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SIAM at the National Math Festival

MoMath president and co-founder Glen Whitney helps young visitors explore the intricacies of the "Amazing Acrobats" exhibit. Photo courtesy of MoMath.

By Byong Kwon and Rachel Levy

SIAM recruited more than sixty volunteers to help MoMath (the National Museum of Mathematics) operate 20 exhibits at the inaugural National Math Festival in Washington, DC, on April 18, 2015. Among the SIAM volunteers were members from the Baltimore–Washington metropolitan area, and student members from Columbia, George Mason, Old Dominion, and Shippensburg Universities, the University of Delaware, the University of Maryland (Baltimore County and College Park), and Worcester Polytechnic Institute. Participation of some of the student chapters was funded by SIAM.

"I'm delighted that so many SIAM student chapter members were able to share their love of mathematics at the festival,"

See **National Festival** *on page 6*

Photo by Tim Fest.

The PETSC team—from left, Satish Balay, Hong Zhang, Lois Curfman McInnes, William Gropp, Jed Brown, and Matthew Knepley (not shown is Barry Smith)—received the SIAM/ACM Prize in Computational Science and Engineering at CSE 2015. PETSC (Portable, Extensible Toolkit for Scientific Computation), according to the prize committee, "has transformed how large-scale software libraries are developed, supported, and used within the CS&E community. Their work spans novel methods for design and development of code; innovative research into scalable algorithms; outreach to the HPC community; support of users; and deep partnership with scientific teams. . . . The creation of this innovative and seminal numerical software package provides the scientific and engineering community with robust, efficient, scalable, and extensible tools that are the backbone of numerous high-performance applications, and the sustained impact of this work has been felt worldwide."

Unprecedented Turnout in Salt Lake City As CSE Conference Marks 15th Year

The SIAM Conference on Computational Science and Engineering has seen dramatic growth since its inception in 2000. CSE15, held at the Salt Palace Convention Center in Salt Lake City, Utah, was in fact the largest SIAM conference to date. The 1687 registered attendees reflect a 23% increase over CSE13—and a four-fold increase since 2000.

A celebration of the 15th anniversary of the SIAM series was a highlight of the program. Linda Petzold gave a featured presentation on the history of SIAG/CSE, beginning in 2000 with a petition to the SIAM Board of Trustees from Steve Ashby, Paul Boggs, David Keyes, Tom Manteuffel, Linda Petzold, and Gil Strang. Their vision and leadership have enabled SIAG/CSE to be a catalyst for advancing the principles of CSE and penetrating the academic and industrial world, with prominent roles in advancing research and innovation and pro-

See **CSE at 15** *on page 8*

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CSE15

Data Science: What Is It and How Is It Taught?

By Hans De Sterck and Chris Johnson

The term "big data" has become ubiquitous. People who can wrangle big data are called data scientists. According to a number of sources, there is a growing need for people trained as data scientists. But what is data science? Is data science its own field, or is it an interdisciplinary mix of computer science, mathematics and statistics, and domain knowledge? Or might it really be what statisticians have been doing all along? Because data science at scale involves large-scale computation, what is the relation between data science and computational science?

At the 2015 SIAM Conference on Computational Science and Engineering, we convened what turned out to be a very lively panel* to discuss the current and future status of data science, its relation to computational science, opportunities for data and computational scientists, and the education of future data scientists.

Here are some surprising things we heard from the panelists:

- data science is *not* statistics;
- data science should be taught by computer scientists;
- in five years, every domain of science and engineering will center on data science;
- in ten years, all of data science will be applying machine learning; and
- data science is not new—it's just the other side of the coin of computational science and engineering.

In the ensuing discussion with the audience, every statement made by a panelist was countered by at least one opposing response, and we heard many additional ideas about data science. For example: Although machine learning and data mining are often taught in computer science departments, many in the audience pointed to the mathematical and statistical foundations and developments that underlie progress in these fields. So statisticians and mathematicians will certainly also teach data science!

*The slides from the panel are available at http://www.sci.utah.edu/~chris/Data-Science-Panel-CSE15.

Classical Science versus Modern Data Science: A Clash of Paradigms?

One of the panelists characterized modern data science as a paradigm in which black-box statistics-based models from data mining and machine learning are unleashed on large data sets to analyze and predict complex phenomena. Presumably, this approach implicitly uncovers the "rules" that govern the behavior of the complex systems. It is undeniable that significant (and sometimes spectacular) progress is made via machine learning approaches in several areas of investigation: image and speech recognition, automatic translation, fraud detection, online recommendation, and business analytics for the retail sector, among others. This work exploits the availability of unprecedented volumes of data in areas in which quantitative data and models were virtually nonexistent until very recently.

Effectively combining computational and data science, CSE15 invited speaker Anna Michalak provided surprising statistics on greenhouse gases, derived in part from an innovative study in which Argentinian researchers used plastic tanks strapped to the backs of cows to estimate methane production. REUTERS/Marcos Brindicci

The situation is different in much of science and engineering, however. In these fields, there is a crucial role for models based on first principles that have been tremendously successful in modeling physical reality. Experimental data has always been essential for validating these models. But the tremendous growth in the volume of scientific data from such sources as high-bandwidth experiments and observations, extreme-scale simulations, and large networks of sensors opens exciting new possibilities. The availability of this data is enabling great progress in quantifying uncertainties in the results produced by physics-based models, and in making these models truly predictive [1].

Incorporating vast amounts of data into scientific applications often relies on statistical techniques, including, for example, Bayesian inference of model parameters and stochastic simulation, which have become essential tools in computational science. Similarly, visual analytics techniques developed for science and engineering often have broad applicability in other areas of data science [4]. The development of all these techniques, including parallel algorithms and implementations that are efficient at scale, constitute key contributions to data science, enabling data-driven scientific discovery. Models based on first principles are essential components of systems that extract valuable insights from massive scientific data, insights that tend to go far beyond what can be recovered by black-box statistical modeling alone.

The Synergy Between Computational Science and Data Science

Given that data science and computational science overlap significantly, both in the expertise required and in the methodologies used, one panelist claimed that data science is just the other side of the coin of computational science: Computational science and data science are both rooted in solid

See **Data Science at CSE** *on page 6*

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Why Have SIAM Journal Papers Grown So Long?

LETTERS TO THE EDITOR

To the Editor:

Recently at Oxford our Numerical Analysis Group spent an hour looking over early volumes of some journals. We were struck at how short many of the articles were, presenting a key idea or two in a style that would be unusual now. There are some classic examples of brevity, like Householder's introduction of Householder reflectors in four pages (*Journal of the ACM*, 1958) and Cooley and Tukey's announcement of the FFT in five pages (*Mathematics of Computation*, 1965).

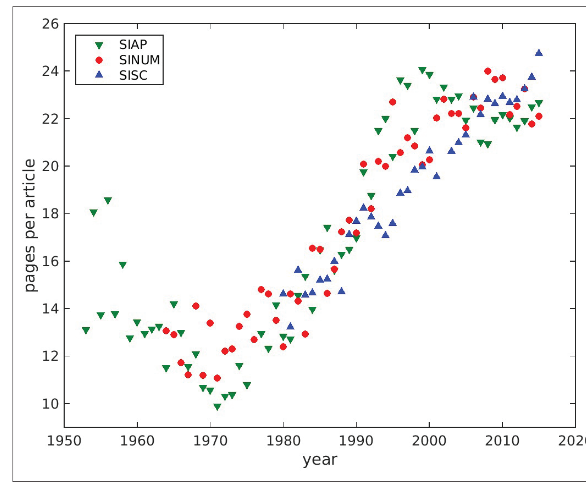
Would such short manuscripts be acceptable for publication nowadays?

We decided to look at some data. The figure shows average pages per published paper in SIAP, SINUM, and SISC over the years (omitting errata, addenda, and prefaces). You can see that in the last 45 years, the average length has doubled. This was not planned by SIAM; it just happened.

Most of SIAM's journals have page limit policies you can find posted on the web. SISC "has a page limit policy of approximately 20 journal pages," SIAP "has a page limit policy of 20 pages per paper," and SINUM "asks that manuscripts not exceed 20 pages." There is little sign of a 20-page limit in the data, however, and as one colleague told me, "It is well known that that page limit is not generally enforced." Thus, recent SIAM journal articles offer a rare example of a dataset whose mean exceeds its maximum!

SIAM began to publish articles online in 1997, by the way, so the move from paper to electronic publication cannot explain the trend.

What should we make of this trend? Why have our papers grown so steadily longer? And is this a bug, or a feature? Would it be better for the applied mathematical community if SIAM journals enforced genuine length limits, as do IEEE journals, for example, or is this not important? If readers have thoughts on this subject I would be glad to hear from you (trefethen@maths.ox.ac.uk), and if interesting responses are received I will report on them later.—*Nick Trefethen, University of Oxford.*



Symposium Yields Insights on Big Data and Predictive Computational Modeling

By P.-S. Koutsourelakis, N. Zabaras, and M. Girolami

Everyone is aware of the revolution that has taken place in the data sciences over the last few years and the impact it has had on medicine, commerce, education, and the media. A multitude of reports on the "Big Data" paradigm and the marked success of companies like Google and IBM provide constant reminders.

