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Uncertainty Quantification 2012

Lagrangian Data Assimilation in Ocean Modeling

By Christopher K.R.T. Jones

In making predictions or estimations of the state of a system, in our case the ocean, uncertainty is derived from many sources. There are errors in the model, as it cannot reflect reality fully, but also in the observations, because of instrument inaccuracies, human error, and the processing of the information. It is particularly important to consider observational errors in ocean studies, in which so much of the data collection is indirect: Model variables, such as fluid velocity, are estimated from measurements made at sea-surface height; gliders measure temperature and density, but their locations are not known exactly.

Data assimilation is the procedure through which the "best estimate" of the state of the system is obtained from all the information available, including model computations and data analyses. In its most comprehensive expression, it is based on Bayes' theorem and gives a full probability distribution function for the system state. It therefore captures all the uncertainty in the estimate or prediction, given the input information.

Much subsurface information in the ocean comes from instruments that, at least to some extent, "go with the flow." *Floats* are pressurized to follow constant-density surfaces and record their position as a function of time through sonar pinging to (or from) a pre-placed receiver (or transmitter). Floats, however, can report their readings only at the end of the voyage, which may last up to a year or more. *Drifters* are instruments that move around on surface currents and are tracked through GPS. *Gliders*, the most modern observational instruments in this family, are designed to combine the strengths of floats and drifters—they use buoyancy changes to submerge and surface, and their frequent surfacings afford regular reporting of data through satellite communication.

The assimilation of data derived from instruments that are not stationary has come to be known as Lagrangian data assimilation. The challenge in assimilating Lagrangian ocean data is twofold: First, the instruments do not give direct readings of state variables, such as flow velocity or temperature; second, these instruments are subject to the chaotic dynamics of the Lagrangian flow, and the data have to be interpreted against this nonlinear backdrop. We have resolved the first issue by using an augmented system that includes position variables for the instruments rendering the data. But the second issue continues to challenge us.

The considerable benefit to be gained from assimilating Lagrangian data became clear when we were able to reconstruct a large eddy in a general circulation model of the Gulf of Mexico from a small number of well-placed floats. In general, we have discovered that the strategic placement of instruments can pay dividends in the form of accurate representations of the flow field. But the key float locations are strategic exactly because they are of dynamical significance in the Lagrangian flow. And it is the passage of trajectories either through or near these locations that causes the assimilation methods to fail.

Some approaches and answers are becoming available, but what is worth noting here is the big picture and its message for UQ and data assimilation. A lot is said about the "curse of dimensionality" in UQ. The difficulty is in sampling probability density functions in high dimensions: When there are too many dimensions to check, you never know whether you have found the peaks of the distribution. The main way to deal with this is to assume a Gaussian approximation for the PDF and a linear approximation for the underlying model. You then have to track only the mean and variance. These approximations form the basis of almost all methods used in high-dimensional problems, including Kalman filtering and variational methods, and they work very well provided that the assumptions of Gaussianity and linearity are good. But we know that for Lagrangian data assimilation, they completely miss the exact features that carry the key information.

Particle filters give very effective ways of sampling potentially multi-modal PDFs. But these statistical methods work most effectively only in low dimensions. Our perspective is that such an approach can work in Lagrangian data assimilation because the observational data is confined to a well-defined low-dimensional subspace—namely, that part of the augmented system that encodes the trajectory behavior.

Perhaps there is a moral here for UQ in general: You do not want to linearize

See **Data Assimilation** *on page 4*

The Boeing Dreamliner. *The mathematics underlying the design—completely by computer—of the first commercial airplane made mainly of composite materials is the subject of one of 18 case studies featured in SIAM's recently updated* Mathematics in Industry *report. See page 2.*

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A Data Deluge in April

By Chandrika Kamath

April was a busy month for those involved in the mathematical aspects of data science. As regular readers of *SIAM News* will know, April is Mathematics Awareness Month and the 2012 topic was Mathematics, Statistics, and the Data Deluge (see www.mathaware.org). An opportunity to address some of the more challenging questions in this field, while raising others, came at the 12th SIAM International Conference on Data Mining, held April 26–28, in Anaheim, California. The popularity and timeliness of the topic were reflected in the best attendance at the conference so far: nearly 300 participants, with papers presented by a set of authors who, true to the conference name, had come from Australia, Belgium, China, Germany, Italy, Japan, Netherlands, Singapore, Switzerland, Turkey, the UK, and the US.

SDM12 was also the first SDM conference after the formation of the SIAM Activity Group on Data Mining and Analytics. Unlike other SIAM conferences, SDM preceded the creation of the SIAG by nearly a dozen years, focusing on the mathematical aspects of data mining and filling a gap left by other conferences in the field.

At the heart of SDM12 were four widely ranging keynote talks, on learning systems in healthcare, network science, transfer learning, and information retrieval. Bharat Rao of Siemens Healthcare focused on practical challenges faced in the application of data mining techniques to problems in healthcare. Medical treatment is largely stochastic, he emphasized: Drugs work in some patients and not in others, leading to individualized care. Data mining techniques play a role in decision support, in the aggregation of data from different sources, and in the injection of knowledge via probabilistic inference. A consequence has been not only a need to combine structured and unstructured data, but also challenges resulting from the breakdown of assumptions on algorithms, such as the availability of i.i.d. data, balanced datasets, and ground truth for comparison.

Susan Dumais, from Microsoft Research, provided illuminating insights on improved web retrieval, achieved through exploitation of the facts that both web content and interactions of a user with the web change over time. To analyze data obtained by conducting large-scale web crawls, her team came up with metrics for determining when a web page had changed and by how much, and identified patterns that reflected revisitation of a site by a user. It was by exploiting the temporal dynamics pervasive in information systems that they were able to improve retrieval.

Qiang Yang, from Hong Kong University of Science and Technology, discussed ways to benefit from cross-domain transfer learning. He considered the case in which major assumptions in traditional learning—namely, that test and training data are in the same feature space and follow the same distribution—are no longer valid. In such problems, he said, ideas from the "transfer of learning," a concept from educational psychology theory, can be applied. The set of references Yang listed at the end of his talk clearly indicated that transfer learning lives up to its name by borrowing ideas from many domains.

A fascinating glimpse into network science was provided by Noshir Contractor of Northwestern, who has been investigating what prompts individuals to form teams and what leads to a successful team. He observed that team science is increasingly carried out by researchers at different universities, who tend to produce higher-impact work than comparable co-located teams or solo scientists. His analysis of a dataset of interdisciplinary scientific teams that submitted proposals to NSF resulted in some interesting findings: Researchers from top-tier institutions and those with high scores on the impact-rating H-index, for example, were less likely to collaborate, and those with tenure were more likely to collaborate. Other interesting insights into what makes a successful team are avail-

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Obituaries

Vera Nikolaevna Kublanovskaya passed away on February 21, 2012, at the age of 91. She was the last surviving member of the generation that shaped modern numerical linear algebra, a group that included George Forsythe, Alston Householder, Heinz Rutishauser, and James Wilkinson. She is most widely known as one of the inventors of the QR algorithm for computing eigenvalues of matrices. Her range/nullspace separation algorithms form the foundation for all later work on algorithms for the Jordan and Kronecker canonical forms of matrix pencils.

Born on November 21, 1920, Vera Nikolaevna Kublanovskaya was one of nine siblings in a farming and fishing family in Krokhono, in Vologda Oblast, Russia. Krokhono was a small village on the bank of Lake Beloye, where the river Sheksna had its source. Vera went to normal school in Belozersk, a city 18 km from Krokhono that dates back to 862 and lies about 430 km east of Leningrad and 470 km north of Moscow.

In 1939 she began studies at the Gertzen Pedagogical Institute in Leningrad to become a teacher. There she met and was encouraged to pursue a career in mathematics by Dmitrii Konstantinovich Faddeev (1907–1989). In 1942, she was obliged to return home because her mother was seriously ill. In 1945, at the end of a stay prolonged by the siege of Leningrad, she wrote to Faddeev. Upon his recommendation she was immediately accepted to study mathematics at Leningrad State University, without undergoing the usual obligatory entrance testing. She graduated in 1948 and then joined LOMI, the Leningrad Branch of the Steklov Mathematical Institute of the USSR Academy of Sciences. She was a member of the staff there for the remaining 64 years of her life.

