Bath Taps into Science," an annual hands-on science festival that aims to promote science and math to the public. Budd has been an active member of SIAM for many years. Here he is pictured with (from left) his wife Sue, his daughter Byrony, and his mother Jillian.

Gromov's Non-squeezing Theorem and Optics

MATHEMATICAL CURIOSITIES
By Mark Levi

A remarkable theorem discovered by Gromov ([1], [2]) states that it is impossible to map the unit ball $q_1^2+p_1^2+q_2^2+p_2^2 \le 1$ in $\mathbb{R}^4$ into a cylinder $q_1^2+p_1^2 \le r^2$ of smaller radius $r<1$ by a symplectic mapping.[1] This general statement has a surprising implication in optics.

Any optical device (a system of lenses and mirrors) gives rise to a symplectic map in $\mathbb{R}^4$ as follows. Placing the device between two parallel planes (Figure 1), we specify an incoming ray by the coordinates (q_1, q_2) of its crossing the first plane, and by the direction sines $(\sin\theta_1, \sin\theta_2)=(p_1, p_2)$. The ray is thus characterized by the point $x=(q_1,q_2,p_1,p_2)\in\mathbb{R}^4$. Let $X=(Q_1,Q_2,P_1,P_2)$ be the similarly-defined "exit data" of the same ray. Now it turns out that the mapping φ from x to X is symplectic, preserving the symplectic form ω mentioned in the footnote. (An intuitive proof, along with a physical interpretation of ω, can be found in [3]).

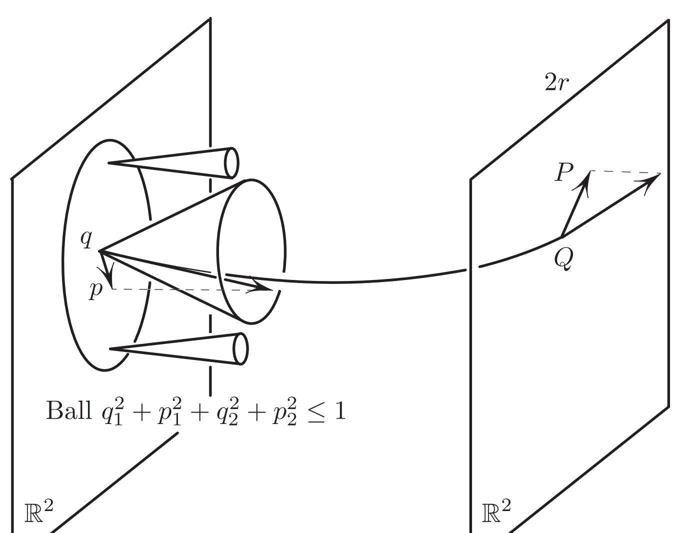

Figure 1.

With such parametrization of rays, the unit ball in $\mathbb{R}^4$ can be seen on the left side of Figure 1: at each point $q=(q_1,q_2)$ we have a cone of rays whose direction sines satisfy $p^2 \le 1-q^2$ (in particular, the cones become narrower near the edge of the unit disk). The cylinder $Q_1^2+P_1^2 \le r^2$ (Figure 2) corresponds to the set of rays exiting through the slit $|Q_1|\le r$ and confined to the dihedral angle with $|P_1|=|\sin\Theta_1|\le\sqrt{1-r^2}$. Again, the aperture of this angle decreases with the distance to the edge of the slit.

And thus Gromov's theorem implies the surprising fact that no optical device can shepherd the unit "ball" of incoming rays (Figure 1) through a narrow slit and with a narrow dihedral angle, as described more precisely in the preceding sentence.

Speaking of applications, the first application of Gromov's theorem to PDEs can be found in the remarkable paper [4].

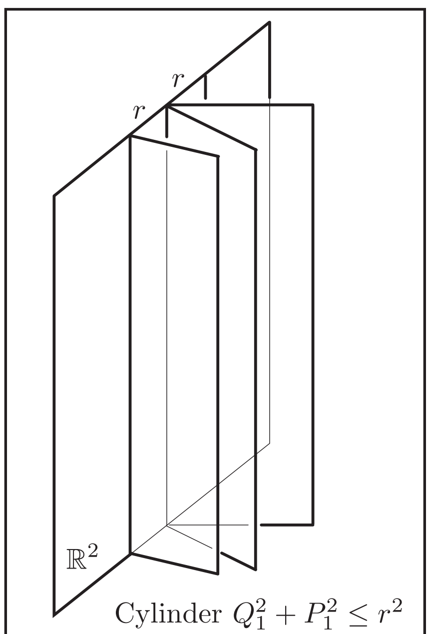

Figure 2.

[1] More precisely, by the map preserving the form $\omega=dq_1\wedge dp_1+dq_2\wedge dp_2$. Geometrically, this amounts to the requirement that for any infinitesimal parallelogram the sum of signed areas of its projections onto the planes (q_1,p_1) and (q_2,p_2) is preserved under the map.

References

[1] Gromov, M. (1985). Pseudo holomorphic curves in symplectic manifolds. *Inventiones Mathematicae, 82*, 307-347.

[2] Hofer, H., & Zehnder, E. (1994). *Symplectic Invariants and Halmiltonian Dynamics*. Birkhauser.

[3] Levi, M. (2014). Classical Mechanics with Calculus of Variations and Optimal Control: an Intuitive Introduction. *AMS*.

[4] Kuksin, S. (1995). Infinite Dimensional Symplectic Capacities and a Squeezing Theorem for Hamiltonian PDEs. *Commun. Math. Phys. 167*, 531-552.

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Electric Grid

Continued from page 2

taining stability and reliability in their region of the grid. The measurement *Y(t)* is a sum of error signals, including deviation in grid frequency (60 Hz in the U.S.). In most cases, the compensator G_c is proportional-integral (PI) control, designed by the grid operator to maintain supply-demand balance.

The actuation block *H* models the cooperation of many *ancillary services* acting in parallel, provided by the electric grid in order to facilitate and ensure the continuous flow of electricity so that supply will continually meet demand. Each service receives a command from a BA and adjusts power up or down in response. Resources providing ancillary service include responsive generators and batteries.

The grid transfer function G_p takes as input power mismatch and output *Y(t),* as shown in Figure 2 (on page 2). We have many observations of the grid following a generation outage that can be used to construct a grid model. It is fortunate that these dynamics are quick, relative to disturbances from nature; the natural frequency in a second order model for G_p corresponds to timescales of less than 20 seconds [2]. The disturbances entering the grid from renewable energy evolve on much slower timescales, where the grid transfer function G_p appears as a static gain.

Demand Dispatch

When viewed as a centralized control problem, renewable energy integration does not appear to be a great challenge because grid dynamics are relatively tame on the timescales of disturbances introduced by solar or wind generation. The challenge lies in finding resources that can be harnessed to create the actuator block *H* in Figure 2. If this is to be achieved using flexible demand, we must investigate what is meant by flexibility.

While consumers expect some guarantees on quality of service (QoS), the grid operator at a BA desires reliable ancillary service obtained from inherent flexibility in the consumer's power consumption. These seemingly-conflicting goals can be achieved simultaneously by local control; an appliance can monitor its QoS and other state variables, receive information from the BA, and adjust its power consumption accordingly. Methods to create "virtual energy storage" (VES) from flexible loads offer reliable resources to grid operators without impacting the needs of consumers.

Experiments conducted at the University of Florida have shown that loads in commercial HVAC systems can provide regulation at timescales of one to 20 minutes through manipulation of the fans in the ventilation system; a local feedback loop ensures that the power deviation provided to the grid tracks the desired regulation signal. The cost is negligible, with no impact on building climate [1]. Installation is simple, because these commercial buildings are already equipped with building automation systems. The aggregate capacity of ancillary service obtained is on the order of gigawatts in this frequency range.