Advances in networking, sensor technologies, and computer science have enabled the collection of gigantic amounts of data at ever accelerating rates. At the same time, developments in machine learning/computational statistics and data mining have led to powerful tools for extracting patterns and trends from the data. Most of this output is mapped to phenomenological but predictive models of increasing complexity and involving huge numbers of parameters.

In parallel, computational scientists in physics, chemistry, biology, and engineering have been experiencing their own Big Data revolution. Thanks to the sophistication of the mathematical models and the availability of high-performance computing platforms, we can simulate physical processes at unparalleled levels of spatiotemporal resolution. With almost every simulation we see exuberant growth of output data.

Despite their sophistication, our models are not always predictive. This can be attributed to various parametric and model uncertainties, as well as to vast differences between the scales at which we want to make predictions and the scales at which accurate simulation tools are available.

Can we extract meaningful information from huge amounts of simulation data? Can we use the data to make predictions at scales that are currently inaccessible? How can we couple tools from the data sciences—tools that are capable of dealing with high dimensions and uncertainty—with physical principles?

These are some of the questions addressed during the symposium Big Data and Predictive Computational Modeling held at the Institute for Advanced Study, Technical University Munich, May 18–21, 2015.

With a mindset firmly grounded in computational discovery, but a polychromatic set of viewpoints, several leading scientists—from physics and chemistry, biology, engineering, applied mathematics, scientific computing, neuroscience, statistics, computer science, and machine learning—met, engaged in discussions, and exchanged ideas for four days.

Some conclusions:

1) Big data can mean different things in different communities. Whereas data in machine learning applications comes at a low price and in abundance, in the physical sciences data is obtained from expensive and computationally demanding simulations. In the latter case what is produced might be better described as "Tall Data": It is high-dimensional and structured, although we can expect neither to have a large number of instantiations nor that this data will uniformly populate the configuration space of the problem.

2) Physical scientists trust their models more than data scientists do. To a large extent, physical models are anchored in venerated physical principles (e.g., conservation of mass, energy). Nevertheless, parts of these models (e.g., constitutive laws) are as phenomenological as regression/classification models used in data mining.

It has been said that you do not need to know the true cause as long as you can minimize the prediction error. This approach has been applied with great success in several machine learning tasks, but physical scientists would also like the discovery of patterns and trends to lead to comprehensible and interpretable physical principles as the underlying drivers of the complexity observed.

3) Quantifying model uncertainties is recognized as an important step. Model-selection issues arise prominently in obtaining reduced or coarse-grained descriptions of physical models (e.g., in molecular dynamics), and along these lines the expertise and arsenal of tools from machine learning/computational statistics can be extremely powerful. Information-theoretic tools and pertinent concepts can be extremely useful in that respect and can be used even in non-equilibrium settings.

4) Models employed in both machine learning and the physical sciences are multilevel and high-dimensional, with thousands of parameters to be inferred or learned. The feasibility of these tasks is often limited to distributed computational environments in which each node is aware of only a portion of the (experimental or simulation) data. Novel methods are needed that reduce communication costs but can nevertheless lead to accurate estimates.

5) A little bias in estimates can be a good thing if it also leads to reduced variance. Advocating approximate inference and learning tools to the applied mathematics and engineering community is preaching to the choir—these groups have become comfortable with the idea of approximate solutions to difficult math-

See **Predictive Modeling** on page 3

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Louis Nirenberg and John Nash in Oslo, where they received the 2015 Abel Prize on May 19. Honored jointly "for striking and seminal contributions to the theory of nonlinear partial differential equations and its applications to geometric analysis," they did not work together but, in the words of the Norwegian Academy, "influenced each other through their contributions and interactions." A discussion of their main individual contributions appeared in the May issue of SIAM News. *In a sad conclusion to a troubled life, Nash was killed with his wife when the taxi in which they were returning to their home in Princeton from the airport was involved in a collision. Nash had received the Nobel Prize in economics in 1994 for his early work in game theory. Photo by Peter Brown.*

Predictive Modeling

continued from page 2

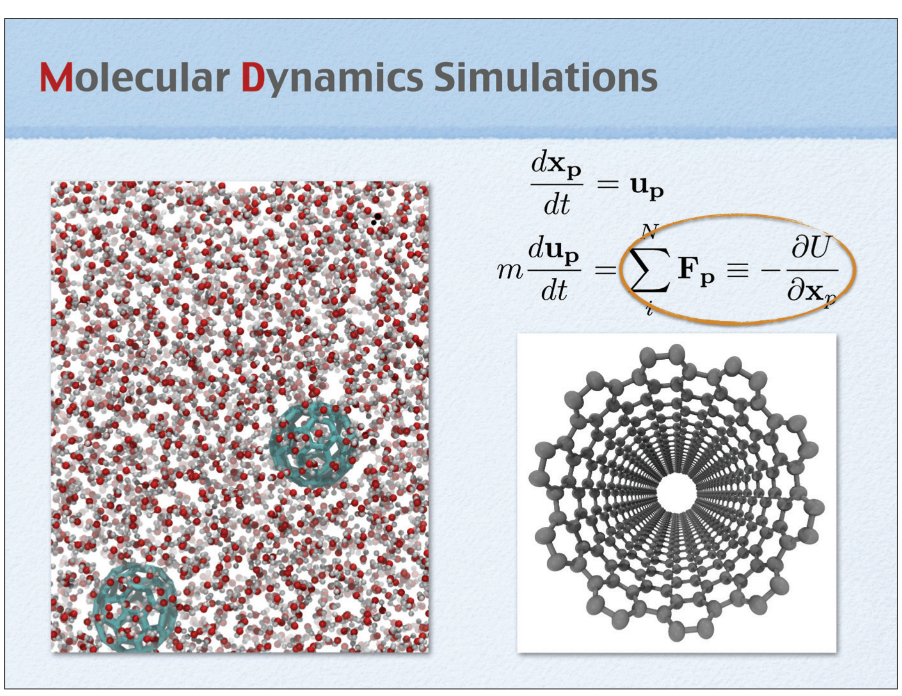
ematical problems. Such algorithms, which have seen explosive growth in the machine learning community in the last few years as part of efforts to address big-data challenges, would be ideal for the computationally demanding tasks of fusing models with data in the physical sciences and in the context of Bayesian model calibration and validation. Deterministic tools from numerical analysis (e.g., adjoint formulations) can frequently complement and enhance probabilistic methods.

6) Many of the events of interest are rare. Whether in seeking transition paths to overcome large free energy barriers in molecular simulations or in assessing the extremely small probabilities of failure in engineering systems, we need new tools that are capable of directing our simulations or data-acquisition mechanisms to the most informative regimes.

7) Symposium participants knew a priori that dimension reduction is a key aspect of the analysis, whether the task is to make sense of atomistic trajectories, to look at huge databases of features or networks, or simply to visualize high-dimensional data. Several nonlinear dimension-reduction tools and low-rank matrix factorization techniques were presented and discussed. It became apparent that for predictive purposes, dimension reduction is necessary but not always sufficient. In addition to a lower-dimensional set of collective variables, we must simultaneously infer a model for their interaction and evolution in time. This will not only enable extrapolation into regions for which data is not available, but also lead to efficient tools that exhibit sub-linear complexity with respect to the fine-scale degrees of freedom.

8) Relationships between different communities can be bi-directional. For a long time, methods and tools developed by the computational physics community (e.g., Markov Chain Monte Carlo) have stimulated developments in statistics and machine learning, where the methods were formalized and their domain of application was expanded. Similarly, tools and techniques from machine learning have inspired developments and advanced our capabilities in the analysis of physical systems (e.g., ISOMAP for dimension reduction, graphical models for UQ).

The video and lecture presentations from the workshop are available on the TUM–IAS website (http://www.tum-ias.de/bigdata2015/), and a post-symposium publication of related papers by the participants is planned. For further information, readers can contact the symposium organizers, P.-S. Koutsourelakis (Technical University of Munich), N. Zabaras (Warwick Centre for Predictive Modelling, University of Warwick, and Institute for Advanced Study, Technical University of Munich), and M. Girolami (University of Warwick).



Insights about computational discovery that emerged from the four-day symposium include recognition that "quantifying uncertainty is an important step," especially for obtaining reduced or coarse-grained descriptions of physical models. Shown here is a slide from the talk of Panagiotis Angelikopoulos, "Large scale Uncertainty Quantification in Molecular Dynamics simulations."

Quick! Find a Solution to the Brachistochrone Problem

MATHEMATICAL CURIOSITIES
By Mark Levi

The brachistochrone problem asks us to find the "curve of quickest descent," and so it would be particularly fitting to have the quickest possible solution. The problem is to find the shape of the perfectly slippery trough between two points A and B such that a bead released at A will reach B in the least time in a uniform gravitational field (Figure 1). The following solution (stating that the answer is a cycloid) may not be the quickest there is, but it is the quickest one I know.