At first she worked on a secret nuclear engineering project, from which she retired in 1955. During those years she bore two sons and, in 1955, finished her candidate's thesis for a PhD, on the application of analytic continuation to numerical methods. At about that time Leonid Vitalievich Kantorovich (1912–1986) was organizing a group in Leningrad to develop a universal computer language, Prorab, for BESM, the first electronic computer in the USSR, which was completed in 1954 in Moscow. Vera joined the group; her task was to select and classify matrix operations that are useful in numerical linear algebra. This experience brought her close to numerical linear algebra and computation. In 1972 she obtained her secondary doctorate, the Habilitation; this time her theme was the use of orthogonal transformations to solve algebraic problems. In October 1985 Vera Nikolaevna Kublanovskaya was awarded an honorary doctorate at Umeå University, Sweden, a place she visited several times and where many researchers who continue her work are active to this day.

Vera Nikolaevna Kublanovskaya, 1920–2012

Kublanovskaya's 1961 paper "On Some Algorithms for the Solution of the Complete Eigenvalue Problem," together with two papers by John G.F. Francis, published independently in the same year, forms the basis of the QR algorithm for computing the eigenvalues of an unsymmetric matrix. Kublanovskaya's paper also presents a convergence proof of the QR algorithm based on sophisticated determinantal theory.

Her 1966 paper "On a Method for Solving the Complete Eigenvalue Problem for a Degenerate Matrix," translated from the Russian in 1968, was another milestone in this area. There she presented a method for computing the Jordan structure of a multiple eigenvalue by unitary similarity transformations, which laid the foundation for the so-called staircase algorithms. This paper stimulated several subsequent papers by different authors on the numerical computation of the Jordan and Kronecker canonical forms, and several groups developed mathematical software.

She continued her work on finding canonical forms of polynomial and rational matrices, leading to a 202-page survey: V.N. Kublanovskaya, "Methods and Algorithms of Solving Spectral Problems for Polynomial and Rational Matrices" (*Journal of Mathematical Sciences*, Vol. 96, 2005, pages 3085–3287; translated from *Zapiski Nauchnykh Seminarov POMI*, Vol. 238, 1997, pages 7–328). This was not the end; she continued to work on nonlinear and two-parameter matrix pencils. A 2009 paper in the same translated journal is titled "To Solving Problems of Algebra for Two-parameter Matrices. Part I."

It was remarkable to follow Vera at work, always serious, happy to hand over her results to younger people in other places. In her own research she always pursued a new problem with the same eagerness as in all her previous projects, all the way to the finished result—which was so clearly built up that it looked as if it had always been there. All of us feel privileged to have been close to a great scientist!—*Bo Kågström, Umeå University, Sweden; Vladimir Khazanov, St. Petersburg, Russia; Frank Uhlig, Auburn University, Alabama, USA; and Axel Ruhe, Royal Institute of Technology, Stockholm, Sweden.*

SIAM Report Reflects a New Era in Industrial Math

In 2008, with funding from the National Science Foundation, SIAM set out to extend and update one of its most influential projects: a study and report (published in 1996) on industrial mathematics. The new version, titled *Mathematics in Industry*, appeared earlier this year.*

Although many of the insights from the 1996 report remain valid, the "landscape of mathematical and computer sciences in industry has changed," the updated report states. "Organizations now collect orders of magnitude more data than they used to, and face the challenge of extracting business enhancing information from it. Computing technology has continued to advance rapidly, and companies are making more and more aggressive use of high-performance parallel computing."

At the same time, the U.S. economy has evolved. By 2010, manufacturing, which once dominated the U.S. GDP, was surpassed by the combination of scientific and technical services and finance. And new programs have been created by both government agencies and private foundations to address educational deficiencies that have prevented a full flourishing of mathematics in industry since the earliest days. Among the new programs are the National Science Foundation's GOALI (Grant Opportunities for Academic Liaison with Industry), the Department of Energy's expansion of its Computational Science Graduate Fellowship program, and Alfred Sloan Foundation-funded efforts to develop professional master's degrees.

Like its predecessor, the 2012 MII report is built on interviews with mathematicians and managers in industry. What's new is mainly a section titled "Trends and Case Studies" that should be informative both to academic departments interested in forming or improving programs in industrial math and to students hoping to learn about, and be educated for, rewarding careers outside academia.

The 18 case studies, the centerpiece of the report, highlight the use of mathematics and computation in eight industry sectors: Business Analytics, Mathematical Finance, Systems Biology, Oil Discovery and Extraction, Manufacturing, Robotics, Communication and Transportation, Modeling Complex Systems, and Computer Systems, Software, and Information Technology.

An eye-catching case study in the manufacturing category considers the use of mathematics (multidisciplinary design optimization and CAD) in the production of the Boeing 787 Dreamliner. Shown on the front page of this issue of *SIAM News* landing at the end of its maiden flight, the Dreamliner, made mainly of composite materials (carbon fiber-reinforced plastic), posed many engineering challenges: Citing the plane's wings, which "flex upwards by three meters during flight," the report points out that "traditional rigid-body models, which describe the wing's shape correctly in the factory or on the ground, do not describe it correctly during flight. To an aerodynamic and a structural engineer, it looks like two different wings—and yet both engineers have to work from the same computer model."

Stimulating in a different way is the final case study, "Serendipity." Beginning with the truism "In any commercial enterprise, basic research with no foreseeable bottom-line impact is always the hardest kind of R&D to justify," the item goes on to present a remarkable counterexample: the 2008 discovery of the memristor at HP Labs.

*The full 2012 report is available online (www.siam.org/reports/mii/2012/). For information about ordering print copies, contact SIAM customer service (service@siam.org; www.siam.org/contact/; (215) 382–9800) or toll-free (800) 447–SIAM (U.S. and Canada).

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Nutty about Writing

FROM THE SIAM PRESIDENT

By Nick Trefethen

I just finished writing a book, and I'm thrilled about it. This is *Approximation Theory and Approximation Practice*, to be published by SIAM at the end of the year. I hope it's OK if I take this as an excuse to offer a rather personal column about the place of writing in my life.

Writing was important to me even as a child, and I think there are two main reasons. One is that I attended a school that cared a lot about it (Shady Hill School in Cambridge, Massachusetts). The other is that my mother was a writer who truly loved the English language and encouraged me to feel the same way. One of her principles was that if you run into an unfamiliar word and wonder if it's worth the trouble to look it up in the dictionary, "it's always worth it!"

But there's no doubt that what cemented my relationship with English was a piece of equipment: the typewriter. When I was 9, my parents hauled a manual typewriter all the way around the world for a sabbatical in Australia, and a couple of years afterward I taught myself to touch-type from a book. (Later I bribed my own children with Gameboys to reach 30 words per minute.) Practicing typing meant practicing writing too. In my early teenage years I hammered away endlessly in my bedroom on a Smith-Corona electric and produced around a thousand pages of single-spaced diary entries. These pages are excruciating to read now, and I would sooner die than let you see any of them.

Having acquired a special skill, I used it in boarding school and college to make money—astonishingly little money. I typed my friends' term papers in the middle of the night for 35 cents a page, correcting their spelling and punctuation as part of the service.

Another sabbatical, seven years later, got the family hooked on a new machine, the IBM Selectric, a magical improvement over previous typewriters—it didn't even need a carriage-return lever! When I returned to Massachusetts at age 17, that became the first big purchase of my life: a Selectric II typewriter, paid for by a summer of lawn-mowing at $1.50 per hour. It was big and heavy and white, and my roommates called it Moby Dick. I loved that machine and produced my undergraduate thesis on complex Chebyshev approximation on it, changing the Selectric "golf ball" every time a Greek letter was needed. I knew by heart which key to hit to get λ, ε, or δ from the Symbol ball. My roommates liked to make fun of "Chevy Chase approximation" (it was the era of Saturday Night Live), and here I am 35 years later, still writing about Chebyshev.

I had started typing ideas on index cards at age 14, shaping my less personal thoughts more carefully than for a diary, and soon the collection grew sizable. Many of you have seen a sample published last year as *Trefethen's Index Cards*. Writing these notes has been a lifelong habit and pleasure. Since they are short, every sentence gets carefully shaped and reshaped as I practice the art of combining substance and clarity. An outstanding freshman expository writing teacher at Harvard, Bill Dowling, strengthened my determination to make each word count. A typing contest with Bill Gates in sophomore year strengthened my conviction that the typists would inherit the earth. He had bragged at the lunch table of his prowess at the keyboard, but two witnesses saw me slaughter him half an hour later in a fair contest in his room in Currier House. Poor Bill with his index fingers never had a chance.

Graduate school brought another game-changing piece of technology, for I started as a PhD student in computer science at Stanford just as Don Knuth was inventing TeX. I liked this very much and wrote my first paper in the new system, an article on Schwarz–Christoffel mapping issued as a technical report by the Stanford CS department in March 1979. There is a chance that this is the first report anyone anywhere ever published in TeX! At least I haven't found an earlier one, not even by Knuth.