Many loads that can provide VES in lower frequency ranges consume power at discrete values. Figure 3 shows power consumption for a typical residential refrigerator. The lighter plot shows the power consumption deviation that would be observed using local control for VES. These minor variations in cycling are not expected to impact QoS to the refrigerator owner. But how can this be useful for the grid?

Through several layers of local control, a collection of many refrigerators can provide VES in a frequency range near the natural frequency of the loads (in this case, corresponding to a period of one hour). A randomized control architecture creates the degrees of freedom required to track the regulation signal received from the balancing authority [3]. The aggregate of loads will appear as a perfect battery, subject to constraints on the frequency range of ancillary service it provides. Of course, residential refrigerators are only a tiny fraction of the flexible loads that can be harnessed in this way.

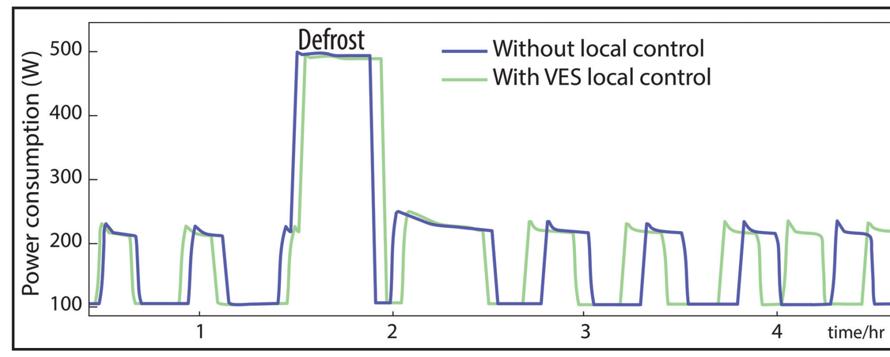

Figure 3. *Nominal power consumption of a residential refrigerator is approximately periodic.*

In conclusion, there is incredible value in placing consumers in the loop. This is only possible through careful design of local control loops to ensure that both the consumer and the grid receive what they need. Naturally, even if there is no cost or loss of QoS, the consumer needs incentives to participate. Contracts between BAs and ancillary service providers are highly successful today. Fixed payments for engagement and regular payments proportional to "services rendered" may incentivize more flexibility from consumers, leading to a more robust grid that can manage greater levels of renewable energy.

Acknowledgments: The research surveyed here was supported in part by NSF grants CPS-0931870 and CPS-1259040. Many thanks to my colleagues and to Bob Moye, who provided comments on the first draft of this article.

References

[1] Lin, Y., Barooah, P., Meyn, S., & Middelkoop, T. (2015). Experimental evaluation of frequency regulation from commercial building HVAC systems. *IEEE Trans. on Smart Grid, 6*(2), 776–783.

[2] Mathias, J., Kaddah, R., Bušić, A., & Meyn, S. (2015). Smart fridge / dumb grid? demand dispatch for the power grid of 2020. Proc. *49th Annual Hawaii International Conference on System Sciences (HICSS).* To appear online at arXiv:1509.01531.

[3] Meyn, S., Barooah, P., Bušić, A., Chen, Y., & Ehren, J. (2015). Ancillary service to the grid using intelligent deferrable loads. *IEEE Trans. Automat. Control, 60*(11), 2847–2862.

[4] Robinson, S. (2005). Math model explains volatile prices in power markets. *SIAM News, 38*(8).

[5] Schweppe, F., Tabors, R., Kirtley, J., Outhred, H., Pickel, F. & Cox, A. (1980). Homeostatic utility control. *IEEE Trans. on Power Apparatus and Systems, PAS-99*(3), 1151–1163.

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Communicating Science as a Mass Media Fellow

By Anna Lieb

As an applied mathematics Ph.D. candidate, it is not inconceivable that I would need to learn about one of the following: the hydrology of dam removal,[1] the algorithms behind computer-generated surrealist art,[2] the subtleties of friction[3] at small scales, or the population dynamics of sex-reversed lizards.[4] But during the summer of 2015, as a SIAM-sponsored AAAS Mass Media Fellow, I had the remarkable opportunity to explore all of these subjects and more by spending 10 weeks writing features and news stories for NOVA Next,[5] the website of PBS NOVA.

The AAAS Mass Media Science & Engineering Fellows[6] program places students in science, engineering, and mathematics at science desks in media outlets around the country. The program seeks to foster stronger communication skills among scientists and promote public understanding of science. I am quite keen on both of these things, and for the past three years have spent much of my free time writing and editing for the *Berkeley Science Review*,[7] a University of California, Berkeley publication with similar goals. I was therefore delighted at the prospect of working with and learning from professional science writers and editors as a Mass Media Fellow.

Figure 2. *In Lieb's first feature, an article about sustainably-sourced palm oil, she reported on extensive mangrove forests in the Sundarbans (pictured above) that protect the region from coastal flooding. Photo credit: Wikimedia Commons.*

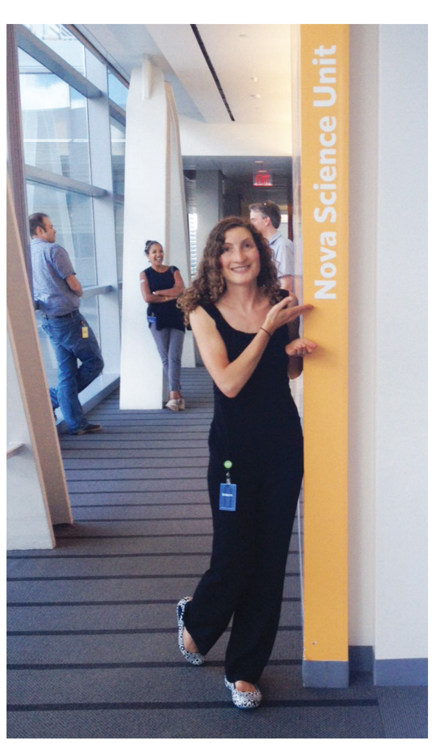
Figure 1. *In an article entitled "Friction Fighters," Lieb discussed the subleties of friction and the fact that even the smoothest surfaces resemble mountain ranges up close. Photo credit: John Town/Flickr (CC BY-NC-ND).*

On my first day at NOVA Next, I arrived a touch disheveled after unwittingly biking through half of Boston. My editor got me started writing immediately. I covered advances in ecology, physics, medicine, computer science, and astronomy, among other topics. One day I'd be chatting with a physicist about how to make graphene;[8] the next I'd be traipsing through a field to get a look at the oldest dam[1] in the US. I enjoyed seeing numerous facets of scientific research and exploring how they related to history, economics, and policy. I had cause to call up to all sorts of fascinating people and request a conversation—and they were usually happy to oblige. I spoke with dozens of scientists, the Director of the California Academy of Sciences, and even the Deputy Secretary of the Department of the Interior.

Covering these diverse subjects solidified my conviction that effectively presenting scientific information to the general public is a challenging and intriguing endeavor in its own right. Writing for popular audiences is not simply a matter of "dumbing down" complex material. Distilling the key ideas in a scientific finding—and reporting them without the crutches of equations or jargon—is no small task. My training in applied mathematics complicates my efforts as a writer; due to many years of coursework and research, my vernacular and frame of reference contain elements that are quite foreign to most people. For example, when covering the science of friction[3] at small scales, I nonchalantly explained that the ratio of atomic spacings in two different surfaces was an irrational number. My editor pointed out that many NOVA readers would not immediately know what the term "irrational number" meant, even if they were actually familiar with some irrational numbers like π. I extended my description and added a visual representation,[9] making the article more readable and thus more accessible.

I learned to step outside of my own experience in order to see the broader appeal in a scientific story. In that regard, my colleagues were especially helpful. I was just around the corner from the office of the "Gross Science" team, whose entire job consisted of digging up disgusting (but also fascinating) scientific topics and making short videos. These folks, and the rest of the NOVA Next team, helped me understand how to present a story in a way that was compelling or humorous without sacrificing accuracy. For example, when I struggled to come up with titles, my editor reminded me that titles are "promos, not promises."