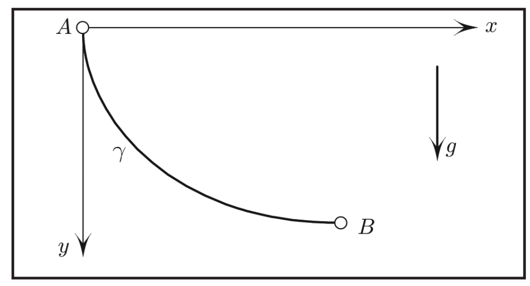


Figure 1

Figure 2 shows the cycloid swept out by a point P on the rim of a circular wheel rolling on the ceiling. Let PC' be the tangent at P, with C' lying on the circle. Note that $PC' \perp CP$: The velocity of a point on the rigid body is perpendicular to the point's radius vector relative to the instantaneous center of rotation C. We conclude that CC' is a diameter. But in that case,

$$y = CP\sin\theta = D\sin^2\theta, \qquad (1)$$

where θ is the angle between the tangent and the vertical.

Looking again at the bead, its sliding time along γ is $\int ds/v$. Given that $v = \sqrt{2gy}$ (using conservation of energy and the assumption $v_A = 0$), this time is

$$k\int_\gamma \frac{ds}{\sqrt{y}}, \qquad (2)$$

where k is a constant we don't care about.

Now, (2) is of the form $\int F(y)ds$, and minimizers of such functionals satisfy $F(y)\sin\theta = \text{constant}$ (a short calculus-free derivation of this can be found in [1]); for (2) this amounts to

$$\frac{\sin\theta}{\sqrt{y}} = \text{constant}, \qquad (3)$$

which is the same equation as (1)!

The cycloid is thus a critical curve for the time functional (2) (although this does not prove minimality; a proof can be found in almost any book on calculus of variations, e.g., [1]).

References

[1] M. Levi, *Classical Mechanics with Calculus of Variations and Optimal Control*, AMS, Providence, Rhode Island, 2014.

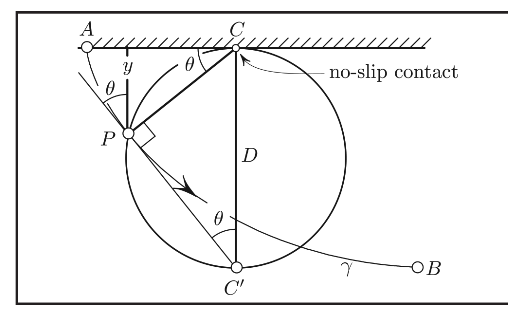


Figure 2

Mark Levi (levi@math.psu.edu) is a professor of mathematics at the Pennsylvania State University. *The work from which these columns are drawn is funded by NSF grant DMS-1412542.*

BGCE Prize Finalists In the Spotlight at CSE15

It has become a tradition: After successful sessions in Costa Mesa (2007), Miami (2009), Reno (2011), and Boston (2013), the SIAM Conference on CSE (held this year, March 14–18, in Salt Lake City, Utah) hosted the student paper competition sponsored by the Bavarian Graduate School of Computational Engineering (BGCE) for the fifth time. Open to both undergraduate and graduate students, this biannual competition recognizes and promotes outstanding student research in CSE.

This year, 24 students representing 23 research institutions in eight countries had submitted the required four-page extended abstracts. Based on the quality and relevance to CSE of those submissions, the following eight finalists were invited to present their work and results in two special sessions in Salt Lake City:

1. **Jessica Bosch (Max Planck Magdeburg):** Efficient solution of Cahn–Hilliard Systems
2. **David Emerson (Tufts University):** Advanced Discretizations and Multigrid Methods for the Energy Minimization of Liquid Crystal Equilibrium Configurations
3. **Evan Gawlik (Stanford):** A High-order Finite Element Method for Moving Boundary Problems Using Universal Meshes
4. **Marija Kranjčević (University of Zagreb):** Towards a Hybrid Parallelization of Chebyshev Filtered Subspace Iteration
5. **Dhairya Malhotra (University of Texas at Austin):** A Parallel Volume Integral Equation Stokes Solver for Flows in Complex Geometries
6. **Giuseppe Pitton (SISSA Trieste):** Computational Reduction Strategies for Bifurcation and Stability Problems
7. **Oliver Weeger (TU Kaiserslautern):** Nonlinear Frequency Response Analysis of Mechanical Vibrations based on Isogeometric Discretization and Model Order Reduction
8. **Mattia Zanella (University of Ferrara):** Uncertainty Quantification in Control Problems for Flocking Models

As in the previous years, the quality of the students' contributions—both the presentations and the technical content—was excellent. The work of all this year's finalists reflected almost perfectly our definition of CSE research; together, the speakers covered a broad range of thriving applications, state-of-the-art modeling and computational methods, and efficient tools and implementations.

After the presentations, the members of this year's international prize committee—Hans-Joachim Bungartz (TU München), Omar Ghattas (University of Texas at Austin), Jan Hesthaven (École Polytechnique Fédérale de Lausanne), Esmond Ng (Lawrence Berkeley National Laboratory), Ulrich Rüde (FAU Erlangen-Nürnberg), Peter Turner (Clarkson University), and Carol Woodward (Lawrence Livermore National Laboratory)—had the challenging task of selecting one winner. They based their selection of David Emerson on the following criteria: scientific depth, importance, relevance to CSE, quality of the written paper, quality of the presentation, and maturity

See **BGCE Prize** *on page 5*

Six of the eight BGCE prize finalists gathered at CSE15 with the prize committee. From left: Esmond Ng, Carol Woodward, David Emerson, Omar Ghattas, Dhairya Malhotra, Jan Hesthaven, Jessica Bosch, Hans-Joachim Bungartz, Peter Turner, Evan Gawlik, Oliver Weeger, Mattia Zanella, and Ulrich Rüde.

A Multifaceted, Multilevel Exploration of the Physics of Sports

Sports Physics. *Edited by Christophe Clanet, École Polytechnique, Paris, 2013, 640 pages, €40.00.*

BOOK REVIEW
By James Case

This unusual book is the outgrowth of a conference on the physics of sports held in Paris, at École Polytechnique, in April 2012. Observing that poetry, physics, and painting all have something to say about a stone and a tree, the brief introduction goes on to suggest that scientific analysis of unusual topics can be especially fruitful, as in the case of sports. As evidence, it cites a pair of 1970s papers on racing strategies by Joe Keller.

The book's first chapter, titled "Physics 'pour tout Le Monde,'" reproduces a dozen non-technical essays from the French daily *Le Monde* by journalists Pierre Lepidi and David Larrousserie. Serialized during the 2012 Olympics, the essays offer non-technical answers to a variety of FAQs, including: Why do race walkers flail their arms? Why do arrows warp? Why do sprinters have swollen calves? Each essay, reproduced both in the original French and in English translation, directs readers to a place in the book where the question is treated technically.

Each of the remaining six chapters consists of a brief introduction to a particular subdiscipline of physics, including aerodynamics, elasticity, and friction, followed by a series of studies in which the associated methods are applied to issues from the world of sports.

Underwater Swimming

In Chapter II, "Waves and Fluids," the seventh section, titled "Wave Drag on the Swimmer," relates to a Chapter I essay question: Why do we swim faster underwater? Experience shows that of the four Olympic strokes, at least two—backstroke and breaststroke—can be swum more rapidly underwater (for backstroke, using the dolphin kick, without arms) than on the surface. Accordingly, the Fédération Internationale de Natation (FINA) now imposes a rule permitting freestyle, breaststroke, and backstroke racers to remain totally submerged during the first 15 meters of each race, and again after each turn.

To quantify the advantages of swimming underwater, Clanet and two associates devised an experimental apparatus consisting of two smooth balls, mounted at opposite ends of a rod left free to pivot about its midpoint, as indicated in Figure 1. When the apparatus was towed at various speeds while deeply submerged, they observed little or no wave action on the surface and no discernible torque about the pivot. But at similar speeds nearer the surface, they observed unmistakable surface waves and significant torque about the pivot. Attributing the latter to "wave drag" on the upper ball, they noted that the torque increased to a maximum as the speed of the apparatus approached $\sqrt{gD}$, where D is the diameter of the sphere and g the acceleration due to gravity, and decreased thereafter.

Thus, when wave drag force is plotted against the nondimensional Froude number $Fr = \sqrt{(V/gD)}$, for various speeds, depths, and sphere diameters, the peaks all seem to cluster about the vertical line $Fr = 1$. Perhaps more importantly, the torque is observed to vary inversely with the depth of submersion, all but vanishing when the upper ball lies more than a diameter below the surface.

Swimmers, of course, are not spherical. But additional experiments suggest that they too experience significant wave drag when swimming just below the surface, and that such drag all but vanishes when they are submerged by more than the thickness of a typical human body. Indeed, taking a swimmer's shoulder-to-shoulder breadth as his or her characteristic length D, the foregoing conclusions appear to apply nearly as well to ordinary swimmers as to spherical ones! Given that (due to fatigue) drag effects are more important in long races than in short ones, it is hardly surprising that long-distance swimmers (up to and including the incomparable Michael Phelps) seem more discerning than sprinters about the depths at which they swim.