My generation of Californian graduate students were delighted to find that with TeX, complex formulas could be rendered perfectly. For people like me, the technology contributed to our perfectionism as writers. Even back then, Stanford had a laser printer (5 feet tall), and I got in the habit of printing out a page or two of mathematics, studying it carefully and improving it, printing again, improving again. These rounds of improvement took place with cups of coffee at Stanford's Tresidder student union. It is hard for me to imagine how I could have produced a thesis of careful mathematics without this loop of printing and polishing. Ever since, I iterate ten or twenty times for most pages of anything I write, a very happy process. Really there's nothing I like better than slipping off to a café with a fountain pen and a draft of some paper or book chapter that needs improving. The 28 chapters of *Approximation Theory and Approximation Practice* have been measured out in cappuccinos.

SIAM president Nick Trefethen (right) gave an invited talk ("How Chebfun Solves ODEs and Eigenvalue Problems") at the joint student conference in Manchester pictured below. He is shown here with SIAM vice president-at-large Nick Higham of Manchester. Photo by Lijing Lin.

With time, my reliance on writing to formulate my thoughts has deepened. The idea for a proof may come offline, but within the hour, I'll be at the keyboard working to make the wording and the formulas precise. My students know that if they want to get through to me, they'd better write their ideas in a memo.

Recently, yet another tool has changed my habits. I had long depended on Matlab in my research, enabling me to explore numerical ideas in the style of "Ten Digit Algorithms." This way of researching wasn't particularly linked to writing, but then Matlab's Publish facility was introduced, analogous to worksheets in Maple or notebooks in Mathematica. These days I find I depend on Publish too as part of the thinking-and-writing loop. So now all the elements are combined: I have an idea, it requires computation, and I head for the keyboard. With Publish, the English and the mathematics and the numerics are coupled from the start.

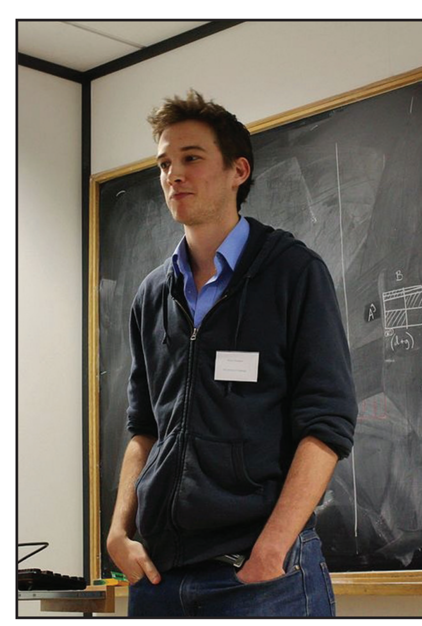
So *Approximation Theory and Approximation Practice* will be an unusual book. Each of those 28 chapters originates in a Matlab M-file. When you Publish the M-file, the comments turn into TeXed English and mathematics, and the commands turn into numbers and plots. Readers will be able to download the chapters and run each one themselves.

For me, writing and thinking are inseparable. Yet it is clear that not everybody is like me. Many mathematicians find writing a chore, and this doesn't keep them from producing outstanding results. The common view is that first you do the mathematics, and then you "write it up." What could be more natural? But that's not how it goes for those of us who are nutty about writing.

Manchester Hosts UK National Student Chapter Conference

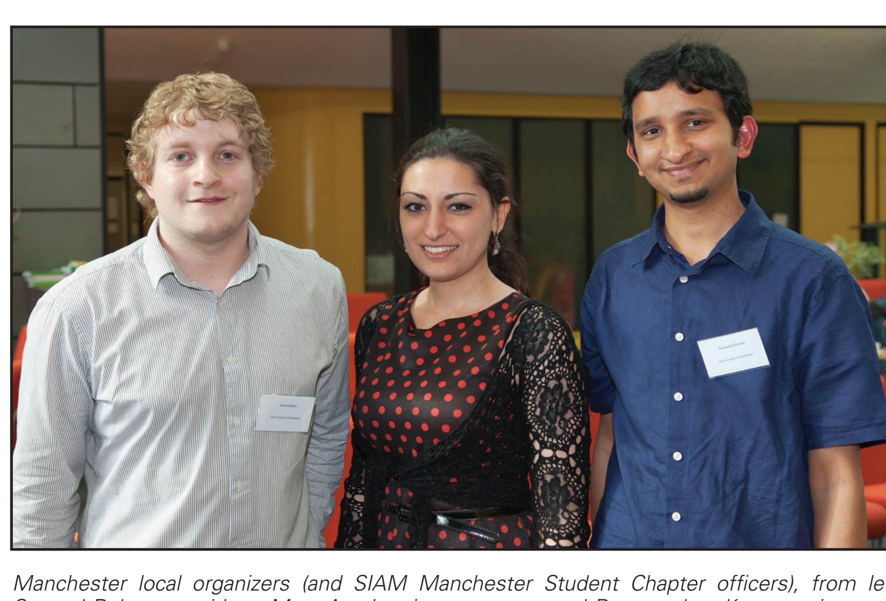
Three SIAM student chapters in the UK—at the Universities of Manchester, Oxford, and Reading—joined forces this year to organize the 2012 SIAM National Student Chapter Conference. Held in Manchester, May 18, the conference drew about 80 people; on the program were 4 invited speakers, 16 student speakers, and 7 poster presenters.

Martin Takac (left) of the University of Edinburgh received a best-talk award for "How to Climb a Billion Dimensional Hill Using a Coin and a Compass and Count the Steps Before Departure." He is shown with Craig Lucas of the Numerical Algorithms Group, who presented several NAG-sponsored awards, including the best-poster award that went to Ndifreke Udosen of the University of Reading ("Automated Optimisation of Measurement Locations to Solve Meta Inverse Problems"). Photo by Nick Higham. Many additional photos and information about other awards presented at the conference can be found at www.maths.manchester.ac.uk/~siam/snscc12.php.



Robin Thompson of the University of Cambridge received a best-talk prize ("Modelling the Biological Control of Crop Disease"). Photo by Lijing Lin.

Françoise Tisseur of Manchester and invited speaker Ernesto Estrada of the University of Strathclyde, who titled his talk "An Invitation to Complex Networks." The other invited speakers were Will Parnell of Manchester ("Elasto-dynamic Cloaking: How to Make an Invisible Building"), Edvin Deadman of NAG ("A Recursive Blocked Schur Algorithm for Computing the Matrix Square Root"), and Nick Trefethen of Oxford. Photo by Nick Higham.



Manchester local organizers (and SIAM Manchester Student Chapter officers), from left: Samuel Relton, president; Mary Aprahamian, treasurer; and Ramaseshan Kannan, vice president. Photo by Nick Higham.

The Enduring Fascination of the Transit of Venus

BOOK REVIEW

By Ernest Davis

Chasing Venus: The Race to Measure the Heavens. *By Andrea Wulf, Knopf, New York, 2012, xxvi+304 pages, $26.95.*

In Providence, Rhode Island, where I grew up, there is a short, quiet street named Transit Street, a few blocks south of the Brown University campus. The name dates from 1769, when the astronomer Benjamin West and Joseph Brown, a merchant, attended by a crowd of interested observers, measured the transit of Venus across the sun's disk. Their report was published in the first volume of the *Proceedings of the American Philosophical Society*, the first American scientific journal. The group in Providence was part of a scientific enterprise of unprecedented international scope. Hundreds of scientific groups all around the world observed the transit. Scientific expeditions had set out months or even years earlier, travelling hundreds or thousands of miles and enduring all the hardships of 18th-century exploration to destinations ranging from Yakutsk, Lapland, and Hudson's Bay to Pondicherry, Baja California, and—for Captain Cook on his first voyage—Tahiti.

The purpose was to measure the distance to the sun. Kepler's theory had determined the orbits of the planets with great precision in terms of astronomical units—the mean distance from the sun to the earth. But how long, in absolute terms, was the astronomical unit? Kepler had computed a lower bound of 14,000,000 miles, Edmund Halley of 69,000,000 miles, but these were very rough estimates.