I did sneak some math into my writing—for example, in my first feature[10] I used published findings to calculate the average number of long-tailed macaques a consumer would save if he/she paid a 60-cent premium for sustainably-sourced palm oil (spoiler alert: it's on the order 10^{-6} macaques for every 500 mL of oil). The piece contained a link[11] to an iPython notebook that tabulated the assumptions and ran the numbers, an addition some readers thoroughly enjoyed. I found that although general audiences may approach mathematics with some hesitation, well-chosen numbers provided compelling details that made a story really stand out. I kept this in mind while writing my piece on the science of dam removal[1], where I illustrated the distribution of US dams with both numbers and interactive maps.[12]



Anna Lieb as a Mass Media Fellow for NOVA Next, the website of PBS NOVA. Photo credit: Tim De Chant.

My summer as an AAAS Fellow taught me how to vary my writing from the crisp, energetic tone of a reporter to the more musing style of an essayist. I learned to size up my audience and offer them engaging material as compensation for the time they devoted to reading my words. Writing is actually an important component of applied mathematics, whether we're communicating results to peers or applying for grants. The opportunity to focus on writing will thus prove very useful within the context of my field, and likely the fields of other scientists. I'm also coming back to my Ph.D. program with a new appreciation for the importance—and challenge—of compellingly communicating science and mathematics to the general public.

If you are a student (undergraduate or graduate) and any of this piques your interest, I encourage you to apply to be a Mass Media Fellow in 2016. Applications are due January 15th: http://www.aaas.org/program/aaas-mass-media-science-engineering-fellows-program.

Anna Lieb is a fifth-year Ph.D. student in the Department of Mathematics at the University of California, Berkeley. She is interested in fluid mechanics, numerical methods, optimization, and applications, and works on modeling urban water distribution under intermittent supply.

1 http://www.pbs.org/wgbh/nova/next/earth/dam-removals/
2 http://www.pbs.org/wgbh/nova/next/tech/left-to-their-own-devices-computers-create-trippy-surrealist-art/
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Annual Symposium Brings Together SIAM Chapters Across Germany

Universität Trier chapter students on their field trip to Bayer AG in Leverkusen, Germany. (First row, from left): Martin Siebenborn, Julian Wagner, Patrick Groetzner, Martin Rupp, Dennis Kreber, and Philip Rosenthal. (Second row, from left): Van Nguyen, Laura Somorowsky, Kathrin Welker, Heinz Zorn, Christina Schenk, Bernd Perscheid, and Ulf Friedrich.

Since the first German SIAM Student Chapter was established at Universität Trier in 2008, there has been a rapid growth in SIAM student chapters in the country. In order to facilitate a regular exchange among students in the region as well as in various disciplines of applied mathematics, the chapter organized an annual symposium in Trier in 2012, which was followed by meetings in Heidelberg in 2013 and Magdeburg in 2014.

The fourth symposium of German SIAM Student Chapters took place this past August in Trier. Chapters across Germany, including Aachen, Berlin, Hamburg, Heidelberg, Magdeburg, and the Czech chapter from Prague were invited to the event, as were mathematicians from the Fraunhofer Institute for Industrial Mathematics in Kaiserslautern.

Scientific sessions covered a broad range of topics in computational optimization, discrete optimization, and numerical analysis, including mathematical models to study risk of bat populations and the cutting of gemstones in an optimal way.

The Trier chapter also organized an excursion to Bayer AG, a life science company at Leverkusen, in September. As a large chemical and pharmaceutical company, Bayer uses applications of mathematics in the optimization of chemical processes, as well as for financial management, and students got a firsthand look at these applications in addition to a tour of BayKomm, the company's communication centre.

— The SIAM Student Chapter at Universität Trier

M³ CHALLENGE

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In 2015, 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 M³ 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.

Problems should:

- 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 down into parts with some parts easier than others so that all teams can make some progress
- Identify references to help get students started

Submit your problem statement idea in the format of 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.

Upload your file at m3challenge.siam.org/problem/submitproblems.php

Previous problem titles

2006: Solving the Social Security Stalemate
2007: Beat the Street!
2008: Energy Independence Meets 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?
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2014: Lunch Crunch: Can Nutritious be Affordable and Delicious?
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- Problems found suitable to add to the M³ problem reserve bank receive $150; an additional $150 will be paid if it is used as a sample or resource on the Challenge website.

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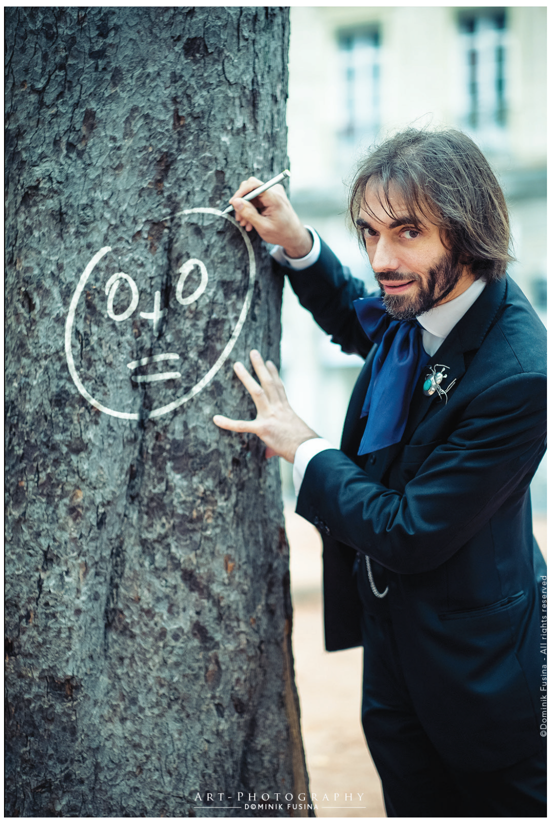
Villani's *Birth of a Theorem*

Birth of a Theorem: A Mathematical Adventure. *By Cédric Villani, Farrar, Straus and Giroux, New York, 2015, 272 pages, $26.00.*

BOOK REVIEW
By Robert McCann

Cédric Villani's newly-translated popular work, *Birth of$_a$ Theorem: $\frac{a}{m}$athematical Adv(e^n)ture,* is a book without precedent. It was apparently born of an encounter with Olivier Nora, who suggested to Villani that, in the wake of his 2010 Fields Medal, the general public would be fascinated to have the opportunity to read anything accessible he might be able to write on the nature of his award-winning work. The author took this to mean not only the mathematical content of what was produced, but also the process by which it was achieved, including the daily life and modus operandi of a leading mathematician. In response to this challenge, Villani offers the reader a window into the three years of his life during which he collaborated with Clement Mouhot on the problem of Landau damping. The result is equal parts diary, documentary, collage, stream of consciousness, mathematical history, biography, and exposition. The translator notes that "The book is meant chiefly as a work of literary imagination...The technical material, though not actually irrelevant, is in any case inessential to the story."

The story opens in the laboratory of the Ecole Normale Superiere de Lyon on a Sunday afternoon. Mouhot and Villani are in the latter's office to discuss prospects for the Boltzmann equation, which describes the statistical evolution of a colliding gas. By the end of the conversation and several pages later, Villani has reconstructed a positivity result for a collisionless gas, which he had heard about from a postdoctoral fellow at Princeton University. Mouhot wonders aloud whether the argument might be relevant to some controversies concerning the longtime behavior of a charged plasma interacting electrodynamically. This is followed by a two page aside on Ludwig Boltzmann, which displays his equation and his entropy law and relates the two by observing that the latter behaves monotonically along the dynamics of the former (exhibiting one particular mathematical incarnation of the second law of thermodynamics). The aside describes its subsequent impact and recalls some tragic details from Boltzmann's life. There is also a depiction of Boltzmann, the first of a dozen or more sketches produced by Claude Gondard that tie together Villani's story and illustrate many of its principal characters, living and dead. The sketches provide a sense of historical evolution in mathematics, portraying great minds revisiting persistent questions century after century, building on each other's insights to peel back layers of some of the most profound mysteries in science. For example, why did structure emerge in the universe, and on what time scale?



