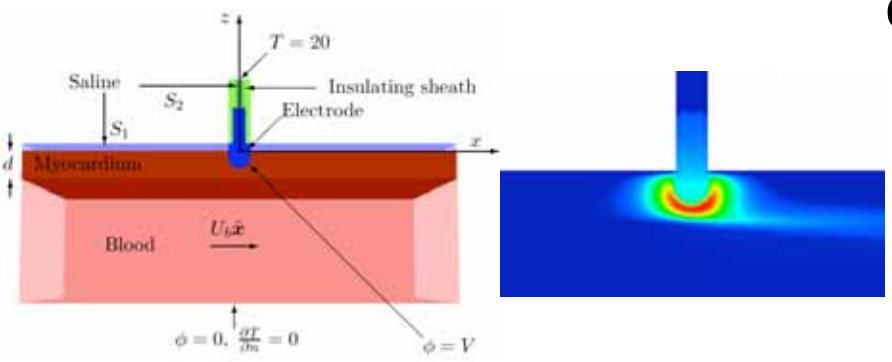
Repairing heart circuits gone awry

Cardiac ablation therapy is a life-saving procedure which uses heat to destroy destructive conduction pathways in the hearts of patients with atrial fibrillation. An IMA industrial postdoc developed a simulation tool used by Medtronic, Inc. to evaluate designs for ablation therapy.

As an IMA postdoc, J.Gopalakrishnan undertook the complex task of modeling the ablation process, and went on to develop a simulation package. Now a professor, Gopalakrishnan continues to consult with Medtronic.



From Gopalakrishnan's work on cardiac ablation simulation.

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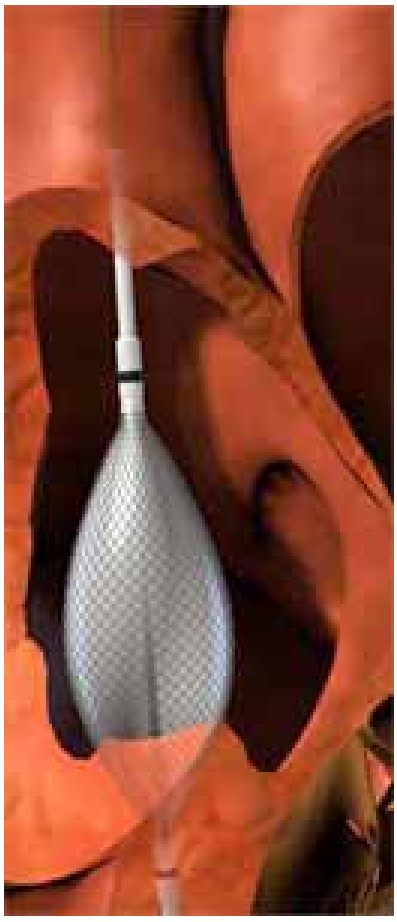
Diagnosing cardiac arrythmias

IMA industrial postdoc Tony Varghese worked with Endocardial Solutions, Inc. on a diagnostic system for cardiac arrythmias that has helped tens of thousands of patients worldwide.



ESI's EnSite® catheter

A catheter inserted into the heart reads voltages, and a difficult mathematical inverse problem must be solved to recover the electrical conductions patterns in the heart muscle. Dr. Varghese's representation of the heart geometry using splines was incorporated into ESI's principal product.

Mathematical Networks

Women in the mathematical sciences, from graduate students to corporate leaders, came together at the IMA to discuss careers, collaborations, and kids. They shared tips and insights and returned home better informed, better connected, and—in many cases—reassured that their professional and personal goals need not conflict.

Getting to know these women who are so successful and so happy with their different career choices makes me much more optimistic about my own future.

—Yelda Aydin, graduate student

I had never realized that there were so many opportunities for research in industry...the networking opportunity was simply wonderful!