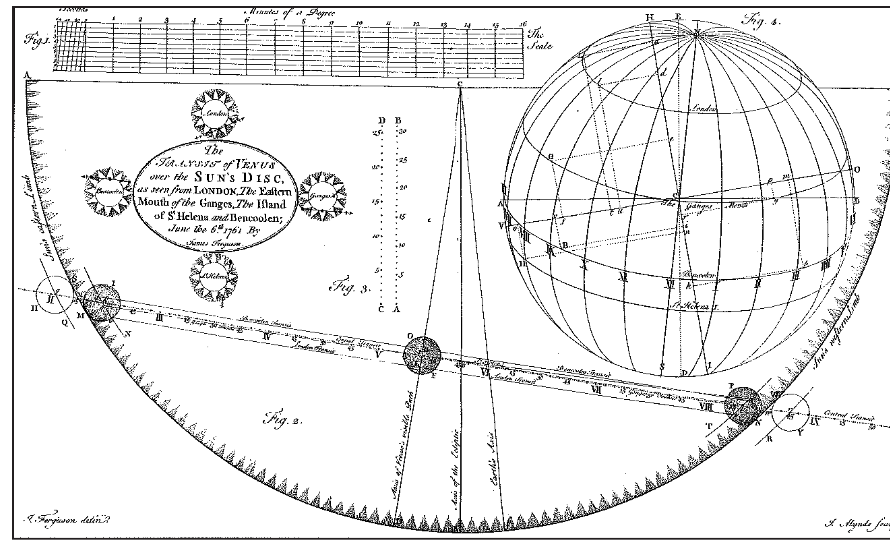
It was Halley who, fifty years before the event, had proposed that astronomers use the transit of Venus to resolve the question. Having observed a transit of Mercury from the island of St. Helena in 1677, Halley realized that a transit of Venus would take different amounts of time when observed from different latitudes and that, by measuring the difference, it would be possible to determine the distance to the sun. The greater the difference in latitude, the greater the divergence in time—and hence the more precise the calculation. Transits of Venus occur in pairs eight years apart, at intervals of more than a century. The most recent occurrence had been in 1639, and was observed by the astronomer Jeremiah Horrocks. The next pair would be in 1761 and 1769.* Halley would no longer be alive by then, but in 1716, he wrote an essay calling on the scientific community, when the time came, to send expeditions north and south to carry out the observations needed for the measurement.

Joseph Nicholas Delisle, the official astronomer to the French Navy, took the lead on the 1761 project. The circumstances were adverse; the Seven Years' War was raging, and France and England, the leading naval powers and the leading countries in science, were on opposite sides. Indeed, ships carrying several of the scientists were attacked en route. Nonetheless, French scientists travelled to Pondicherry, Rodrigues, and Tobolsk; British scientists travelled to St. Helena and the Cape of Good Hope; a Swedish scientist made his way to eastern Finland, and John Winthrop of Harvard went to Newfoundland, the only part of the western hemisphere in which any part of the transit would be visible. When the measurements were collected, tabulated, and combined, the new estimates were 77.1 million to 98.7 million miles—not as precise as hoped, but a tremendous improvement.

Circumstances in 1769 were much more favorable. The Seven Years' War had ended, though international relations were still tense. Catherine the Great had come to power and gave her full support to the enterprise with her characteristic élan; seven scientific teams were sent out to points all over Russia, after meeting with her for her personal blessing. Captain Cook and Joseph Banks set sail for Tahiti, William Wales for Hudson's Bay, Jean-Baptiste Chappe d'Auteroche for Baja California. When in the end the data was collected, the estimate was 93,726,000 miles, within 400,000 miles of the true figure, with an estimated uncertainty of about 4,000,000 miles.

Andrea Wulf gives a vivid account of the difficulties, hardships, and dangers of these long expeditions through unknown territories, each carrying half a ton of delicate astronomical equipment. William Wales had to set out for Hudson's Bay a year before the event and over-winter there—and he hated the cold. In 1761, travelling to Siberia, Chappe d'Auteroche risked his life crossing frozen rivers whose ice barely supported the weight of his carriage, just before the spring thaw. In 1769, he gave his life to the enterprise by landing in Baja California despite an epidemic of typhus. He died there of typhus, but not before he had succeeded both in measuring the transit and in computing the longitude.

And, of course, after all that, a cloudy day could render it all useless. Joseph LeGentil left Brest in March 1760 for Pondicherry. Before he could get there, Pondicherry had fallen to the British, and LeGentil found himself, on June 6, 1761, on a boat in the middle of the Indian Ocean. He gamely tried to make his observations from there, but the rolling of the ship made it impossible to keep the sun in view. Opting to remain in the region until 1769, he made his way to Manilla, where cloudy days were rare, and made his preparations there. The French Academy sent a message ordering him to go to Pondicherry (back in French hands) instead. In Pondicherry on June 3, 1769, the skies were overcast for the first time in months. LeGentil disconsolately made his way back to Paris; when he arrived in August 1771, he found that his heirs had had him declared dead and that the Academy had removed him from its payroll.



Drawing of the transit of Venus as predicted to occur in London, India, St. Helena, and Bencoolen on June 6, 1661; published in James Ferguson's book on the subject. From Chasing Venus.

Even when measurements could not be obtained, though, many of these expeditions made tremendous contributions to scientific, geographic, and anthropological knowledge. The results of Captain Cook's voyage and Joseph Banks's botanical collections from the South Pacific are well known. None of Catherine the Great's teams ended up getting usable measurements of the transit, but they returned with an extraordinary collection of reports on parts of Russia almost as unknown as Tahiti. János Sajnovic, who travelled to Lapland in 1769, discovered that the Finnish and Hungarian languages are closely related.

Like Andrea Wulf's previous book, *Founding Gardners*, about the horticultural enterprises of the American founders, *Chasing Venus* is a fascinating read, wonderfully well written, a vivid portrayal of the world of 18th-century science and its interactions with the wider intellectual and political world of the time. It is extensively researched, with a bibliography of about 500 items, mostly primary sources, in seven languages (English, French, German, Latin, Russian, Dutch, and Swedish), and beautifully illustrated with reproductions of contemporary drawings and portraits. Wulf makes the excitement of the enterprise and the heroic courage and dedication of its participants come dramatically alive.

Thinking of the Church in the 12th century and science in modern times, Kenneth Clark wrote,

> "Where some way of thought or human activity is really vital to us, internationalism is accepted unhesitatingly."

The enterprise to measure the transits of Venus in the 1760s was one of the most extraordinary manifestations of that noble thought.

Ernest Davis is a professor of computer science at the Courant Institute of Mathematical Sciences, NYU.

*The most recent pair occurred on June 8, 2004, and June 5/6, 2012; the next will be in 2117.

Data Deluge

continued from page 1

able at the SDM12 website (www.siam.org/meetings/sdm12/), which includes slides from all the keynote presentations.

A major part of the SDM conference is the presentation of refereed papers, some as talks in parallel sessions, others as two-minute "spotlights" given prior to a poster session on the first day, along with a welcome reception. The topics covered in this year's papers include pattern mining, time series and sequence analysis, clustering, social media, and graphs, as well as applications from healthcare, climate, and networks. All papers, including those from past SDM conferences, are available at the SDM proceedings website (www.siam.org/proceedings/). The best papers from the conference (identified by a committee from the papers that were highly ranked in the review process) will appear in expanded form in a special issue of the Wiley journal *Statistical Analysis and Data Mining*.

Complementing the paper sessions were several workshops, as well as five tutorials, on distance metric learning, discovering roles and anomalies in graphs, multi-task learning, privacy-preserving medical data sharing, and advice on doing good research and getting it published in top venues. The last of these was especially relevant to the large number of students who attended SDM, many as the first authors of presented papers. Other student activities included a doctoral forum, which gave nearly fifty students the opportunity to receive feedback on their work; among this group were students from minority and underrepresented groups who attended a workshop designed to increase the participation of these groups in data mining. Another student activity was an NSF panel, "The Case for Interdisciplinary Research: Challenges, Pitfalls and Career Advice," moderated by Srinivasan Parthasarathy of Ohio State University.

Two minisymposia complemented the rest of the program. For one of them, local area chair Yan Liu had invited several local leaders in data mining, including Charles Elkan (UC San Diego), Eamonn Keogh (UC Riverside), Shanghua Teng (University of Southern California), and Padhraic Smyth (UC Irvine), to present their recent work. The other minisymposium was organized jointly by the SIAGs on Uncertainty Quantification and on Data Mining and Analytics, to explore the common threads in the two areas. Presenters included Hadi Meidani (USC), Sonjoy Das (SUNY, Buffalo), Julien Emile-Geay (USC), and Omar Knio (Duke).

The SDM12 sponsors—the journal *Data Mining and Knowledge Discovery*, Google, IBM Research, NSF, and the SIAM travel award program—provided generous support, in particular for student travel. The organizing and program committee members put together an exciting meeting that resulted in packed sessions, many with standing room only, despite the venue with its own competing attractions. I hope that this short article will bring SDM and SIAG/DMA to the attention of the broader SIAM community. On behalf of the other SIAG/DMA officers—Charu Aggarwal (IBM Research), Huan Liu (Arizona State), and Michael Mahoney (Stanford)—I invite you to join us early next May in Austin, Texas, for another exciting conference.