Cédric Villani, recipient of the 2010 Fields Medal and author of the newly-translated Birth of a Theorem: A Mathematical Adventure. *© Fusina Dominik.*

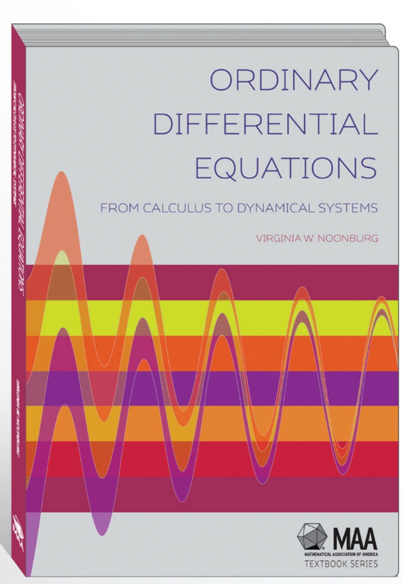
The second chapter flashes back to a lunch at Oberwolfach two years earlier, during which a conversation with a pair of experts about the Landau damping phenomenon in plasma physics piques Villani's curiosity. The discussion concerned a paradox Landau predicted based on a linearization of dynamics. In the paradox, the Vlasov equation (which gives a statistical description of a Coulomb gas — either attractive in the case of gravity, or repulsive as in the case of electrically-charged particles), despite being reversible in time, possesses certain equilibria which are stable, in the sense that the equation drives nearby initial data back to them both as $t \to +\infty$ and $t \to -\infty$. Many experiments observed this damping phenomenon, while there were others that seemed to violate it. Conservation of the Liouville measure precludes such behavior for a finite dimensional Hamiltonian system, but the Vlasov dynamics describe an infinite dimensional (statistical) limit. During a subsequent visit to Brown University, Mouhot learned that the mathematical crux of the matter, which had never been resolved, was whether or not linearization correctly predicted the nonlinear dynamics, and if so, in what sense.

Their combined eventual resolution of this problem was among the principal contributions that garnered Villani his Fields Medal. (For those who want to know the answer: they show that the nonlinear equation indeed produces the local damping effect, but only for analytic or near-analytic initial data. For such data, the dynamics smooth the spatial density while producing oscillations in the velocity variable; the convergence back to equilibrium occurs in a weak topology which does not see these oscillations.)

However, the book attempts to trace the actual, meandering trajectory Villani traversed during the years he spent searching for this result, the many random (and some less random) encounters which shaped his thinking on this problem. There are certainly excursions into a variety of far-flung mathematical realms, including questions in number and graph theory, which have no relation to Landau damping. But there are equally many excursions to faraway conferences, children's music lessons, a semester at the Institute for Advanced Study, a change in employer, and explorations of the author's taste in poetry (e.g. William Blake), music (e.g. Catherine Ribiero), and books (e.g. Japanese comics). Also reproduced throughout the text are email correspondences from the period in question — many between Villani and his collaborator, Mouhot, but also others tangential to Villani's story (including one from yours truly). Further additions include pages from a few different math papers, excerpts from Villani's book on optimal transport, a figure illustrating one of the reviewer's theorems, and slides from a lecture on an unrelated topic. *Birth of a Theorem* is a charming insider's guide to a mathematician's world, meant to convey the mystery, excitement, agony, ecstasy, and quotidian that seduce mathematicians into the profession. Designed to be accessible to outsiders, the original was a bestseller in France, titled *Théoréme Vivant,* meaning *Living (the) Theorem* or *Theorem Alive!* Insiders will find it delightful as well. *Birth of a Theorem* offers readers not only the chance to tag along with a future recipient of the Fields Medal as he does some of his best work, but also a delightful glimpse into the foreign land in which mathematicians seem to spend so much of their time.

Robert McCann (mccann@math.toronto.edu) is a professor of mathematics at the University of Toronto. He is the originator of displacement convexity and an authority on optimal transport. He has also co-authored publications on kinetic equilibration in granular media with Cédric Villani.

Modern ODEs at an Affordable Price



Ordinary Differential Equations: From Calculus to Dynamical Systems
By V.W. Noonburg
MAA Textbooks

The author's writing style is very clear and should be quite accessible to most students reading the book. There are lots of worked examples and interesting applications, including some fairly unusual ones...This book offers a clean, concise, modern, reader-friendly approach to the subject, at a price that won't make an instructor feel guilty about assigning it. —MAA Reviews

The writing is clear, the problems are good, and the material is well motivated and largely self-contained. This new book is highly recommended for students anxious to discover new techniques. —SIAM Review

This book presents a modern treatment of material traditionally covered in the sophomore-level course in ordinary differential equations. While this course is usually required for engineering students the material is attractive to students in any field of applied science, including those in the biological sciences.

The standard analytic methods for solving first and second-order differential equations are covered in the first three chapters. Numerical and graphical methods are considered, side-by-side with the analytic methods, and are then used throughout the text. An early emphasis on the graphical treatment of autonomous first-order equations leads easily into a discussion of bifurcation of solutions with respect to parameters.

The book is aimed at students with a good calculus background that want to learn more about how calculus is used to solve real problems in today's world. It can be used as a text for the introductory differential equations course, and is readable enough to be used even if the class is being "flipped." The book is also accessible as a self-study text for anyone who has completed two terms of calculus, including highly motivated high school students. Graduate students preparing to take courses in dynamical systems theory will also find this text useful.

Catalog Code: FCDS
ISBN: 978-1-93951-204-8
334 pp., Hardbound, 2014
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MAA Member: $48.00

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The Models are Incomplete, the Intuitions are Unreliable

By Karl Kempf

Business decision–making is the focus of my work. I am especially interested in those business decisions where the difference between a good answer and a poor one is a billion dollars or more. Although such decisions are relatively common today, they have only been so for roughly the last 140 years. The Industrial Revolution set the stage for the so-called "big company." Old businesses merged and reorganized while entrepreneurs formed new businesses to leverage the confluence of mass production and mass distribution, meant to stimulate mass consumption. Standard Oil was established in 1870 and quickly became the largest oil refining company in the world. General Electric resulted from the merging of two small companies in 1892 and grew to become one of the 12 original companies included in the Dow Jones Industrial Average. In 1901, the combination of three companies resulted in U.S. Steel. Capitalized at $1.4B, it was the world's first billion-dollar corporation, and at one point the largest corporation in the world. The flow of new technologies continued to grow throughout the 20th century and is expanding even more rapidly today. At $486B, Sinopec Limited (the China Petroleum and Chemical Corporation) topped the 2014 list of largest companies. Even at Intel Corporation, whose 2014 revenue was only $56B, billion-dollar decisions are made on a regular basis. Such decisions include determining what features to incorporate in the next product, when and where to build the next factory, how much inventory to hold, and where to hold it, among others.