—Allison Baker, postdoc

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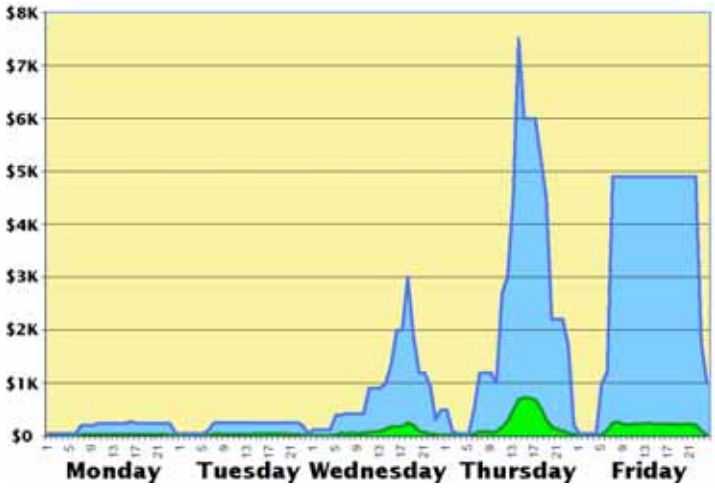
Damn!...no dial tone?

Mathematical models of telephone networks pinpointed the cause of a rash of dead phone lines in 2001 that resulted in as many as 90 blocked emergency calls each day.

A research effort led by an AT&T scientist visiting the IMA not only saved lives, but also yielded savings of roughly $15M per year to AT&T, and resulted in multiple patents and a prize-winning paper. Their stochastic model implicated very long calls associated with internet dial-ups. These models were then used to design both short and long term remedies.

Shedding light on blackouts



Tremendous volatility in power prices is to be expected in deregulated markets, analysis shows.

The control of power networks presents tremendous challenges and affects almost every citizen of the United States. Lively discussions at the 2004 IMA workshop Control and Pricing in Communication and Power Networks concerning the rash of blackouts experienced in California a few years before led an electrical engineer and an economist to a new model. It demonstrates convincingly that volatility and high prices can be expected in a deregulated power market whenever the market achieves an efficient allocation, even without Enron-style market manipulation. Their striking result not only requires a rethinking of what put out the lights in California in 2000, but also opens the way for a new understanding of the implications of deregulation for other commodities.

Roaches and robots

A 1998 IMA workshop on animal locomotion launched a collaboration of mathematicians, biologists, and engineers, resulting in the development of spectacular hexapod robots.

> *This work has its origins in a remarkable IMA workshop on gait patterns and symmetry held in June 1998, that brought together biologists, engineers and mathematicians... Workshop discussions in which we all took part also inspired the creation of RHex, a six-legged robot whose unprecedented mobility suggests that engineers can aspire to achieving the capabilities of such fabulous runners as the humble cockroach.*
>
> — Holmes et. al. 2005

RHex, the robotic cockroach

The team was recently funded at $5M by the NSF for their project "Neuromechanical systems biology: How exactly do animals move?" to uncover the neuromuscular feedback mechanisms controlling whole-body motion in animals.

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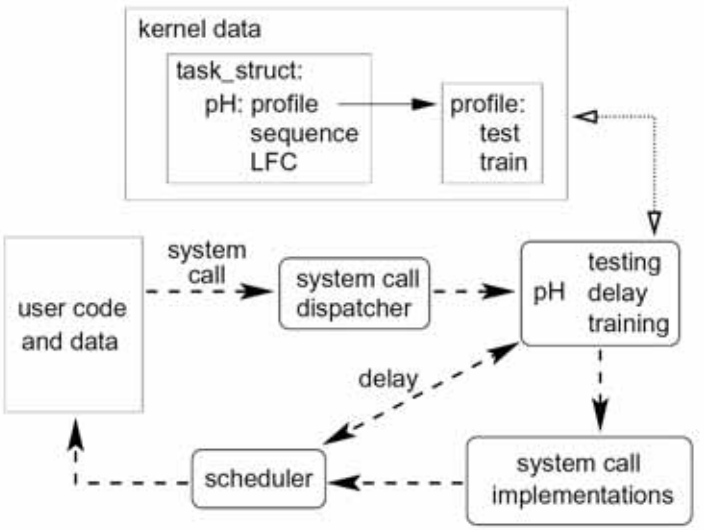
Homeostasis in computer security