Chandrika Kamath is a researcher at Lawrence Livermore National Laboratory, where she is involved in the analysis of data from scientific simulations, observations, and experiments. She chairs both the SDM Steering Committee and SIAG/DMA.

Data Assimilation

continued from page 1

genuine nonlinear effects; after all, you are then quantifying the uncertainty in an oversimplified, and incorrect, problem. If viewed in terms of the assimilation of data, it may be tractable to capture the "nonlinear" uncertainty if it is known, a priori, to come from a well-defined, low-dimensional subspace where the data lives. This is the case for Lagrangian-type data, but it may be true in other circumstances as well.

Christopher K.R.T. Jones is the Bill Guthridge Distinguished Professor in the mathematics department at the University of North Carolina, Chapel Hill. The article describes joint work with Amit Apte (Tata Institute of Fundamental Research, India), Kayo Ide (University of Maryland), Damon McDougall (University of Warwick), Naratip Santitissadeekorn (UNC Chapel Hill), Elaine Spiller (Marquette University), Andrew Stuart (Warwick), and Guillaume Vernieres (National Aeronautics and Space Administration). The research is supported by the Office of Naval Research and the National Science Foundation.

Uncertainty Quantification 2012

Applied Mathematics at the Forefront of Energy Efficiency in Buildings

By Bryan Eisenhower

If only occupants of commercial buildings knew even roughly how much energy their buildings consume, talk of high-performance buildings would be as common in popular media as news snippets about electric and hybrid vehicles. The truth is, personal transportation consumes only about three quarters of the amount of energy needed to run the buildings we live and work in, educate our students in, and use as healthcare and retail facilities. Buildings account for approximately 40% of the energy consumed in the United States, and this has been the case for decades. Unfortunately, much of this energy is wasted—either because designs are poor or fragile, or because daily operation strategies are deficient. This presents a ripe opportunity for applied mathematicians.

The physics underlying these shortcomings includes a wide range of scales in both time and space, a vast collection of networked systems of systems across different physical domains and manufacturers, as well as uncertainty in model-based energy predictions and in the eventual usage of the buildings. The importance of these uncertainties and their impact on high-performance buildings has drawn significant attention, and speakers at the 2012 SIAM Conference on Uncertainty Quantification, held in Raleigh, North Carolina, in April, unveiled some of the recent results.

Residential and commercial buildings are the largest single source of energy consumption and pollution in the U.S.; efficient design and operation of buildings, therefore, are necessary to both energy security and environmental stability. During the design process, physics-based energy models are used to perform design trades, in which an optimal balance of first cost, annual energy consumption, and occupant comfort is determined. If these models are to have widespread use in the design community, however, process times (for creating the model, inputting partially certain parametric information, and simulating for annual performance numbers) need to be 50 times shorter, accompanied by 30–50% improvements in accuracy.

Speakers at the meeting presented methods for accelerating the input of parametric information and for capturing uncertainty in model predictions in a tractable way. The challenge is that energy models for buildings typically have thousands of parameters, some describing mundane attributes, like the density of one of the material layers in an external wall, others concerning specifics like the number of people expected to occupy the northwest wing of a building on Friday mornings. Compounding the analysis are computation times on the order of minutes to a half hour, which puts Monte Carlo-like parametric uncertainty experiments out of reach for the designer on a tight time budget. Such numerical sampling experiments can give the modeler an idea of how certain predictions, perhaps on energy and comfort, are based on realistic ranges in the necessary inputs of the model. A dynamical systems sampling method presented at the 2011 SIAM Conference on Applications of Dynamical Systems and further discussed in Raleigh speeds up this process, allowing for studies of parameter sets two orders of magnitude larger than in previous work. (See Figure 1.)

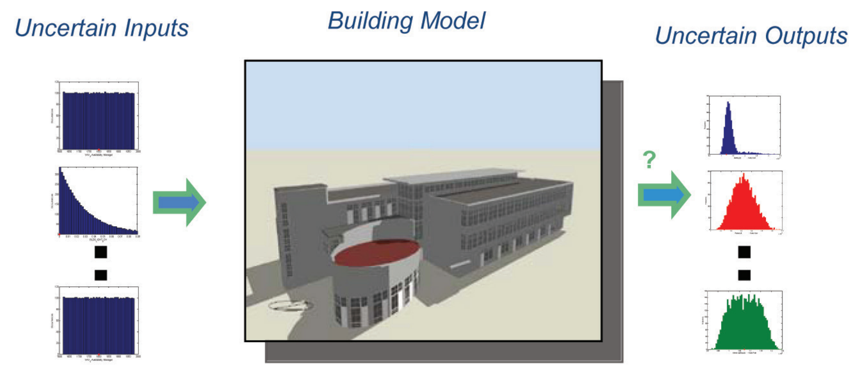


Figure 1. *Energy models with thousands of uncertain parameters are efficiently sampled with dynamical systems algorithms to quantify the uncertainty in their predictions and to identify the parameters that have the most impact on this uncertainty.*

The goal of accelerating the process of parameter specification surfaced again in discussion of an algorithm for critical parameter identification. In this approach, influential parameters are identified and isolated from others that will return little difference in model accuracy—even after hours spent determining their best values. In other words, if the modeler has limited time to input parametric information, it is useful to know which subset of parameters to focus on getting right—the others will have little impact on predictions. As speakers at the meeting showed, only a small percentage of the parameters have this sort of significance, which becomes vital when the parameter set contains a thousand parameters.

Once the design is complete and the building is built, a commissioning process is performed to bring online the computer-based building heating and cooling management system. To many occupants, building management systems are a ubiquitous technology to be taken for granted; in reality, such systems consist of numerous time-sequenced control loops implemented to maintain a comfortable environment for users in the building. As the building ages, or its usage changes, uncertainty begins to take its toll and the management system no longer performs optimally—wasting energy along the way and missing comfort targets. Building management systems are rarely re-commissioned to take these factors into account. The sad truth is that even a building with the finest windows and insulation can squander energy by heating and cooling when not needed for occupant comfort and productivity. (See Figure 2.)

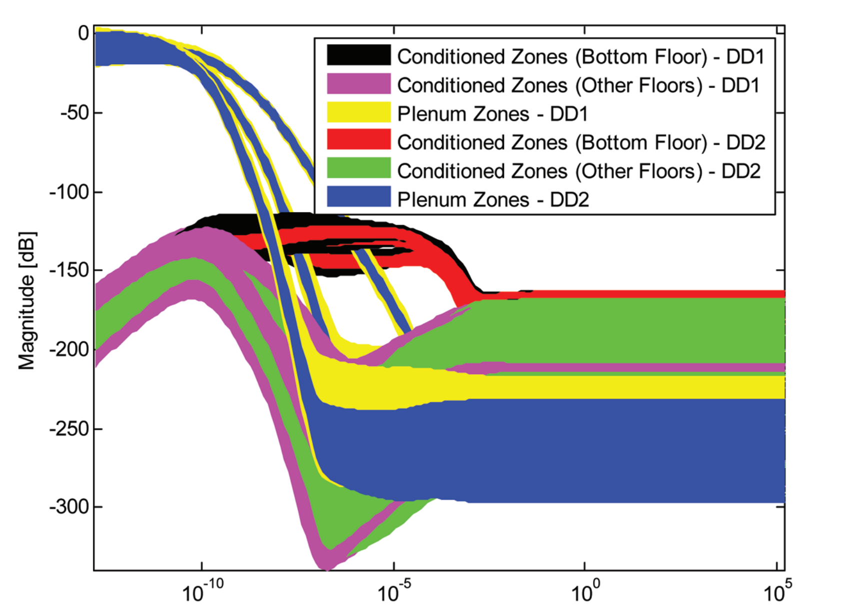


Figure 2. *Frequency response magnitude from ground temperature input to zone temperatures. Uncertainty in the frequency response of a building energy model impacts the ability to control the heating and cooling systems without squandering energy as a consequence of poor dynamic response.*

The meeting program included discussions of advanced control approaches that take into account these forms of uncertainty (including sources of static and dynamic uncertainty—like weather). Algorithms that identify the heart of the interconnectedness of the dynamics within a building were presented, with methods for quantifying uncertainty in the dynamics and their connection. Also considered was model-based control that offers a robust solution for uncertainty of this type.

Management of uncertainty in high-performance buildings is just one example of the key role applied mathematics is playing in an energy-efficient future for the built environment. As mathematicians, scientists, and engineers, we are living in an exciting time—in which the impact of our work directly influences the well-being of generations to come.

Bryan Eisenhower is an associate director of the Center for Energy Efficient Design at the University of California, Santa Barbara.