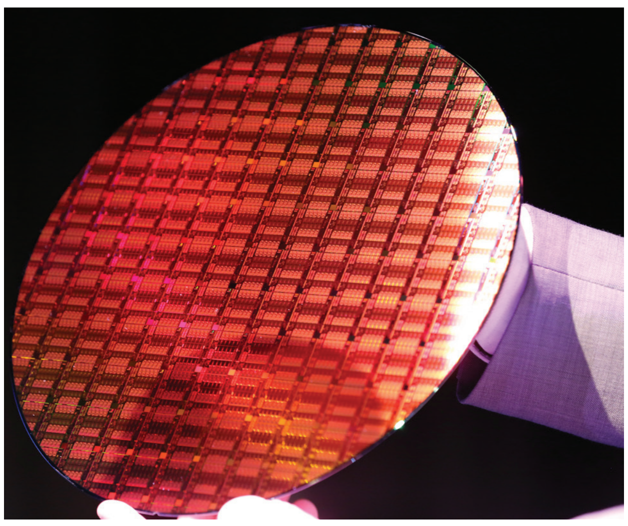

Figure 1. *Wafer with Intel® Xeon® processor E7 v2 family chips, each made of 4.3 billion 22nm transistors. Credit: Intel Newsroom.*

Over this 140-year time span, the intuition of senior management has played a major role in making big-business decisions. In this case, "intuition" refers to the bringing of one's entire life experience and learned heuristics to bear on current circumstance. This capability has been developed for millions of years in the limbic or emotional layer of the human brain, augmented only in the last few hundred thousand years by the neocortex or rational layer. These two layers, or systems, are so interconnected that it is impossible to use them independently. It is also important to note that, as most people have likely experienced, sometimes intuition is useful and sometimes it is not. Experts have arrived at a consensus on this point [1]. When a) the situation under consideration has structure, b) decisions made can be evaluated after the fact by some feedback loop, and c) the person supplying an intuitive response has experienced many repetitions, intuition can be very valuable. But when one or more of these conditions are violated, as they are in the vast majority of big-business decisions, intuition is unreliable.

Applied mathematicians would likely recognize that many big-business decisions involve large-scale stochastic combinatorial optimization problems. Instead of the emotional brain, the rational brain, or a combination of both, why not use today's high-speed digital hardware to solve strong algorithms encoded in modern software? Mathematical optimization techniques can solve large problems in minutes or hours. Powerful search techniques, like genetic algorithms and simulated annealing, can also provide near-optimal solutions. But there are issues. The Turing machine of 1937 became practical with the invention of the transistor in 1947 and the integrated circuit in 1959. The circuit then begat the 2,300 transistor microprocessor of 1971, which morphed into the multibillion transistor processor of today. Similar timelines exist for algorithms and software. However, a few decades of development for the computational approach versus the developmental timeline for purely mental decision-making is apparently inadequate to convert senior managers. This is especially true of those who believe that their superb business intuition propelled them to their current positions. Another issue concerns modeling. Although optimization techniques may quickly return an optimal or near-optimal solution to the model of the business problem, senior managers are correct in thinking no model can possibly include all important factors or relationships. Their skepticism is well founded.

The work of two Nobel Laureates begins to bridge the gap between unreliable intuition and incomplete models. Theoretical economists had assumed that humans exhibit perfect rationality in decision-making, collecting all relevant data and considering all rational alternatives. Herbert Simon showed, specifically in business decision-making, that our rationality in considering possibilities is bounded by incomplete data and inadequate computational resources (mental or electronic), as well as the urgen-

See **Models are Incomplete** *on page 12*

Professional Opportunities

Send copy for classified advertisements to: ***marketing@siam.org****; (215) 382–9800 ext. 364. The rate is $3.00 per word (minimum $375.00). Display advertising rates are available on request. For details 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****.*

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.

Baylor University

Department of Mathematics

The Department of Mathematics invites applications to fill the Jean and Ralph Storm Chair of Mathematics. The successful candidate, who is expected to be at the full-professor level, will be an excellent mathematician, with national and international recognition for scholarship, demonstrated excellence in teaching at the undergraduate and graduate levels and a history of successful, sustained grantsmanship. This endowed position provides an annual discretionary research fund to the successful candidate. Applications in all areas of mathematics will be considered. Active research areas in the department are in the general areas of algebra, analysis, differential equations, mathematical physics, numerical analysis, computational mathematics, representation theory, and topology. Several faculty in the department are engaged in interdisciplinary research with other departments on campus. Baylor encourages women, minorities, veterans and individuals with disabilities to apply. Detailed information about the department can be found at the http://www.baylor.edu/math.

To ensure full consideration, complete applications must be submitted by 02/15/16. Applications will be reviewed immediately after this date and will be accepted until the position is filled.

We encourage all applicants to submit their materials online at http://www.mathjobs.org/jobs. Candidates should possess an earned doctorate in the appropriate field of study. A complete application includes a cover letter of application (please refer to the job number BQ 34499), at least three letters of recommendation, a current curriculum vitae, original doctoral transcripts, and a statement of support for Baylor's Christian mission (see http://www.baylor.edu/profuturis/), indicating your religious affiliation and a few brief statements about your faith. Alternatively, candidates can arrange for their application materials to be sent directly to: Dr. Lance L. Littlejohn, Department of Mathematics, Baylor University, One Bear Place #97328, Waco, TX 76798-7328.

Baylor University is a private Christian university and a nationally ranked research institution, consistently listed with highest honors among The Chronicle of Higher Education's "Great Colleges to Work For." Chartered in 1845 by the Republic of Texas through the efforts of Baptist pioneers, Baylor is the oldest continuously operating university in Texas. The university provides a vibrant campus community for over 15,000 students from all 50 states and more than 80 countries by blending interdisciplinary research with an international reputation for educational excellence and a faculty commitment to teaching and scholarship. Baylor is actively recruiting new faculty with a strong commitment to the classroom and an equally strong commitment to discovering new knowledge as we pursue our bold vision, Pro Futuris (www.baylor.edu/profuturis/).

Baylor University is a private not-for-profit university affiliated with the Baptist General Convention of Texas. As an Affirmative Action/Equal Opportunity employer, Baylor is committed to compliance with all applicable anti-discrimination laws, including those regarding age, race, color, sex, national origin, marital status, pregnancy status, military service, genetic information, and disability. As a religious educational institution, Baylor is lawfully permitted to consider an applicant's religion as a selection criterion.

California Institute of Technology

Department of Computing and Mathematical Sciences

The Computing and Mathematical Sciences Departmnet (CMS) at Caltech invites applications for a tenure-track faculty position. Our department is a unique environment where innovative, interdisciplinary, and foundational research is conducted in a collegial atmosphere. We will consider candidates in all areas of computing, broadly defined; research areas of particular interest include (but are not limited to) learning and computational statistics, security and privacy; robotics and autonomous systems; networked and distributed systems; optimization and computational mathematics. Additionally, we are seeking candidates who have demonstrated strong connections to other fields, including the physical, biological, mathematical, and social sciences.

A commitment to high-quality teaching and mentoring is expected. The initial appointment at the assistant-professor level is for four years and is contingent upon the completion of a Ph.D. degree in Computer Science, Applied Mathematics or related field.

To ensure the fullest consideration, applicants are encouraged to have all their application materials on file by November 1st, 2015. For a list of documents required and full instructions on how to apply on-line, please visit http://www.cms.caltech.edu/search. Questions about the application process may be directed to: search@cms.caltech.edu.

Caltech is an Equal Opportunity/Affirmative Action Employer. Women, minorities, veterans, and disabled persons are encouraged to apply.

Southern Methodist University

Department of Mathematics

Applications are invited for the Clements Chair of Mathematics (position no. 00050961) to begin in the fall semester of 2016. The department is searching for senior scholars with outstanding records of research in computational and applied mathematics as well as a strong commitment to teaching, including an established history of advising doctoral students. We are seeking candidates whose interests align with those of the department and who would contribute in a substantial way to the university's initiatives in high performance computing and interdisciplinary research. In addition we expect the Clements Chair to provide leadership in the further development of our graduate and undergraduate programs.

The Department of Mathematics offers graduate degrees in Computational and Applied Mathematics and includes 17 tenured or tenure-track faculty researchers, all of whom work in application areas. Visit http://www.smu.edu/math/ for more information. To apply send a letter of application with a curriculum vitae, a list of publications, research and teaching statements, and the names of three references to: The Faculty Search Committee, Department of Mathematics, Southern Methodist University, P.O. Box 750156, Dallas, Texas, 75275-0156. The Search Committee can also be contacted by sending e-mail to mathsearch@mail.smu.edu. (Tel: (214)768-2452; Fax: (214)768-2355).