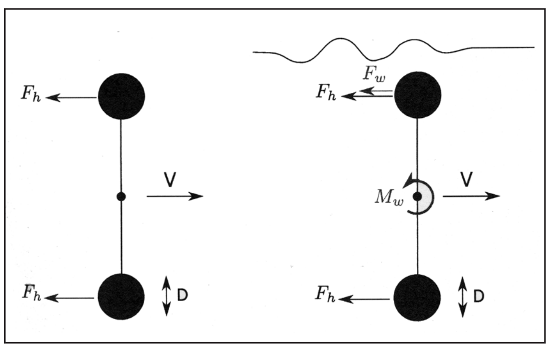


Figure 1. *Wave drag measurement apparatus: far from the surface (left), close to the surface (right).*

Ballgame Dynamics

The chapter on aerodynamics includes several studies of balls in flight, both with and without spin. "The Aerodynamics of the Beautiful Game," by J.W.M. Bush, examines the flight characteristics of soccer balls.* Elsewhere in the chapter are studies of ski jumping, shuttlecocks, tennis strokes, and discus throwing, along with a surprising one—for a book published in France—called "What New Technologies Are Teaching Us About the Game of Baseball," by A.M. Nathan.

The fruitful new technologies are of two kinds. In the so-called f/x systems, two 60-Hz digital cameras mounted high above the playing field send images to a nearby desktop computer. The cameras are mounted such that their principal axes meet roughly halfway between the pitcher's mound and home plate. Proprietary software determines the camera coordinates of the baseball in each image and converts them into a location on or above the field. The most common of these systems, known as PITCHf/x, has been installed in every Major League Baseball park since 2007. The HITf/x system uses the same cameras to track the initial trajectories of batted balls, including their speeds, their vertical launch angles, and their "spray angles" to the right or left of the line through home plate and second base. The more ambitious FIELDf/x is intended to track almost everything that moves on the field, including the fielders, base runners, umpires, and batted or thrown balls; to date it has been installed at a few parks.

The rival TrackMan system is a phased-array Doppler radar installation that is also in use at a number of Major League parks. When installed high above home plate, its field of vision covers most of the playing field. For pitched balls, it is about as accurate as PITCHf/x; for batted balls its accuracy is as yet undetermined.

Because the drag and Magnus forces on baseballs in flight can be nearly as strong as the gravitational force, it seems unlikely that either can be ignored in any serious study of baseball trajectories. To dramatize the effects of those two forces, Nathan considers the flight of an actual home run that came off the bat with an initial speed of 112 mph, at a launch angle of 27° above the horizontal, with initial backspin of 1286 rpm. In the absence of both drag and Magnus forces, such a ball would travel nearly 700 feet. In the event, it travelled only 430 feet. Figure 2 suggests that, had it been subject to drag alone, it would have gone only about 380 feet. The Magnus force from backspin caused it to fly some 30 feet higher and 50 feet farther.

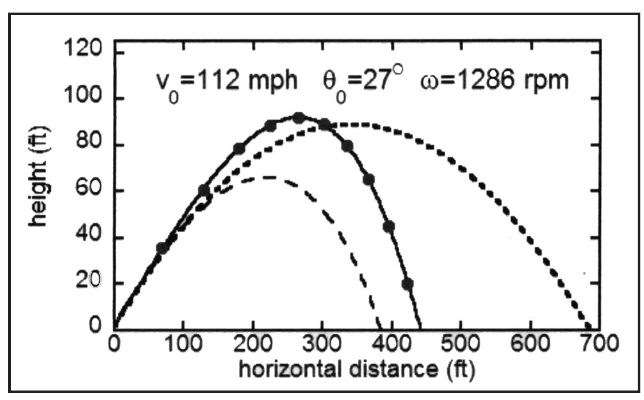


Figure 2. *A fly ball trajectory (solid curve), with the initial conditions shown; the dots show the location of the ball at 0.5-sec intervals. Also shown are trajectories for the same initial conditions and neither drag nor Magnus force (short-dashed curve) and with drag but no Magnus (long-dashed curve).*

Much has been learned about the flight of baseballs through the use of these and other technologies, and Nathan's article rather neatly summarizes the current state of the art. Still open are questions regarding the onset of the so-called drag crisis, wherein the drag coefficient C_D decreases temporarily as a function of airspeed. For speeds lower than 40 mph, the coefficient is about 0.50, while for speeds on the order of 90 mph, it falls to about 0.30. But experiments designed to determine the precise speeds at which the reduction occurs appear to disagree, leaving the phenomenon poorly understood.

See **Sports** *on page 7*

*It can be seen as a precursor of the soccer ball study described in *SIAM News*, June 2014; http://sinews.siam.org/DetailsPage/tabid/607/ArticleID/13/Designers-Fine-tune-the-Aerodynamics-of-World-Cup-Soccer-Balls.aspx.

The Art of Knowing When and How To Apply Linear Algebra in the Real World

When Life Is Linear: From Computer Graphics to Bracketology. *By Tim Chartier, Mathematical Association of America, Washington, DC, 140 pages, 2015, $50.00.*

BOOK REVIEW
By Kevin Hutson

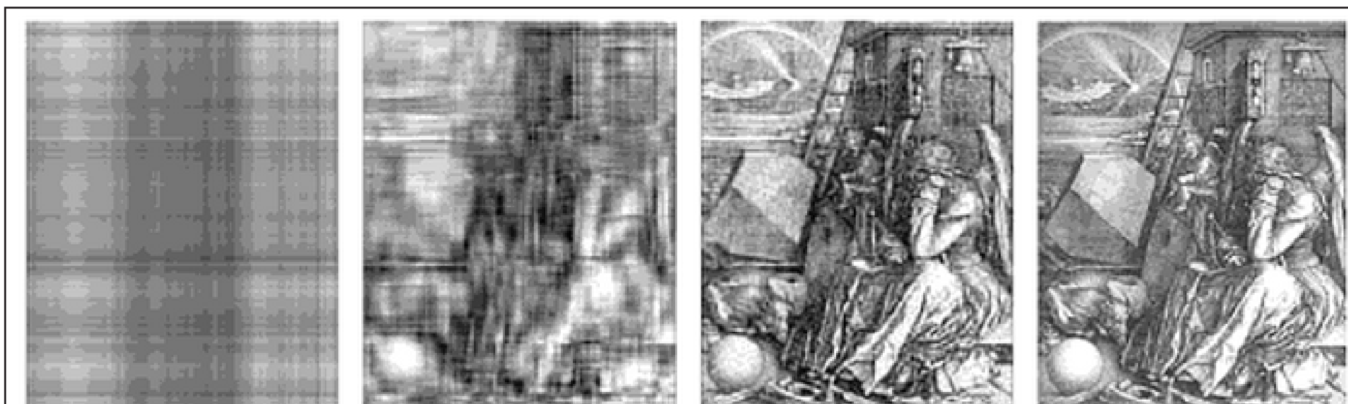
When students ask me what the most useful mathematics course is, I always respond, "Linear algebra." The students are sometimes surprised, as their experiences in linear algebra appeared to them anything but useful. The students' reactions stress that linear algebra courses vary in scope and purpose. Some are computationally focused, while others are theoretical and abstract and aim to develop students' proof-writing abilities.

When our graduates visit after a few semesters of graduate school, however, they often echo comments about the usefulness and importance of this course. These are often the students who go into applied mathematics or related graduate programs—which usually present all of the applications of linear algebra and its role as the mathematical underpinnings for many theoretical and algorithmic results.

Tim Chartier's book *When Life Is Linear* highlights the main concepts of a first course in linear algebra while developing their power through applications. The applications are engaging because Chartier uses examples that are accessible to most students, even high school students. Most inquisitive students have asked questions like: What goes into producing 3D animation? How does Google produce a ranking of web pages following a search inquiry? It is Chartier's hope that by seeing applications of math and learning how it relates to the world, students will be enlightened, inspired, and motivated to find the usefulness of linear algebra.

The book is also a useful resource for the instructor, in that it shows how different techniques affect an application. For instance, one of the applications presented is in the area of classification and similarity measure. Chartier shows how the techniques of distance and angle calculation, least-squares analysis, eigenvectors, and principal component analysis all play roles in answering the question of how closely related items are, whether those items are movies, colleges, or purchases on

See **Linear Algebra** *on page 5*



The closest rank 1 (far left) and rank 10 (second from left) approximations to the images of the Dürer print shown in the two right-hand images, one of which is the closest rank 50 approximation and the other the original print. Can you tell which is which? From When Life Is Linear *(Figure 9.2).*

Linear Algebra

continued from page 4

Amazon. In addition, even simple matrix operations—such as addition, subtraction, elimination, and multiplication—are motivated and applied to the areas of graphics and image manipulation. The book shows how the use of each operation affects an image differently, providing motivation and application for operations whose coverage in a standard textbook is usually just a definition and some computational examples. The book also breaks images down into component parts, using the singular value decomposition and PCA to give the reader ideas about ways in which images can be compressed for storage.

What is remarkable about the book is that Chartier not only explains how these techniques are applied in the real world, but also inspires readers to be creative both in applying the techniques themselves and in choosing the types of problems to which they can be applied. As he says, "The difficulty in applying math isn't in the complexity of the mathematical method but more in recognizing that a method, which can be quite simple, can be applied." A great example occurs in his discussion of modeling college basketball game results as a simple system of linear equations and using Gaussian elimination to produce ratings for college basketball teams. He then shows how these ratings can be used to predict future (tournament) games. Chartier has gained celebrity in the media for his and his students' research in predicting NCAA Basketball Tournament games. In the book, Chartier outlines some of the simpler ranking methods, such as the Colley and the Massey methods, and tells how some of his students were sufficiently inspired by the application to be successful in predicting previous tournament games.