Swarming

continued from page 8

from a box 5 cm on a side and traveling for 20 seconds (2000 timesteps) show that the rules are capable of keeping a swarm together and heading in the right direction—dissent among the streakers slows the swarm's progress but doesn't prevent it. If all 10 streakers agree on a destination, the swarm motors along at approximately 1 m/sec (roughly a bee's body length per timestep); even if 4 of the 10 want to go in the opposite direction, the swarm follows the majority, albeit with considerable dithering (see Figure 1, page 8). Only in the case of an exact 50:50 split—and in trials with *no* streakers—does the swarm fail to budge.

Even Whirligigs Do IT

Ants and bees aren't the only insects that exhibit orderly behavior in the midst of seemingly random motion. Locusts, such as *Schistocerca gregaria*, are well known for marshalling the repeated random jumps of individuals (interspersed with destructive munching) into an almost military march. One recent discovery, reported by Stephen Simpson of the University of Sydney, is how "shy, green, harmless grasshoppers" turn into brightly colored, voracious swarmers.

The trigger for the change, Simpson and colleagues found, is crowding. When *S. gregaria* individuals in their solitary phase bump into one another, touch-sensitive neurons in hairs on their back legs release a pulse of serotonin. In *S. gregaria*, the mood-altering neurotransmitter precipitates a radical, Jekyll-to-Hyde transformation. "We've got the soul of the locust, almost, in those two neurons," Simpson says.

At some threshold of crowding, the locusts begin to move en masse. The global motion arises strictly from local interactions, although the insects have a somewhat grisly motivation to keep moving in one direction: The neurochemical transformation includes a sudden cannibalistic appetite for protein, and laggards are likely to wind up as so much locust lunch.

Whirligigs, as described by William Romey, a biologist at the State University of New York at Potsdam, form a somewhat more benign version of a gregarious group. A family (*Gyrinidae*) comprising some 700 species, whirligigs are tiny beetles that live on the surface of ponds and rivers; they are named for their peculiar spinning behavior. At night whirligigs tend to scatter and scavenge for food (mainly insects stuck in the surface tension of the water), but by day they clump together, primarily for safety's sake—birds prey on them from above, fish from below.

Romey and colleagues have studied how whirligigs position themselves and circulate within a clump. (There is constant movement within a cluster, which itself usually wanders around the surface of the water.) Being on the perimeter has advantages, such as having first dibs on any food that floats by, as well as disadvantages: Predators inexplicably favor attacking at the margins. When predators and prey are constrained to the same dimensionality, such as lions attacking a herd of antelope, it makes sense for the predators to concentrate on the edges, which they'll reach the earliest, but that's not the case for predators that have an extra dimension to work with. Nonetheless, in a study published in 2007, Romey and colleagues A.R. Walston of Cornell and Penelope Watt of the University of Sheffield found that fish, specifically goldfish and bass, have a marked preference for the periphery of prey groups.

By manipulating the hunger level of whirligigs (and the demographics of sex and age), then watching how the beetles organize themselves when they circle the wagons, the researchers can test mathematical models that describe the group dynamics. The models indicate that simple rules can account for whirligigs' meanderings. It's possible, for example, to get one group of simulated beetles to linger on the perimeter while another group gravitates toward the center by using two different "attraction/repulsion" functions to describe the way a given beetle reacts to its nearest neighbors: Amped-up repulsion tends to drive an individual toward the edge. (It's not clear that this drives actual whirligig swarms, but that's one reason for running simulations. The models can be mined for quantitative predictions that suggest experiments on actual swarms.) In addition, models for evolutionary optimization indicate that the beetles' group behavior is individually adaptive: It increases each beetle's chance of survival, not just the group's. Significantly, whirligigs—unlike bees and ants—are not closely related, so that altruism and kin selection are not high priorities.

The MBI workshop also featured talks on group dynamics of birds, fish, Princeton undergraduates, and robots. (The undergraduates were participants in a "flock logic" study conducted at Princeton by Naomi Leonard in collaboration with choreographer Susan Marshall. The basic idea was to record and analyze the motions of groups of "dancers" instructed, for example, to stay at arm's length from at least two other dancers at all times while not actually bumping into anyone.) Overall, the mathematical study of insect and other swarms is revealing a rich range of phenomena that occur as emergent, self-organizing behavior. Someday it might even explain the traffic patterns around the coffee urns when a swarm of mathematicians take a break between talks.

Barry A. Cipra is a mathematician and writer based in Northfield, Minnesota.

SIAM Responds to PCAST Report

In February 2012, the President's Council of Advisors on Science and Technology called for a nationwide initiative to improve education in the STEM disciplines—science, technology, engineering, and mathematics—with the emphasis on the first two undergraduate years. The call came in a report, *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics*, that makes five recommendations for avoiding a projected shortfall of U.S. graduates with STEM degrees.

Only one of the report's five recommendations is specific to mathematics: "Launch a national experiment in postsecondary mathematics education to address the mathematics-preparation gap." As part of that experiment, the report advocates "college mathematics teaching and curricula developed and taught by faculty from mathematics-intensive disciplines other than mathematics, including physics, engineering, and computer science." Objecting to that approach, SIAM prepared a written response to the report.

"We believe this is the wrong approach," the response states. "Collaboration, rather than removing mathematicians from the education equation, will ensure that students have access to relevant and exciting learning experiences with appropriate breadth and depth."

Welcoming the idea of a national experiment, as well as various national initiatives for improving K–16 mathematics education, SIAM went on to make recommendations of its own. Quantitative and computational skills are "increasingly necessary across the STEM disciplines as data analysis, modeling, and simulation become critical tools of research and innovation," the response states; modeling and applications should be emphasized early in students' math education and in the undergraduate curriculum. "SIAM encourages applied mathematicians to collaborate with scientists and engineers to embed computational learning and exposure to modeling and simulation in early STEM courses."

SIAM posted its response to the PCAST report at www.siam.org/reports/pcast_12.pdf.

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 $2.55 per word (minimum $295.00). 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 2012 issue is August 31, 2012).

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

U.S. Army Research Office

Research Triangle Park, NC
Atmospheric Scientist

Applications are being solicited by the U.S. Army Research Office in Research Triangle Park, North Carolina, for a scientist with the qualifications of meteorologist, physicist, mathematician, computer scientist, chemist, environmental engineer, or aerospace engineer. Applicants must meet the qualifications of at least one discipline to apply. There is one vacancy at either the DB–04 level (GS 14/15 equivalent), $99,638–$152,364 per annum; or DB–03 level (GS 12/13 equivalent), $70,906–$109,611 per annum. Starting salary includes a locality adjustment and will depend upon qualifications and salary history. This is an interdisciplinary position. The work involves formulation, management, and leadership of an innovative, high-payoff extramural (primarily through grants to university faculty) basic research program in the atmospheric sciences. Expertise required includes capability to manage and direct successful fundamental basic research programs in areas of physical meteorology to include energy propagation through the environment and into the near subsurface, optical and acoustic monitoring, determination of aerosol properties, and boundary layer processes. The successful candidate will initiate new research projects to advance the frontiers of atmospheric science with the goal of pursuing basic research to create unprecedented scientific opportunities relevant to Army needs. Some travel is required. A security clearance is required.

Interested individuals must apply at http://www.usajobs.gov. Announcement numbers are NEAC12832014671992D for the DB–04 and NEAC12832014672129D for the DB–03. This position is open to application from May 16, 2012, to July 31, 2012. Prospective applicants can send questions to: Bruce Spruell, HR specialist, (301) 394-3396; bruce.d.spruell.civ@mail.mil, or Wanda Wilson, administrative officer, Army Research Office, (919) 549–4296; wanda.e.wilson.civ@mail.mil.

U.S. Army Research Office

Research Triangle Park, NC
Terrestrial Scientist

Applications are being solicited by the U.S. Army Research Office in Research Triangle Park, North Carolina, for a scientist with the qualifications of geologist, geophysicist, physicist, mathematician, computer scientist, or environmental engineer. Applicants must meet the qualifications of at least one discipline to apply. There is one vacancy at either the DB–04 level (GS 14/15 equivalent), $99,638–$152,364 per annum; or DB–03 level (GS 12/13 equivalent), $70,906–$109,611 per annum. Starting salary includes a locality adjustment and will depend upon qualifications and salary history. This is an interdisciplinary position. The work involves formulation, management, and leadership of an innovative, high-payoff extramural (primarily through university faculty) basic research program in the terrestrial sciences. Expertise required includes capability to manage and direct successful fundamental basic research programs in areas to include, but not limited to, environmental sensing, problems of transport, and mathematical and statistical methods for analysis of complex soil, air, and hydrospheric systems. The successful candidate will initiate new research projects to advance the frontiers of terrestrial science with the goal of pursuing basic research to create unprecedented scientific opportunities relevant to Army needs. Some travel is required. A security clearance is required.