Applications received by December 15, 2015 will receive full consideration, but will continue to be accepted until the position is filled. A Ph.D. in applied mathematics or a related field is required. Applicants will be notified when the search is concluded.

SMU, a private university with active graduate and undergraduate programs in the sciences and engineering, is situated in a quiet residential section of Dallas. The Dallas-Fort Worth Metroplex is America's fourth largest metropolitan area, and residents enjoy access to world-class cultural and entertainment activities.

Southern Methodist University will not discriminate in any program or activity on the basis of race, color, religion, national origin, sex, age, disability, genetic information, veteran status, sexual orientation, or gender identity and expression. The Executive Director for Access and Equity/Title IX Coordinator is designated to handle inquiries regarding nondiscrimination policies and may be reached at the Perkins Administration Building, Room 204, 6425 Boaz Lane, Dallas, TX 75205, 214-768-3601, accessequity@smu.edu.

Hiring is contingent upon the satisfactory completion of a background check.

Boston University

Department of Mathematics and Statistics

The Department of Mathematics and Statistics invites applications for a tenure-track Assistant Professor level position in Number Theory. Ph.D. required. The position will begin July 1, 2016. A strong commitment to research and teaching at the undergraduate and graduate levels is essential. A complete application will consist of a cover letter, CV, research statement, teaching statement, and four letters of recommendation, at least one of which addresses teaching. Please submit all materials online to mathjobs.org. Alternatively, please have hardcopies mailed to Number Theory Search, Department of Mathematics and Statistics, Boston University, 111 Cummington Mall, Boston, MA 02215. The application deadline is December 15, 2015. We are an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law. We are a VEVRAA Federal Contractor.

Colorado School of Mines

Department of Applied Mathematics and Statistics

The College of Engineering and Computational Sciences' Department of Applied Mathematics and Statistics at the Colorado School of Mines (Mines) invites applications for an open rank faculty position in applied mathematics. Multiple appointments or appointment at a more senior level may be considered for exceptional candidates. We seek candidates excited to share in our mission to address the challenges of a sustainable global society by educating the next generation of leading engineers and scientists and by expanding the frontiers of knowledge through research. Preference will be given to those with expertise commensurate with departmental needs in applied mathematics research and teaching. Faculty research areas in the department are: applied mathematics, applied analysis, computational mathematics, numerical analysis, and statistics.

For the complete job announcement, full statement of qualifications, and directions on how to apply, visit: http://inside.mines.edu/HR-Academic-Faculty.

Mines is an EEO/AA employer and is committed to enhancing the diversity of its campus community. Women, minorities, veterans, and individuals with disabilities are encouraged to apply.

Professional Opportunities

Continued from page 10

Colorado School of Mines

Department of Applied Mathematics and Statistics

The College of Engineering and Computational Sciences' Department of Applied Mathematics and Statistics at the Colorado School of Mines (Mines) is seeking a dynamic and enthusiastic leader to head the Department. We seek candidates excited to share in our mission to address the challenges of a sustainable global society by educating the next generation of leading engineers and scientists and by expanding the frontiers of knowledge through research.

Department heads at Mines generally continue to teach undergraduate and graduate courses, mentor graduate students, and carry out research. Further, the successful candidate will be expected to work effectively in a collaborative, interdisciplinary environment within the Department and across the Mines.

Applicants must have a Ph.D. in one of the Department's research areas and possess a distinguished record of accomplishment in scholarship, teaching and service. Administrative experience and evidence of successful personnel and financial management are highly desirable. Strong leadership qualities, including effective interpersonal communication and organizational skills, are a must. The successful candidate will have demonstrated high ethical standards and will be expected to operate in a transparent and collegial way.

For the complete job announcement, full statement of qualifications and directions on how to apply, visit: http://inside.mines.edu/HR-Academic-Faculty .

Mines is an EEO/AA employer and is committed to enhancing the diversity of its campus community. Women, minorities, veterans, and individuals with disabilities are encouraged to apply.

California State University, Fullerton

Department of Mathematics

Applications invited for at least one tenure-track position in applied mathematics. Candidates for these position(s) should be applied mathematicians with a background in computation, operations research, machine learning and mathematical modeling (with preference to statistical modeling). Responsibilities include teaching undergraduate and graduate courses in applied mathematics, conducting research resulting in publications in high-quality peer-reviewed journals, directing faculty-student collaborative research, and advising undergraduate students. The successful candidates will contribute to the mathematics community at Cal State Fullerton through teaching, research, professional activities, and service. In particular, they will be expected to solicit industrial consulting projects for students in the graduate program in applied mathematics, mentor the students in completing these projects, and participate in the transdisciplinary Center for Computational and Applied Mathematics (CCAM) within the College of Natural Sciences and Mathematics.

The qualified candidate must have a Ph.D. in applied mathematics or related field, plus at least one year of post doctoral experience either in research, teaching, or a related industrial field. For more details, please visit us at http://math.fullerton.edu.

Applicants must submit their materials through www.mathjobs.org. A full ad may be viewed at this site. Application Deadline is November 23, 2015.

University of Michigan

Department of Mathematics

Pending approval, the University of Michigan's Department of Mathematics is initiating a multi-year search for anticipated appointments at the tenure-track assistant, associate, or professor levels. These will be university-year appointments for September 1, 2016 or 2017. All ranks are encouraged to apply. Candidates should hold a Ph.D. in Mathematics or a related field (e.g. Statistics); have extraordinary credentials in any area of pure, applied, computational or interdisciplinary mathematics; and show outstanding promise and/or accomplishments in both research and teaching. Salaries are competitive and are based on credentials. Junior candidates should furnish a placement dossier consisting of a letter of application, curriculum vitae and three letters of recommendation; senior candidates should send a letter of application, curriculum vitae and names of three references. In all cases, please provide a statement of teaching philosophy and experience, evidence of teaching excellence and a statement of current and future research plans. Application materials should be submitted electronically through the AMS website http://www.mathjobs.org/. Alternatively, applications may be sent to: Personnel Committee, University of Michigan, Department of Mathematics, 2074 East Hall, 530 Church Street, Ann Arbor, MI 48109-1043. Applications are considered on a continuing basis but candidates are urged to apply by December 1, 2015. Inquiries may be made by e-mail to math-fac-search@umich.edu. More detailed information regarding the Department may be found on our website: http://www.lsa.umich.edu/math/. Women and minority candidates are encouraged to apply. The University of Michigan is supportive of the needs of dual career couples and is an equal opportunity/affirmative action employer.

University of Michigan

Department of Mathematics

The University of Michigan's Department of Mathematics expects to have Lecturer positions for 2016-2017. These are not tenure-track but may be renewed, annually, for up to the first four years, and thereafter, for intervals of three to five years. These are 100% university-year appointments with an expected start date of September 1, 2016. A typical full-time (100% effort) load for a Lecturer I in the College of Literature, Science, and the Arts is three courses per semester. Criteria for selection and for renewal is excellence in the classroom. Interest and activity in pedagogical research is encouraged but not essential for reappointment. The successful candidate is likely to have substantial experience in teaching mathematics and a doctorate in mathematics or a closely related area. Please submit a curriculum vitae, a statement of teaching philosophy and experience, evidence of teaching excellence and the names of at least three references. Application materials should preferably be submitted electronically through the AMS website http://www.mathjobs.org/. Alternatively, applications may be sent to: Lecturer Hiring Committee, University of Michigan, Department of Mathematics, 2074 East Hall, 530 Church Street, Ann Arbor, MI, 48109-1043. Applications are considered on a continuing basis but candidates are urged to apply by December 1, 2015. Inquiries may be made by e-mail to math-fac-search@umich.edu. More detailed information regarding the Department may be found on our website: http://www.lsa.umich.edu/math/. Women and minority candidates are encouraged to apply. The University of Michigan is an equal opportunity/affirmative action employer. This appointment is subject to the UM/LEO Agreement.