One of the strengths of the book lies in its appropriateness as a companion text for either a computationally based or a proof-based course in linear algebra. Chartier wrote it as a companion text to his MOOC at Davidson College, and it would be perfect for a course that requires students to find and analyze real-world projects. It would serve equally well as outside reading to give students in more theoretical classes an idea of the applicability of the methods.

The book is not intended, though, as a stand-alone text. Chartier does not explain the derivation or calculation of certain methods in detail, and he often assumes the existence of calculator buttons that will perform certain operations, such as the SVD and least-squares analysis. Such material would need to be introduced in a course through lecture or supplied via a more traditional textbook or journal article. Moreover, some applications not presented in the book might serve as background material for other courses, notably techniques related to systems of differential equations and linear programming. However, I don't think the purpose of the book is to give a comprehensive listing of all applications of linear algebra, and the missing applications can be supplied by more traditional texts if desired.

I find the book highly readable and think it would be enjoyable especially for students who have been exposed to some elementary mathematical topics, such as cosine functions, vectors and matrices, and distance functions. It is thus certainly appropriate for mathematically oriented high school students as well as more advanced students. Chartier succeeds in making the book simultaneously entertaining for students and informative for instructors. A lot of the applications are novel and not included in standard linear algebra texts, and I think many instructors of linear algebra will find the topics presented here new and interesting. Fans of Chartier's earlier *Math Bytes** will see several similar topics, including the prediction of March Madness games and image manipulation. These topics are covered in more detail in *When Life Is Linear* and more of the linear algebra underpinnings are explained. But the main strength of the text is its ability to inspire creative thinking about ways to apply mathematics in real-world settings. For students beginning their journey of mathematical discovery, this book will serve as a valuable and inspirational resource.

*T. Chartier, *Math Bytes: Google Bombs, Chocolate-Covered Pi, and Other Cool Bits in Computing*, Princeton University Press, Princeton, New Jersey, 2014.

Kevin Hutson is an associate professor of mathematics at Furman University.

BGCE Prize

continued from page 3

of the work.

A student at Tufts University, Medford, Emerson works on the simulation of nematic liquid crystals, whose uses include display technologies. He derived an energy-minimization method and implemented a framework based on tailored multigrid methods for efficiently solving the linear systems.

Emerson, accompanied by his wife, was scheduled to begin his visit to Bavaria at the beginning of July, with a one-week stay at BGCE's two home universities, Universität Erlangen-Nürnberg and Technische Universität München.

Having hosted four excellent BGCE Student Prize winners in Bavaria (see http://www.bgce.de/news/bgce_prize.html), we eagerly await David's arrival. And we already look forward to the sixth BGCE Student Prize competition in 2017!

—Hans-Joachim Bungartz, Ulrich Rüde, Regina Ammer, and Tobias Neckel

Data Science at CSE

continued from page 1

foundations of mathematics and statistics, computer science, and domain knowledge, and this common core can be exploited in educational programs that will prepare the computational and data scientists of the future [2]. Indeed, many computational science competencies translate directly to the analysis of massive data sets at scale with high-end computing infrastructure. As complementary interdisciplinary endeavors, both data science and computational science suffer from the entrapments created by disciplinary boundaries. To provide rigorous, multifaceted educational preparation for the growing ranks of computational and data scientists needed to optimally advance scientific discovery and technological development in the years to come, universities will need to implement new multidisciplinary structures.

Data Science Research at CSE15: Estimating Greenhouse Gas Emissions from Human Activity

As to the synergy between data science and model-based computational science, Anna Michalak of the Carnegie Institute and Stanford provided a case in point in her invited presentation, "Statistical and Computational Challenges of Constraining Greenhouse Gas Budgets." The main question she addressed was how we can properly quantify the amount of greenhouse gases released in the atmosphere as a result of human activity [3]. Self-reporting by local governments and tracking of inventories, she pointed out, have been shown to lead to inaccurate estimates.

Michalak described how continuous measurements of atmospheric concentrations at a large set of locations can be used to estimate surface fluxes through the solution of large stochastic inverse problems. In data for 2013, 10^6 fluxes were estimated from 10^5 observations, resulting in large computational problems with dense $10^6 \times 10^6$ matrices. She showed how efficient algorithms and large-scale implementations for matrix multiplication and posterior covariance make it possible to solve such problems. Citing studies in which extensive data and physics-based models were combined with advanced mathematical and statistical algorithms and large-scale computing, she revealed that U.S. anthropogenic methane emissions were actually 50% higher than EPA estimates. Emissions from cattle were shown to be nearly double what inventories suggest, and oil and gas emissions five times as high as data reported in the reference international database on global greenhouse gas emissions [3]. A great example of computational and data science at work!

Data Science Education

So how do we teach data science? One of the panelists described graduate programs at the University of Utah that include a Big Data Certificate and MS and PhD programs in Computing with a Data Management and Analysis track [5]. These programs, which are centered in the Utah School of Computing, focus on fundamentals that include databases, algorithms, data mining, machine learning, statistics, and visualization.

Among other models is a new undergraduate program at Virginia Tech, Computational Modeling and Data Analytics [6], which is organized by an interdisciplinary group of faculty with majority representation from mathematics and statistics. This genuinely new degree mainly comprises new classes, starting with a year-long 12-credit course called Integrated Quantitative Sciences that is team taught by a mathematician and a statistician. Covering topics from multivariable calculus, differential equations, linear algebra, and basic probability and statistics, this course is intended to provide a solid foundation for an education in data science. In a sense, creating such a program offers the opportunity to rethink curricula on classical topics like calculus that have at many institutions not seen substantial change throughout most of the past century. It is a significant investment, but it appears to pay off—the first year the program was offered, with minimal advertising, almost 90 freshman applicants at Virginia Tech specified it as their first-choice major, and more than 200 as their second choice.

Another interesting example of a data science program is the Data Engineering and Science Initiative at Georgia Tech [7]. Degree programs offered include a one-year MS in analytics, and MS and PhD programs with a data focus in CSE and biotech fields. The MS in analytics is offered jointly by the School of Computational Science and Engineering (College of Computing), the School of Industrial & Systems Engineering (College of Engineering), and the Scheller College of Business. About a quarter of the extensive set of courses are offered by the School of CSE, with the focus on computational algorithms and high-performance analytics.

The Utah, Virginia Tech, and Georgia Tech programs are just three of a quickly growing number of data science-related programs in the U.S. An overview of almost 100 U.S. master's programs in analytics and data science (when this article was written) can be found in [8]. Enrollment began in 2014 or 2015 for more than half of these programs. Not surprisingly, due to the recent successes of business intelligence applications in many sectors of the economy, including retail and banking, more than 40 business analytics programs hosted by business schools appear on the list. Many of these are professional degrees (estimated tuition costs are also listed in [8]) with a more applied focus, but business analytics is quickly evolving from its roots in data warehousing and standard statistical methods to more sophisticated approaches in terms of algorithms and computation. About 15 of the other programs in [8] are hosted by colleges of arts and sciences, another 15 by engineering and computer science colleges, and, reflecting the interdisciplinary nature of data science, an additional 15 are organized by interdisciplinary data-focused institutes or consortia of colleges. The picture on the international scene is similar: For example, 51 programs in data science in Europe (about 20 of them in the UK), mostly at the master's level, are listed in [9].

Data Science and Computational Science: Synergy with a Bright Future?

It is clear that the data tsunami is only increasing in intensity and that the current focus on data analytics will not easily fade. The data revolution is shaping up to become one of the great new quantitative endeavors of our time, and, as in all quantitative fields, mathematics is poised to play an important role. The synergy between data science and computational science makes it clear that educational programs in areas like "computational and data science" or "mathematics of data and computation" hold significant promise for interdisciplinary success. Readers wishing to offer thoughts and insights on data science and how to teach it are invited to join the discussion at the companion blogpost [10] to this article.

References

[1] M. Adams et al., *Report of the National Academies Committee on Mathematical Foundations of Verification, Validation, and Uncertainty Quantification*, National Academies Press, Washington, DC, 2012.

[2] J. Chen et al., *Synergistic Challenges in Data-Intensive Science and Exascale Computing*, DOE ASCAC Data Sub-committee Report, Office of Science, Department of Energy, 2013.

[3] S.M. Miller et al., *Anthropogenic emissions of methane in the United States*, Proc. Natl. Acad. Sci., 110.50 (2013): 20018–20022.

[4] P.C. Wong et al., *The top 10 challenges in extreme-scale visual analytics*, IEEE Comput. Graph., 32 (2012), 63.

Notes

[5] http://www.cs.utah.edu/bigdata/

[6] http://www.science.vt.edu/ais/cmda/

[7] http://bigdata.gatech.edu/, http://www.analytics.gatech.edu/

[8] http://analytics.ncsu.edu/?page_id=4184

[9] http://www.kdnuggets.com/education/index.html

[10] http://blogs.siam.org/data-science-what-is-it-and-how-to-teach-it/

Hans De Sterck is a professor of computational mathematics and scientific computing in the Department of Applied Mathematics at the University of Waterloo. Chris Johnson is director of the Scientific Computing and Imaging Institute and a Distinguished Professor of Computer Science at the University of Utah.

National Festival

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says Rachel Levy, SIAM vice president for education.