Interested individuals must apply at http://www.usajobs.gov. Announcement numbers are NEAC12831983670873D for the DB–04 and NEAC12831983671216D for the DB–03. This position is open to application from May 16, 2012, to July 31, 2012. Prospective applicants can send questions to: Bruce Spruell, HR specialist, (301) 394–3396; bruce.d.spruell.civ@mail.mil, or Wanda Wilson, administrative officer, Army Research Office, (919) 549–4296; wanda.e.wilson.civ@mail.mil.

Institute for Computational Engineering and Sciences

The *Institute for Computational Engineering and Sciences (ICES)* at *The University of Texas at Austin* is engaged in a comprehensive initiative to bring advances in computer modeling and simulation to bear on the scientific and engineering Grand Challenges that affect our nation's well-being and competitiveness. In support of this goal, the ICES Initiative for Simulation-Based Engineering and Sciences is searching for outstanding researchers in computational science and engineering to fill endowed faculty positions at the Associate Professor level and higher. Searches are under way to find world leading researchers in three areas: 1) computational geophysical fluid dynamics, with particular interest in ocean modeling; 2) structural bioinformatics, the computational modeling of structure and function of biological macromolecules; and 3) the broad area of predictive science and uncertainty quantification in computational science and engineering. These endowed positions will provide the successful candidates with the resources and environment needed to tackle frontier problems in science and engineering via advanced modeling and simulation. The initiative builds on the world-leading program at ICES in Computational Science, Engineering and Mathematics (CSEM), which features 16 research centers and groups as well as a graduate degree program in CSEM.

Candidates for these new positions are expected to have an exceptional track record in interdisciplinary research at the intersection of advanced mathematical and computational techniques and target scientific and engineering problem. To be considered, please visit: w*ww.ices.utexas.edu/moncrief-endowed-positions-app/.*

The University of Texas at Austin is an Affirmative Action/Equal Employment Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability, age, citizenship status, Vietnam era or special disabled veteran's status, or sexual orientation. This is a security sensitive position; background check on selected applicant is required.

The University of Texas at Austin

Tenured Faculty
Operations Research & Information Engineering
Cornell University

Cornell is a community of scholars, known for intellectual rigor and engaged in deep and broad research, teaching tomorrow's thought leaders to think otherwise, care for others, and create and disseminate knowledge with a public purpose.

Multiple tenured faculty positions in Operations Research and Information Engineering are available at Cornell's new CornellNYC Tech campus in New York City. Faculty hired in these positions will be tenured professors in the School of Operations Research and Information Engineering, which will span the Ithaca and New York City campuses.

Subject areas of interest include optimization, applied probability and statistics. Application areas of interest include information technology modeling, logistics, and health care operations. Applicants must hold a Ph.D. and have demonstrated ability to conduct outstanding research and education at the level of tenured faculty in the School of Operations Research and Information Engineering. Applicants must also have a strong interest in the technology commercialization and entrepreneurship mission of the campus. In addition, interest in international programs and/or precollege (K-12) education is advantageous.

To ensure full consideration, applications should be received by September 1, 2012, but we will begin reviewing and interviewing candidates before this date and continue until the positions are filled. Applicants should submit a curriculum vitae, brief statements of research and teaching interests, and the names and contact information of at least three references on-line at **https://academicjobsonline.org/ajo/jobs/1516**.

Cornell University is an inclusive, dynamic, and innovative Ivy League university and New York's land-grant institution, with its main campus in Ithaca, NY, its medical campus on the Upper East Side of Manhattan, and its new CornellNYC campus planned for Roosevelt Island in New York City. The University's staff, faculty, and students impart an uncommon sense of larger purpose and contribute creative ideas and best practices to further the university's mission of teaching, research, and outreach. These faculty positions are based in New York City at the CornellNYC Tech campus which will be located in temporary facilities until moving to its permanent home on Roosevelt Island.

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Call for Nominations: CRM–Fields–PIMS Prize

The Centre de recherches mathématiques, the Fields Institute, and the Pacific Institute for the Mathematical Sciences invite nominations for the joint 2013 CRM–Fields–PIMS prize, awarded in recognition of exceptional research achievement in the mathematical sciences. The successful candidate's research should have been conducted primarily in Canada or in affiliation with a Canadian university.

The prize was established as the CRM–Fields prize in 1994. Renamed in 2005, prizes awarded in 2006 and later have been chosen jointly by the three institutes. Previous recipients are H.S.M. Coxeter, George A. Elliott, James Arthur, Robert Moody, Stephen A. Cook, Israel Michael Sigal, William T. Tutte, John Friedlander, John McKay, Edwin Perkins, Donald Dawson, David Boyd, Nicole Tomczak-Jaegermann, Joel Feldman, Allan Borodin, Martin Barlow, Gordon Slade, Mark Lewis, and Stevo Todorcevic. The selection committee formed by the three institutes will select a recipient for the 2013 prize on the basis of outstanding contributions to the advancement of the mathematical sciences, with excellence in research as the main selection criterion. A monetary prize will be awarded, and the recipient will be asked to present a lecture at CRM, at the Fields Institute, and at PIMS.

Nominations, to be submitted by at least two sponsors of recognized stature, should include the following elements in a single PDF file: three supporting letters, curriculum vitae, a list of publications, and up to four preprints. Nominations should be submitted by November 1, 2012, and will remain active for two years. During any academic year, no more than one prize will be awarded. Nomination files should be submitted to: nominations@pims.math.ca. Only electronic submissions (of a single PDF file) will be accepted.

14th International Conference in Approximation Theory

San Antonio, TX
April 7–10, 2013

Organizers: Greg Fasshauer and Larry Schumaker.

Invited Speakers: Peter Binev, Annalisa Buffa, Mike Floater, Kai Hormann, Gitta Kutyniok, Grady Wright, and Yuan Xu.

The seventh Vasil A. Popov Prize will be awarded at the meeting (for nominations go to http://imi.cas.sc.edu/popov-prize-call-nominations/).

Papers in all areas of approximation theory will be organized into contributed sessions, and the organizers invite suggestions for minisymposia.

Travel Support: The organizers especially encourage students and postdocs to attend and to present their work, and hope to be able to provide some support for this group as well as for members of other underrepresented groups. An application form is available on the website.

Information: For details about the conference, readers should see http://www.math.vanderbilt.edu/~at14.

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Mathematicians, Biologists Teeming Up to Study Swarms

By Barry A. Cipra

Picture a hive of mathematical biologists, buzzing with excitement as they collect the sweet nectar of data and convert it into the geometric comb of understanding. Scouts zip off in a dozen directions, exploring the nooks and crannies of alternative new theories, then report back to the others, performing a PowerPoint waggle dance in hopes of conveying their enthusiasm for a possible new home. The hive, somehow making sense of all the competing reports, reaches consensus and, in a chaotic cloud, swarms off to a new nest.

Or picture a colony of computational biologists, emerging groggily from their underground network, milling about in apparent confusion until they get their code debugged, then marching ahead with quiet, serial determination until they fan out for the day's foraging, leaving trails of numeric pheromones for each other to follow.

Or picture a plague of physicists descending on a field of biology. Solitary in nature, they stimulate one another into a gregarious horde, advancing in a broad front driven largely by fear that those coming up from behind will, if given the chance, eat them alive.

Picture all this, and you've got a fairly good idea of life at the workshop Insect Self-organization and Swarming, held in March 2011 at the Mathematical Biosciences Institute at Ohio State University. About a hundred researchers gathered to discuss the latest findings in a field that's tailor-made for multidisciplinary research.

"This field is special and very effective because mathematicians and biologists actually rub shoulders and elbows together at the lab bench," says Nigel Franks, an expert on ants at the University of Bristol. "It isn't just a case of theoreticians sitting on high, sort of throwing theoretical proofs down at muddy-booted biologists. It's a case of us really working together. And it's just fabulous for that reason."

"It isn't just a case of theoreticians sitting on high, sort of throwing theoretical proofs down at muddy-booted biologists. It's a case of us really working together."

Ants Do IT

Consider the notoriously industrious ant, say of the species *Atta colombica*, a Central and South American leaf cutter. Audrey Dussutour of the University of Toulouse described experiments she and colleagues have done to understand the "rules of the road" these invertebrates obey while scurrying between nest and foraging site. *A. colombica* travel in a more or less straight, pheromone-laced line, which means that, like commuters on a busy highway, they encounter two-way traffic.