The University of Alabama

Department of Mathematics

The Department of Mathematics at the University of Alabama invites applications for a tenure-track Assistant Professor position in the area of Topology beginning on August 16, 2016. We are particularly interested in applicants researching low dimensional topology or knot theory and their connections with gauge theory, Floer theories, or symplectic/contact topology. However, applicants from other areas of topology or related areas in differential geometry may also be considered. The University of Alabama is a Learner Centered institution. The ideal candidate should be committed to providing stellar education to undergraduate and graduate students. In addition, the successful candidate should be interested in supervising undergraduate research opportunities and graduate dissertations. The University is also pushing to improve its research position, and expects the successful candidate to develop a strong research program and to pursue external funding.

Applicants should complete the online application at https://facultyjobs.ua.edu/postings/37682. The application should include a letter of application, a current curriculum vita, a research statement, a teaching statement, and four letters of recommendation (one of which concerns teaching). The recommendation letters should be sent electronically to: math@ua.edu. Candidates must possess a doctoral degree in mathematics or a closely related field by August 16, 2016. Further experience in teaching and research is desirable. Applications will be reviewed on an ongoing basis starting December 12th, and will continue to be accepted until the position is filled. The University of Alabama is an Equal Opportunity/Affirmative Action employer and actively seeks diversity among its employees. Women, Hispanic, African-American and other minority candidates are strongly encouraged to apply. For more information about the department and the university visit our website at math.ua.edu.

Southern Methodist University

Department of Mathematics

The Department of Mathematics at Southern Methodist University invites applications to its MS and Ph.D. programs in Computational and Applied Mathematics. We offer high quality teaching in small classes focused on numerical analysis, high performance computing and mathematical modeling. Students in our PhD program pursue research in close collaboration with faculty in application areas including fluid dynamics, electromagnetics, computational physics, data analysis, and biology.

The department offers financial support in the form of teaching and research assistantships that include full tuition and a competitive stipend. For exceptionally qualified applicants we also offer a limited number of Gladwell-Shampine fellowships, as well as competitive University fellowships which provide an addition of up to $5,000 of annual stipend. Recent Ph.D. graduates have found employment in academia, national labs, and the private sector.

For further information visit http://www.smu.edu/Dedman/Academics/Departments/Math/Graduate.

University of Texas at Austin

Institute for Computational Engineering and Sciences

Opportunities for post-doctoral research in Computational Oncology job summary: Applications are invited for a Postdoctoral Research Fellowship in the Institute for Computational and Engineering Sciences at The University of Texas at Austin. The openings are for post-doctoral scholars to develop algorithms and techniques for modeling and predicting tumor growth and treatment response. The successful applicant(s) will join a highly collaborative, multi-disciplinary team (The Tumor Modeling Group, led by Dr. Tom Yankeelov) and have the opportunity to work on all aspects of tumor modeling, from theory to experiment. For more information on the position and projects of interest, please do not hesitate to contact: Thomas Yankeelov, Ph.D. W. A "Tex" Moncrief, Jr., Simulation-Based Engineering and Sciences Professorship II - Computational Oncology Institute for Computational Engineering & Sciences, Professor of Biomedical Engineering, The University of Texas at Austin, yankeelov@ices.utexas.edu.

Qualifications: Applicants must have a Ph.D. in computational sciences, engineering, physics, systems/computational biology, or a related field with a strong background in numerical solutions of partial differential equations. Experience in biomedical imaging and/or cancer biology is highly desirable.

How to Apply: Interested applicants should send a cover letter, 500 word statement of research interests, current CV, and a list of three references as a single PDF file to yankeelov@ices.utexas.edu.

The University of Texas at Austin is an Equal Employment Opportunity/Affirmative Action Employer. This job is a security-sensitive position.

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Yau Mathematical Sciences Center

Yau Mathematical Sciences Center
Tsinghua University, Beijing, China

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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 0.15-1.0 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 2015, and closes by April 30, 2016.

Applicants are encouraged to submit their applications before December 31, 2015.

INSTITUTE FOR COMPUTATIONAL ENGINEERING & SCIENCES

The *Institute for Computational Engineering and Sciences (ICES)* at *The University of Texas at Austin* is searching for exceptional candidates with expertise in computational science and engineering to fill several Moncrief endowed faculty positions at the Associate Professor level and higher. These endowed positions will provide the resources and environment needed to tackle frontier problems in science and engineering via advanced modeling and simulation. This initiative builds on the world-leading programs at ICES in Computational Science, Engineering, and Mathematics (CSEM), which feature 16 research centers and groups as well as a graduate degree program in CSEM. Candidates are expected to have an exceptional record in interdisciplinary research and evidence of work involving applied mathematics and computational techniques targeting meaningful problems in engineering and science. For more information and application instructions, please visit: www.ices.utexas.edu/moncrief-endowed-positions-app/. This is a security sensitive position. The University of Texas at Austin is an Equal Employment Opportunity/Affirmative Action Employer.

THE UNIVERSITY OF TEXAS AT AUSTIN

Ethics and Raw Data

By Ted Lockhart

Scientists have a well-established tradition of disseminating their research results. Those results often include collected data, which researchers are generally willing to share. There are limits, of course. If research involves human subjects, their privacy must be protected. If data contains trade secrets, employers may insist that researchers maintain confidentiality. And it is easy to imagine other exceptions, such as those related to human safety, legal requirements, business contracts, etc. However, scientists who do basic research — research intended to develop, test, or extend general theories — are likely to have broad discretion concerning the use of their data. The following discussion will focus on this kind of scientist.

Although research scientists are accustomed to sharing their research results, in some situations they may be reluctant to give others unrestricted access to their data. This can happen when scientists are on opposing sides of a political or ideological debate, such as climate change. When a scientific disagreement has important public policy ramifications, scientists can become as polarized as the public itself. They may split into opposing camps and regard each other as competitors rather than colleagues. In extreme cases, they may even disparage each other's integrity and competence. Conflict replaces cooperation in this atmosphere, and scientists may be as interested in discrediting other scientists' research as they are in conducting their own.

One way in which researchers criticize other scientists' work is to accuse them of ignoring or misinterpreting important *raw* data. Thus, if a scientist's research is under attack, he/she may be tempted to make his/her raw data off limits to opposing scientists, or at least impede their access. But is a general policy of scientists denying other scientists access to their raw data justified? Or should researchers freely share all their data with other scientists?

The so-called "Climategate" affair, which garnered significant press back in 2009, serves as a strong illustration of how the scientific community can become politicized and polarized. A large number of especially sensitive emails of the Climatic Research Unit (CRU) at the University of East Anglia were hacked and released to the public, prompting an intense and widespread reaction. Climate-change skeptics charged that the emails revealed a conspiracy among climatologists to suppress and manipulate temperature data. Critics also used the emails to argue that climatologists were attempting to discredit and marginalize climate change skeptics. For example, they cited messages in which two CRU scientists discussed how to handle skeptics who asked to see their raw temperature data. In one email, a CRU scientist mentioned that he was having trouble with a certain journal editor who had instituted a new policy requiring that authors of papers submitted for publication make their raw data available to reviewers. He declared indignantly that he would not submit any more papers to the journal unless the editor reversed his policy.

It is not hard to sympathize with the CRU scientists. They had good reason to fear that skeptics would use their raw temperature data to mislead the public about the evidence for climate change. In the past, skeptical scientists and their journalistic allies had exploited the fact that climatologists use "adjusted" temperature data to support their conclusions. The skeptics called the climatologists' use of adjusted data a "scandal," an obvious attempt to perpetrate a fraud on the public and argued that the real data — i.e., the raw data — proved that global temperatures were not increasing at all. In their opinion, climatologists were manipulating temperature data to make the data appear to support climate change when in fact the opposite was true. Even today, a number of conservative politicians and commentators remain convinced that scientists are part of a vast conspiracy to manipulate and indoctrinate the electorate. One U.S. Senator has for years maintained that the entire climate change movement is a "hoax." Unsurprisingly, such accusations resonate with many non-scientists, because increases in worldwide temperatures are apparent in the adjusted data but not in the raw data.