"As the nation's only museum of mathematics, MoMath was delighted to bring over 20 hands-on, engaging math exhibits to the nation's capital," said Cindy Lawrence, MoMath executive director and co-founder. "MoMath is grateful to the many volunteers who came out to share their own love of math with others, and is especially appreciative of the large role played by SIAM in bringing out a volunteer force over 100 strong."

The enthusiasm level among children and parents was high. Visitors to the exhibits, which were located in the Enid A. Haupt Garden of the Smithsonian complex, especially enjoyed those that were low-tech and tactile, such as "Space Tessellation," where visitors built icosahedrons from wire coat hangers, and the "Mysterious Harmonograph." The most popular MoMath exhibit, "Pedal on the Petals," a bicycle with square wheels on a catenary-shaped track, frequently had a long line of visitors waiting to ride the bicycle.

"It was amazing to see literally thousands and thousands of people enjoying the beauty and wonder of mathematics," said Glen Whitney, MoMath president and co-founder.

Typical visitors were K–8 children and their parents, many of whom were already involved in Math Circles, MATHCOUNTS, and other STEM activities. Many parents sought recommendations on extracurricular math or STEM programs from our volunteers. "There is an insatiable demand for math education resources and activities," says Byong Kwon, a SIAM student volunteer from George Mason University. "Developing engaging math exhibits for a festival takes much thought and design effort, and volunteers with math backgrounds were invaluable when interacting with a STEM-savvy audience."

MoMath exhibit "Pedal on the Petals," operated by student volunteers. Photo by Byong Kwon.

In addition to the MoMath exhibits, the festival offered 27 public lectures throughout the day in the Smithsonian complex. Among the speakers were SIAM fellows Steven Strogatz and Richard Tapia. Asked how he finds the time and motivation to participate in outreach events, Tapia said, "I get to do something that is fun, relaxing and when you succeed, you help somebody. . . this is my therapy."

There is a need to show young people that math has many applications, Tapia continued, and that it "is important in all our lives."

Byong Kwon is a graduate student in applied mathematics at George Mason University. Rachel Levy, SIAM vice president for education, is an associate professor of mathematics at Harvey Mudd College.

Sports

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Elasticity in the High Jump and Pole Vault

The chapter on elasticity includes analyses of high jumping and pole vaulting ("Energy Transformation in the Pole Vault"). Unlike the bamboo and aluminum poles of old, modern fiberglass poles are highly flexible. In bending, they acquire significant quantities of potential energy, which can be transferred to the jumper in the form of kinetic energy, as suggested by Figure 3.

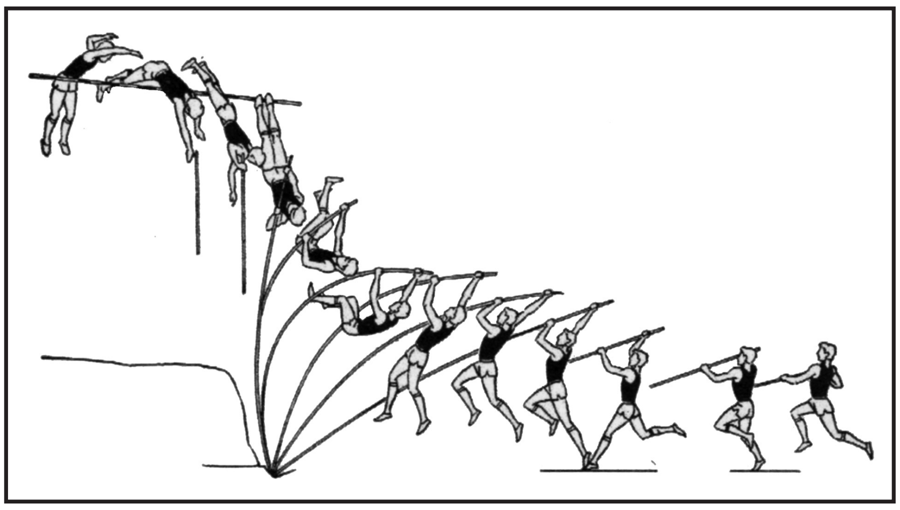

Figure 3. *Typical sequence of actions in the pole vault. Reproduced in* Sports Physics *from Ganslen (1979).*

Among the more unexpected revelations of the book's discussion of high jumping and pole vaulting is that, whereas a competitor's entire body must pass over the bar, his or her center of mass (CM) need not. To see why, imagine the human body to consist of a rod 80 inches long—high jumpers tend to be tall—and hinged in the middle. Once airborne, the rod's CM cannot deviate from its initial parabolic path. So if the zenith of that path lies 9 inches below the bar, and if the rod is instantaneously bent at an angle of 120°, with one segment on either side of the bar, the hinge point H will stand 1 inch above the bar, as indicated in Figure 4.

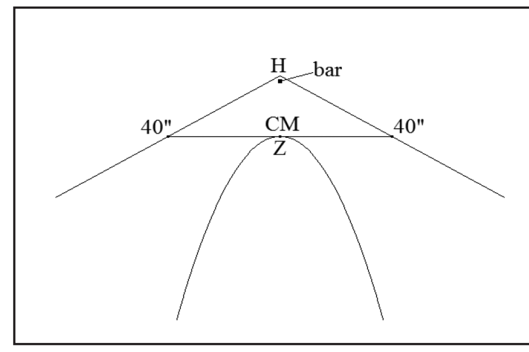

Figure 4. *When the jumper's center of mass CM reaches the zenith Z of its parabolic trajectory, the jumper's hinge-point H would lie 10 inches above Z and 1 inch above the bar.*

Still to be explained is how a jumper should contort his or her body while airborne in order to reach such a position above the bar, but the drawing in Figure 3 looks enough like the stop-action photos taken of actual world-class high-jumpers to suggest that at least a few of them have mastered the trick. In practice, only a few of the most gifted seem to have done so.

All in all, Clanet has assembled an extraordinarily informative volume—one that belongs on the shelf of anyone seriously interested in understanding athletic endeavor.

James Case writes from Baltimore, Maryland.

Professional Opportunities

Send copy for classified advertisements to: Advertising Coordinator, SIAM News*, 3600 Market Street, 6th Floor, Philadelphia, PA 19104–2688; (215) 382–9800; fax: (215) 386–7999; marketing@siam.org. The rate is $3.00 per word (minimum $375.00). Display advertising rates are available on request.*

Advertising copy must be received at least four weeks before publication (e.g., the deadline for the October 2015 issue is August 31, 2015).

Advertisements with application deadlines falling within the month of publication will not be accepted (e.g., an advertisement published in the October issue must show an application deadline of November 1 or later).

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

University of Arizona

Graduate Interdisciplinary Program in Applied Mathematics

The University of Arizona seeks an outstanding individual at the rank of tenured associate or full professor to provide scientific, educational, and administrative leadership in the field of interdisciplinary applied mathematics, with the expectation that the selected candidate will assume the position of chair of the University's Graduate Interdisciplinary Program in Applied Mathematics. The program is noted for its interdisciplinary breadth, with faculty consisting of some 75 researchers from numerous colleges and departments throughout the university and with approximately 50 doctoral candidates currently enrolled. Applicants should visit http://appliedmath.arizona.edu/ for further information.

The successful candidate is expected to have a proven commitment to teaching and advising graduate students and to the recruitment and training of women and members of underrepresented minorities as well as having demonstrated excellence in teaching at the undergraduate and graduate levels. The appointee will be expected to maintain an active, widely recognized, and externally funded research program and to actively seek external training grants to support it. As chair, the appointee would be expected to provide leadership in the continued development of the program's quality and recognition and would have the opportunity and resources to participate in faculty recruitment initiatives in partnership with other academic units. The chair would teach at the graduate and/or undergraduate levels and would be appointed as a tenure-track or tenured faculty member in whichever department is most appropriate, with the possibility of joint appointments in other relevant departments.

Applications should be submitted at http://www.uacareertrack.com (job #58068). Applicants should include a letter of interest; curriculum vitae, including full list of publications and names and contact information of at least three references; and a personal statement, including research interests and plans, teaching experience and philosophy, and vision of research and graduate education in applied mathematics. For further information, potential applicants may contact Dr. P. Deymier (deymier@email.arizona.edu) or Dr. T. Secomb (secomb@email.arizona.edu).

The University of Arizona is an EEO/AA, M/W/D/V employer.

Max Planck Institute for the Physics of Complex Systems

The Center for Systems Biology Dresden

The Center for Systems Biology Dresden, a joint activity of the Max Planck Institute of Molecular Cell Biology and Genetics (MPI-CBG) and the Max Planck Institute of the Physics of Complex Systems (MPI-PKS), focuses on developing and using computational methods to address key questions in biology and to transform data into knowledge. It is a highly interactive and collaborative workplace with an international atmosphere where English is the working language. It has a strong commitment to interdisciplinary training and career development and provides access to cutting-edge computer infrastructure and laboratory facilities. The MPI-CBG was named one of the "Best Places To Work for Postdocs" in 2011. Dresden was awarded "City of Science" in 2006 and is one of the leading scientific centers in Europe, with three Max Planck and thirteen other research institutes, and the Dresden University of Technology as one of eleven Universities of Excellence in Germany. Dresden has half a million inhabitants and is considered one of the most beautiful cities in Germany, located two hours from Berlin and Prague.