Humans, of course, have adopted oft-violated traffic laws and rules of etiquette to accommodate their competing interests. Ants get by with something simpler, in part because they have a common goal: to get as much food to the nest as quickly as possible with a minimum of effort. *A. colombica*'s solution involves three lanes of travel. Outbound ants mainly take the center lane. Inbound leaf-laden ants also take the center lane, while inbound *unladen* ants tend to take the two outer lanes.

Other species also adhere to three lanes, although the rules governing who belongs in which lane can differ. Larger and laden ants tend to get the middle lane, most likely because they have greater inertia and less mobility: When two ants meet head on, the smaller, more nimble one is more likely to give way, veering either right or left. In a 2002 paper, Franks and Iain Couzin, now at Princeton, analyzed a mathematical model of formican collisions. The three-lane structure, they hypothesized, helps keep the trail well defined and straight.

Things are more interesting on narrow portions of the trail—a condition researchers can easily create in a laboratory setting. Dussutour and colleagues have compared ants' solution of their traffic-flow problems on bridges 5 and 50 mm wide. Their findings suggest that simple, easily implemented rules can produce efficient, nearly optimal solutions. When an outbound *A. colombica* encounters an inbound leaf-laden ant along a bottleneck, it pulls over to the shoulder to let its less-maneuverable brother by. Inbound *unladen* ants, on the other hand, yield to their outbound counterparts. The exception occurs when an inbound unladen ant gets in line behind a laden ant, in which case it benefits from the laden ant's right of way.

Indeed, this exception proves to be the rule: Even though they could easily pass the slower-moving laden ants, it's common to see a string of unladen ants "drafting" on a leaf-bearing leader. Dussutour's group found that the occurrence of large groups on wide bridges fell off at roughly the 3/5 power of group size, with no groups (in their experiments with thousands of ants) having more than 14 ants and the average group having only 1.9 ants. On narrow bridges, by contrast, the occurrence fell off at around the 1/5 power of group size, with 73 ants in the largest observed group and 5.2 in the average group. Moreover, inbound and outbound platoons tended to follow a strict alternation on the narrow bridge, while they proceeded more or less at random on the wider bridge. Ants, it seems, are good at taking turns, possibly because their close genetic kinship makes it advantageous to do so.

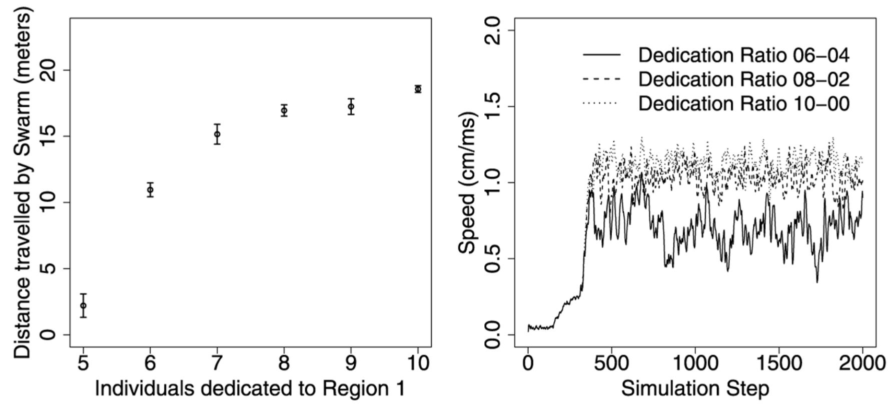

Figure 1. *Pilgrims' Progress. If* k *streakers are dedicated to a destination in Region 1 and 10 −* k *streakers to a destination in the opposite direction, a simulated swarm of 500 bees makes progress in 2000 time steps (20 sec) unless there's an exact 50:50 split (left), but the swarm's average speed is lower and more variable if there is a lot of dissent (right). Figure courtesy of Konrad Diwold, Timothy M. Schaerf, Mary R. Myerscough, Martin Middendorf, and Madeleine Beekman: "Deciding on the wing: In-flight decision making and search space sampling in the red dwarf honeybee* Apis florea*,"* Swarm Intelligence*, 5:2 (2011),121–141.*

On occasion, an entire ant colony will up and move. In studying the factors that affect a colony's decision making, Franks has found, for example, that house-hunting ants have a nifty way of estimating the size of a new nest. In essence they take a random walk within the site, depositing pheromone as they go and counting the number of times they encounter their own scent: The larger the number, the smaller the site. He has also found that no individual ant needs to investigate more than one new site for the colony as a whole to pick the best next site.

Franks has even experimented with forcing colonies to pick among equally desirable new homes. You might expect a colony to either freeze up or scatter, but almost invariably it comes to a quick, unanimous decision. (Franks has a way to speed up the process: destruction of the old nest. But even if he leaves it intact, ants are always on the move.) "Househunting ants have solved every problem we've thrown at them," he says.

Bees Do IT

Bees are also expert househunters. Apiologists have long known that scouts keep careful track of direction and distance to potential new hive sites (as well as to better pollen sources) and report back by means of a "waggle dance." Only more recently have they begun to tease out the details of how the hive decides among competing dances. In one case, at least, the short answer is vector arithmetic.

Take *Apis mellifera*, the European honeybee. *A. mellifera* nests in enclosed spaces, such as holes in trees—or boxes provided by researchers. Its "dream home," according to honeybee expert Thomas Seeley of Cornell, is capacious (40 liters, say), high off the ground (5 meters), and with a small, invader-discouraging entrance (less than 15 square centimeters). Seeley and colleagues have done experiments in which they take a bunch of bees out to an isolated and somewhat inhospitable island and present them with a choice of several boxes for a new nest site, one of which is far superior to the others; the bees ultimately opt for the best site approximately 90% of the time.

Seeley likens the bees' selection process to political campaigns; the scouts' waggle dances are the equivalent of campaign ads. The greater a scout's enthusiasm for a site, the longer she dances. During a campaign, which can go on for the better part of a day, dances advertising the weaker sites slowly fade away, like rallies for the weaker candidates who initially clutter presidential primaries.

One mechanism that speeds up consensus building is the "stop signal": Bees actively discourage competing waggle dances by sidling up to the dancer and vigorously buzzing it. Although this signal had been heard for decades, its purpose was discerned only recently, thanks in part to directional speakers capable of mimicking it. The combination of honest enthusiasm and the negative feedback of stop signals, it seems, is enough for *A. mellifera* to make the best decision almost all the time.

For other species, there is no obvious "best" decision. Mary Myerscough, a mathematical biologist at the University of Sydney, described studies of swarming behavior in *Apis florea*, the red dwarf honeybee. *A. florea* is an open-nesting species: It typically builds nests that hang from tree branches. Because its requirements are less specific than those of its European cousin, the red dwarf honeybee can make do with settling on a general direction when the hive is ready to go. Myerscough and colleagues have found that the swarm takes off in what is, in effect, the vector sum of the directions indicated by the waggle dances.

However they reach the decision to depart, bees in flight make a parade of ants look orderly and linear. It's virtually impossible to discern the direction of a swarm by following the trajectory of a random individual for a few seconds—each bee seems to be going nowhere in a hurry. Nonetheless, swarms manage to maintain cohesion over great distances. How do they do it?

An answer is beginning to emerge through an interplay of theory and observation. Using stationary cameras pointing up at the sky, researchers have filmed swarms in flight. What the cameras record is a mix of mostly slow-flying bees moving in more or less random directions, and a small subset of "streakers" headed in the direction of the overall swarm. The theory is that individual bees react to the motion of nearby bees, trying to match their neighbors' trajectories while avoiding midair collisions, but that they respond especially to fast-moving neighbors. Presumably (and this remains to be demonstrated), the streakers are the scouts that originally chose the new nesting site. By streaking from the back to the front of the swarm and then more slowly returning from front to back, a scout could be keeping the swarm on track to the desired destination.

The model that Myerscough's group has developed specifies that streakers (called "informed" bees) zip in a direction parallel to the line connecting the center of the swarm to the desired destination. (In the model, different informed bees may have different ideas as to exactly where they're heading, again relying on the swarm to do the correct vector arithmetic.) They figure they've reached the front of the swarm when there are fewer than 10 bees within a preset threshold (20 cm in the model), at which point they fly more slowly in the opposite direction, until they find themselves again amidst fewer than 10 bees. Meanwhile, the model has the "uninformed" bees constantly adjust their flight paths by specifying each bee's velocity at 10-msec intervals as a weighted combination of components corresponding to contributions of avoidance (don't let anyone get too close), coherence (try to stay near the center of the swarm), alignment (watch the streakers), and randomness.

Simulations with 10 digital streakers guiding a swarm of 500 *A. florea* starting

See **Swarming** *on page 6*