These are some of the challenges climate change proponents are up against. If they are to win the public policy debate, they must counter these attitudes and convince non-scientists that adjusting data is a legitimate scientific practice. Again, let's consider climate change. In order to study global climate, climatologists have measured temperatures at multiple locations around the globe and collected data over many years. During that time, newer, more accurate thermometers replaced older ones. Consequently, not all thermometer readings could be directly compared. This meant that scientists needed a way to homogenize different sets of temperature data. For example, where simple mathematical relationships existed among readings from different thermometers, it made sense to take the newest type of thermometer as the standard and calculate "equivalent" temperatures for the older thermometers. This is a classic case of data adjustment. Furthermore, changes in the physical characteristics of the locations where scientists collected temperature data required another type of data adjustment. For example, new buildings might be built near a particular thermometer and cast new shadows, change wind patterns, etc. It is perfectly reasonable to try to compensate for such changes by making suitable adjustments to the raw temperature data. Which adjustments are suitable, however, might be very difficult to say, and scientists themselves might honestly disagree about which adjustments are best.

Considering the many ways skeptics can criticize how scientists adjust their raw data, one may wonder whether to allow anyone, scientists included, unrestricted access to it? Why not just make one's raw data off limits to other scientists, especially those who are out to cause trouble? Although adopting such a policy might be tempting, there are compelling reasons not to do so. Even though critics are sometimes unfair and insincere in their criticisms, it is often a good idea for scientists to reconsider and reevaluate the methods they are using to interpret their raw data. Doing so can help researchers avoid myopia, groupthink, and similar pitfalls. Of course, when a scientist's research is entangled in heated political and ideological controversies and that research and the scientist's integrity are attacked, sharing raw data with scientific and political opponents may feel like unilateral disarmament. Yet in the long run, withholding and suppressing raw data is likely to discredit scientists and their research in the eyes of the public. This happened in the Climategate affair to a considerable degree.

There are also deeper, ethical reasons why research scientists should freely share their data with other scientists. As a profession, scientists have an unstated but generally accepted mission in a free society. In a nutshell, this mission is to endeavor to identify and understand the fundamental "building blocks" and dynamics of the natural universe. Experience indicates that facilitating and encouraging the flow of ideas and information within the scientific community is the most effective way to do this. The free exchange of information and ideas is an ideal to which the vast majority of scientists aspire. It is the foundation of scientists' *ethical* obligation to allow each other unrestricted access to the results of their research, including their data. This obligation to share research results should always take precedence over extraneous, competing considerations, such as political or ideological allegiances or personal animosity toward other scientists. This is why it was wrong for the CRU scientists to put obstacles in the way of the researchers who requested access to their temperature data. As a general rule, scientific data, including raw data, should be available for everyone to see.

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Models are Incomplete

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cy of time [4]. Amos Tversky and Daniel Kahneman went even further and identified a wide variety of biases in human decision-making [5]. Decision processes are not only bounded, but are also inescapably biased. Yet the Laureates left two important practical questions unanswered. How bad are the results from our bounded, biased processes, and (assuming the results are too bad) how can they improve?

A broad portfolio of decision support projects completed at Intel Corporation allows us to estimate, based on data, an answer to the question "how bad are we?" This is a measure of improvement achieved by migrating from weak methods, which in the vast majority of cases can be characterized as automating intuition with spreadsheets to strong methods using powerful algorithms. We use these results when discussing new projects with our senior management. We commit to a range of 10-15% in improvements to the quality of decisions; this is measured by increasing revenue, decreasing cost, or some combination of both. Regarding the amount of time required to reach a decision, we commit to a range stretching from a 5x decrease in process duration for exploring the traditional number of business scenarios to a 5x increase in the number of business scenarios explored in the traditional process duration. Our most successful projects have realized a 25% improvement in quality and a 10x reduction in duration of the decision process.

When implementing these decision support systems, we have explored three distinct approaches to answering the question "how do we do better?" Initially we employed strong algorithms in brute force mode to try to overwhelm intuitions. After users helped ratify initial conditions and specified goals, our system produced a solution for complex tactical problems, like factory floor execution, that was carried out without modification. With appropriate user training to understand the algorithm and feedback loops to improve it, this worked well. But upon addressing more strategic problems, such as demand forecasting, we began leveraging intuitions in our decision support systems in ways intended to reduce the impact of biases. For example, we employed "wisdom of crowds" and "decision markets" to great advantage. Recently, in building decision support systems for our most senior management, we are making explicit use of intuition. We model and solve the business problem, ultimately providing a small set of very good solutions and a suite of graphical interrogation and what-if tools. Users can apply their business intuitions to select between the candidates or generate and evaluate additional candidates. The analytics inform the intuitions and the intuitions inform the analytics. This third approach has generated very positive outcomes on multi-billion dollar decisions [3], much improved over previous methods.

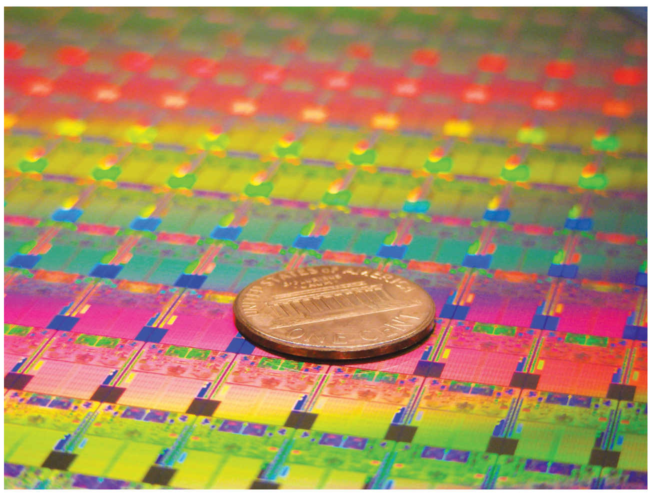

Figure 3. *Intel's 300mm 45nm wafers like the one shown here are used to make it's newest dual and quad-core processors that are made up of hundreds of millions of the company's new 45nm transistors with Hafnium-based high-k metal gate silicon technology. Credit: Intel Newsroom.*

These are encouraging results, but we are still only in the early stages of understanding how to optimally combine ancient and deeply-ingrained human mental processes with modern computers and algorithms [2]. The desire for faster, better decisions as a competitive business advantage drives our experimental work, but we continue to hope for a strong theory to offer guidance.

Figure 2. *Intel's wafer fabrication facilities in Chandler, Ariz. were recently converted to high-volume 14-nanometer processes, supporting a wide range of high-performance to low-power products including servers, personal computing devices and others for the Internet of Things. Credit: Intel Newsroom.*

References

[1] Kahneman, D., & Klein, G. (2009). Conditions for intuitive expertise: a failure to disagree. *American Psychologist*, 64(6), 515–526.

[2] Kempf, K. (2015). Applied mathematics for business decision making: the next frontiers, presented at *8th Inter. Congress on Industrial and Applied Mathematics*, Beijing, 2015, 135-158.

[3] Sampath, S., Gel, E. S., Fowler, J. W., & Kempf, K. (2015). A Decision-Making Framework for Project Portfolio Planning at Intel Corporation. *Interfaces, 45*(5), 391-408.

[4] Simon, H. A. (1972). Theories of bounded rationality. In C. McGuire & R. Radner (Eds.), *Decision and Organization*, (pp. 161-176). Amsterdam: North-Holland Publishing Company.

[5] Tversky, A., & Kahneman, D., (1974). Judgment under uncertainty: heuristics and biases. *Science, 185*(4157), 1124-31.

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