The Center for Systems Biology Dresden calls for applications for several open postdoc positions in computer science, computational science, and applied mathematics within the prestigious ELBE Postdoctoral Fellowship Program. The Center seeks outstanding candidates with both a strong computational background and interest in working in a multi-disciplinary environment toward developing data analysis, computer vision, bioimage analysis, high-performance computing, and numerical simulation algorithms and theories to establish computational biology as an integral part of the life sciences. ELBE Fellowships are awarded on a competitive basis to outstanding young researchers with a doctoral degree. To foster collaboration, fellows are usually affiliated with two hosting groups working in different disciplines. The deadline for applications is August 20, 2015. For details about the application procedure, prospective applicants should visit http://mpg-sysbio.de/index.php?id=jobs.

The Max Planck Society is an equal opportunity employer: Individuals with disabilities are strongly encouraged to apply. The Center for Systems Biology, the MPI-CBG, and the MPI-PKS aim to increase the number of women in scientific positions. Female candidates are therefore particularly welcome.

Georgia Institute of Technology

Chair of the School of Mathematics

The Georgia Institute of Technology (Georgia Tech) invites nominations and applications for the position of chair of the School of Mathematics. Candidates must have demonstrated outstanding leadership and scholarship, and possess strong commitment to interdisciplinary research, educational activities, and faculty/staff development. An earned doctorate in mathematics or a related discipline is required.

Georgia Tech is one of the premier public institutions for STEM disciplines in the U.S. In the span of a quarter century, the School of Mathematics has transformed itself from a service department into one of the top 30 nationally ranked research departments, with significant potential for future growth in quality and reputation.

The School offers BS, MS, and PhD degree programs in mathematics and participates in several interdisciplinary graduate programs. All students at Georgia Tech take calculus, and the School places significant emphasis on its educational mission within an engineering university.

For further information, prospective applicants should refer to the Georgia Tech webpage: http://www.math.gatech.edu.

Applications and nominations should be sent by e-mail to science@cos.gatech.edu or by regular mail to: Mathematics Chair Search Committee, Dean's Office, College of Sciences, Georgia Institute of Technology, 225 North Ave., SE, Atlanta, GA 30332-0365, U.S.A. Applications will be considered until the position is filled. For best consideration, materials should be submitted by October 1, 2015. Applications should include a letter of interest and a current resumé that describes the applicant's research, teaching and administrative experience, and publications, as well as the names of at least five references (with addresses, phone numbers, and email addresses).

Georgia Tech is a unit of the University System of Georgia and an Affirmative Action/Equal Opportunity Employer and requires compliance with the Immigration Control Reform Act of 1986.

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Old Dominion University

Graduate Programs in Computational and Applied Mathematics

The Department of Mathematics and Statistics at Old Dominion University invites outstanding students to apply for graduate assistantships in its vigorous applied mathematics and statistics master of science and PhD programs for the 2016–2017 academic year.

University faculty are active in various areas of applied and computational mathematics, scientific computing, analysis, and numerical analysis; they play a key role in ODU's multidisciplinary Modeling and Simulation graduate program as well as the Center for Computational Science. They also enjoy an excellent funding record, including grants from the NSF, the NIH, NASA, the AFOSR, the U.S. Army, and other state and federal funding agencies.

For further information, prospective applicants should see http://ww2.sci.odu.edu/math/academics/grad.shtml.

Read Professional Opportunities online:

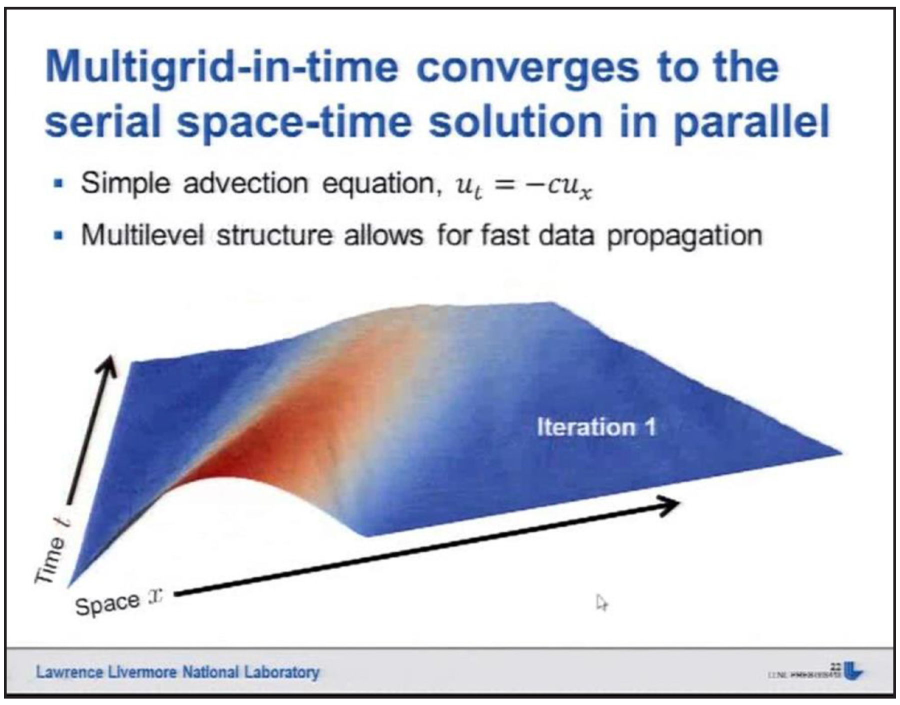
jobs.siam.org/

CSE at 15

continued from page 1

viding interdisciplinary education.

The CSE15 program offered an enormous diversity of topics across computational science and engineering. Popular themes among the 301 minisymposia included CSE software, big data analytics, physics-compatible numerical methods, high-accuracy numerical methods, and compressed sens-



A slide from invited speaker Robert Falgout's talk, "Extreme-scale Multigrid in Space and Time."

ing. *SIAM Journal on Scientific Computing*, in conjunction with CSE15, will devote a section of an upcoming issue to the two special themes, CSE software and big data analytics (see article on page 1): Guest-edited by Hans De Sterck, Chris Johnson, and Lois Curfman McInnes, the section will feature high-quality scientific computing papers in one or both of these areas.

Slides with synchronized audio are available for most of the talks mentioned in this article,* including the invited plenary talks with their inspiring examples of CSE in real applications. The talk on extreme-scale multigrid by Rob Falgout of Lawrence Livermore National Laboratory is an example (a slide from the talk appears on this page); another interesting application surfaced in the talk of Anna Michalak, who drew on mathematical, statistical, and large-scale computing to show that emissions of methane from cattle were nearly double those estimated by EPA (see page 1).

To promote cross-disciplinary education for both students and experienced CSE practitioners, CSE15 featured two hands-on minitutorials on the conference's special themes. Python Visual Analytics for Big Data, led by Jonathan Woodring (Los Alamos National Laboratory), covered interactive plotting, the building of web visualizations, mapreduce, and NoSQL. Lab Skills for Scientific Computing, led by Greg Wilson (Software Carpentry Foundation, www.software-carpentry.org), introduced test-driven software development and the use of Git and GitHub for open collaboration. Wilson explained how by integrating these practices, researchers can get more done in less time, and with less pain.

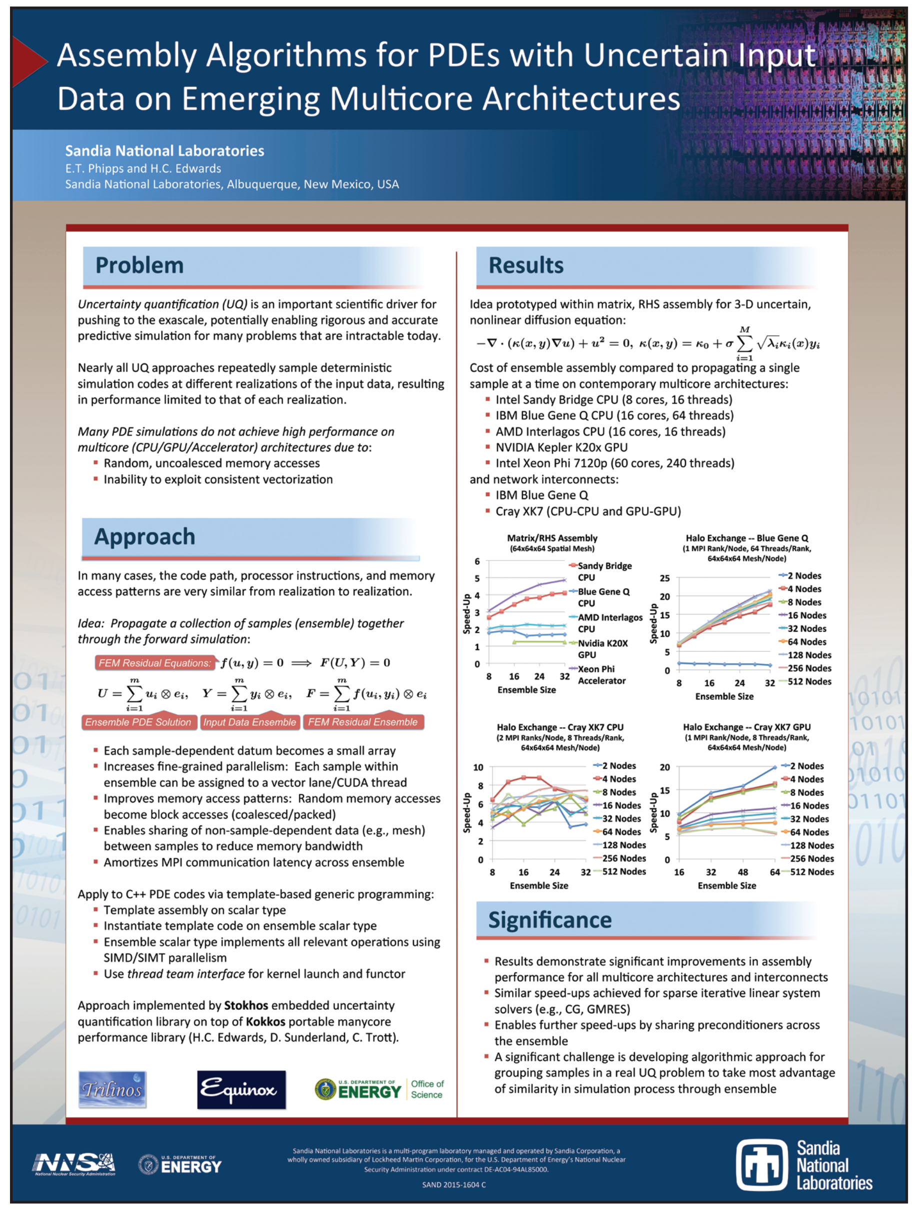
CSE15 introduced several features designed to make poster sessions more useful for networking and sharing ideas, and as a means to handle conference growth. Poster presenters were invited to include demos with their posters, using their laptops to demonstrate CSE simulations and software. The CSE15 poster call also included a new submission category: a "minisymposterium" (that is, a minisymposium of posters), a collection of three or more posters by different presenters with a central theme. CSE15 poster sessions included 14 minisym-posteria on a broad range of themes, with 4 to 16 posters per group. An online "poster sizzle" video shows that CSE15 poster sessions fostered a vibrant exchange of ideas.

CSE15 organizing committee members Luke Olson, Pavel Bochev, and Tom Bartol coordinated the teams of judges who selected the recipients of poster prizes from nearly 300 candidates—a new CSE conference record. Monetary awards for poster prizes were generously sponsored by HP. Eight prizes were awarded in three categories:

■ **Best Poster Awards:** Computational Methods to Study the Coordination of Mechanical Forces Involved in Amoeboid Cell Migration (Calina Copos, University of California, Davis); Computational Homogenization for the Modeling of Soft Matter Materials (Christian Linder, Stanford University); The Sparse Grid Combination Technique for Solving Eigenvalue Problems (Christoph Kowitz, Technische Universität München); Dolfin-Adjoint (Simon Funke, Simula Research Laboratory).

■ **Best Minisymposterium Awards:** Scalable Finite Element Assembly, chaired by Irina Demeshko and Eric Cyr (Sandia National Laboratories), 7 posters by various presenters; CSE Software, chaired by Anders Logg (Chalmers University of Technology), 16 posters by various presenters.

■ **Best Poster Design and Presentation Awards:** Finite Element Methods for the Evolution Problem in General Relativity (Vincent Quenneville-Belair, University of Minnesota); Inducing Approximately Optimal Flow Via Truthful Mediators (Ryan Rogers, University of Pennsylvania).



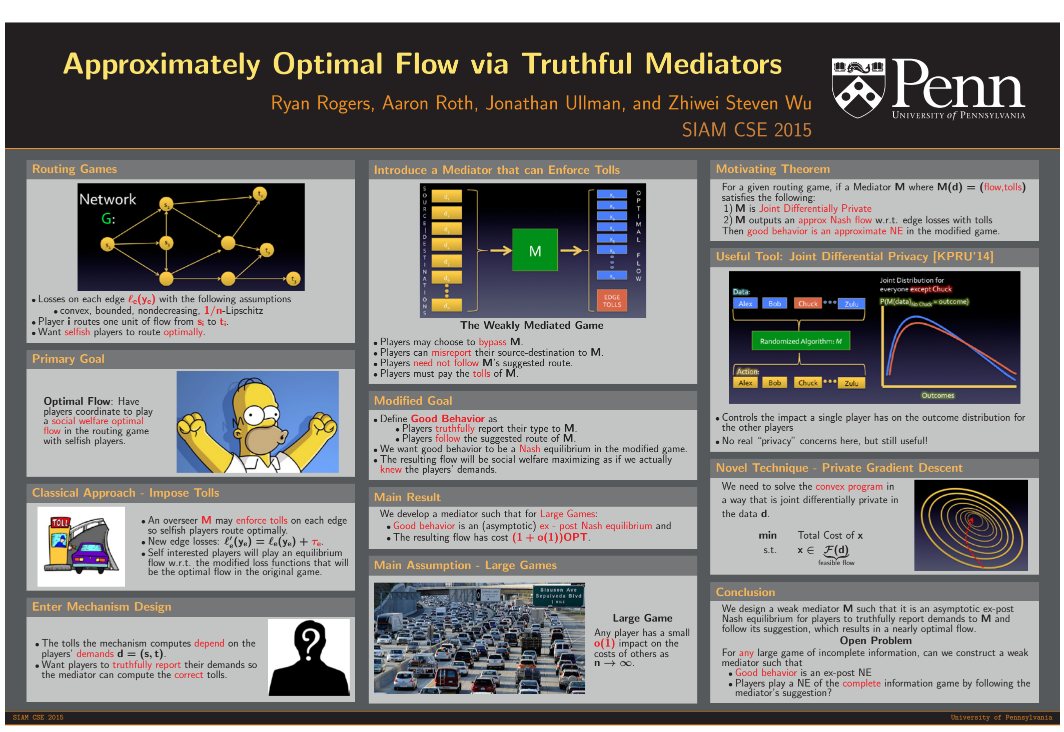
With an immense conference on their hands—not only in attendance, but also in numbers of sessions to be scheduled, the CSE15 organizers devised an approach for grouping posters, for which they coined the term "minisymposterium," and offered prizes for the best in the category. Shown here, from the winning minisymposterium "Scalable Finite Element Assembly" is the poster by Eric Phipps. This poster combines next-generation algorithms and architectures that specifically target acceleration of assembly. Interested readers can learn more about algorithms and abstractions for assembly in E.C. Cyr, E. Phipps, M.A. Heroux, J. Brown, E.T. Coon, M. Hoemmen, R.C. Kirby, T.V. Kolev, J.C. Sutherland, and C.R. Trott, Algorithms and Abstractions for Assembly in PDE Codes: Workshop Report, *Sandia Technical Report, SAND2015-1379, February 2015; http://www.sandia.gov/~eccyr/pubs/assembly-wksp-report-2015.pdf.*

CSE15 also introduced Featured Minisymposia, solicited by the CSE15 organizing committee to provide overview presentations on fundamental advances in fields related to the conference themes. Featured minisymposium topics and organizers were Big Data Analytics (Han-Wei Shen, The Ohio State University); CSE Software (Hans Petter Langtangen, Simula Research Laboratory and University of Oslo); Distributed Methods for Optimization (Wotao Yin, UCLA); Fast Multipole Methods Maturing at 30 years (Lorena Barba, George Washington University); Modeling and Computing Complex Flows (Gretar Tryggvason, University of Notre Dame); and Physics-compatible Numerical Methods (Mikhail Shashkov, Los Alamos National Laboratory).

A highlight of CSE15 was its engagement with SIAM student members through Student Days, organized by the SIAM Education Committee (chaired by Rachel Levy, Harvey Mudd College). Student Days are designed to encourage student participation in SIAM, help students learn more about applied mathematics and computational science both as fields of study and as careers, and provide a forum for emerging mathematicians to learn about their field from professionals. Events included a career panel and full-day career fair featuring non-academic employers, professional development sessions and a reception, presentations by student chapter representatives, a student lounge, sessions on undergraduate research, and a session for students with selected conference invited speakers; a pilot program, Broader Engagement, also engaged many students and early-career CSE researchers. The SIAM Student Chapter at the University of Utah helped with conference operations. We were thrilled to see the next generation of computational mathematicians, scientists, and engineers so energetically involved.

Going into the conference, the organizers had concerns regarding the large attendance, which resulted in an unprecedented 27 parallel sessions running for a full five days. The actual conference atmosphere was overwhelmingly positive, however, reflecting the upside of a large conference—a great variety of session topics to choose from at all times, and excellent networking opportunities, given the significant portion of the community in attendance.

The CSE15 organizers gratefully acknowledge conference sponsorship by Intel, HP, Mathworks, Kitware, KAUST, and the University of Utah's Scientific Computing and Imaging Institute, which contributed to the energizing conference atmosphere. The SIAG business meeting saw a vigorous discussion of the future of the CSE conference, including possible structural changes that may be needed if the conference continues to grow. That remains to be seen at CSE17.—*Lois Curfman McInnes (Argonne National Laboratory), Hans De Sterck (University of Waterloo), and Chris Johnson (University of Utah).*



Ryan Rogers and collaborators are the authors of a winning poster in the Design and Presentation category.

*Via the CSE15 website (http://www.siam.org/meetings/cse15/).