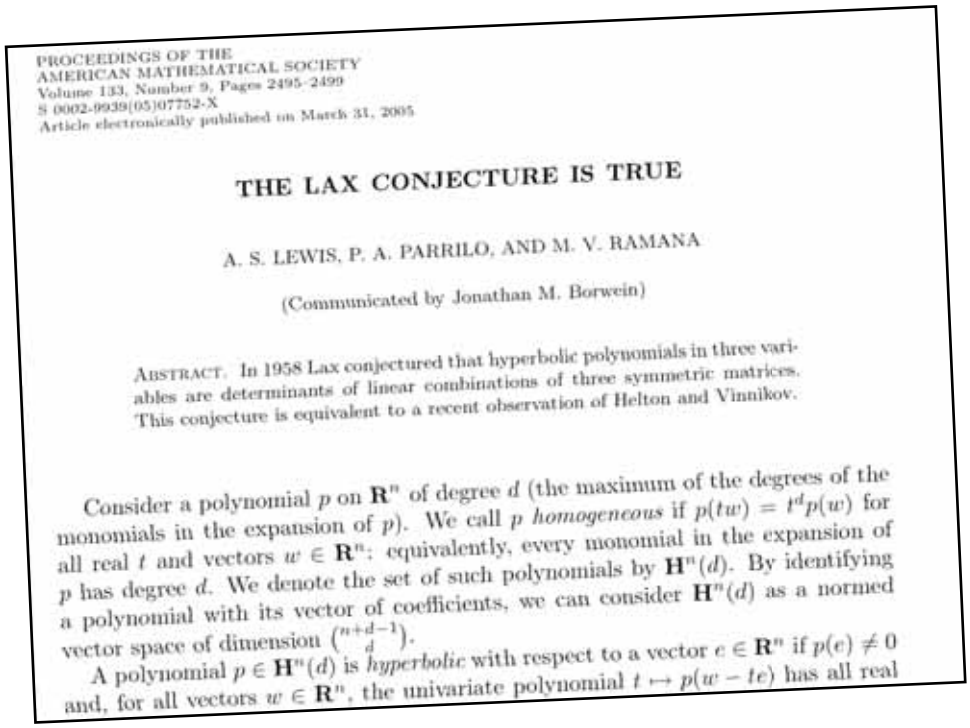
A comp sci PhD student got talking to a medical student at the IMA. The result: safer computers.



Flowchart from Somayaji's thesis

Computer systems are constantly attacked and infected by viruses and worms, but reliable and automatic intrusion detection exacts a large cost in system performance. Thanks to his discussions in 1998 at the IMA, CS student A. Somayaji realized that the *homeostatic* response of the human immune system to infection might well be appropriate for computer systems: containment and regulated coexistence is often the best strategy; drastic countermeasures are rarely called for. This idea evolved into a PhD thesis and a linux kernel extension, and was later commercialized by a collaborator and then in Hewlett-Packard's Virus Throttle software, release in 2005.

Breakthrough!



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THE LAX CONJECTURE IS TRUE

A. S. LEWIS, P. A. PARRILO, AND M. V. RAMANA

(Communicated by Jonathan M. Borwein)

ABSTRACT. In 1958 Lax conjectured that hyperbolic polynomials in three variables are determinants of linear combinations of three symmetric matrices. This conjecture is equivalent to a recent observation of Helton and Vinnikov.

Consider a polynomial p on $\mathbf{R}^n$ of degree d (the maximum of the degrees of the monomials in the expansion of p). We call p *homogeneous* if $p(tw) = t^d p(w)$ for all real t and vectors $w \in \mathbf{R}^n$: equivalently, every monomial in the expansion of p has degree d. We denote the set of such polynomials by $\mathbf{H}^n(d)$. By identifying a polynomial with its vector of coefficients, we can consider $\mathbf{H}^n(d)$ as a normed vector space of dimension $\binom{n+d-1}{d}$.

A polynomial $p \in \mathbf{H}^n(d)$ is *hyperbolic* with respect to a vector $e \in \mathbf{R}^n$ if $p(e) \neq 0$ and, for all vectors $w \in \mathbf{R}^n$, the univariate polynomial $t \mapsto p(w - te)$ has all real

The Lax conjecture, an open problem of 45 years standing with important applications in optimization, fell in a just few weeks after the right connections were made at the March 2003 IMA workshop on Semidefinite Programming and Robust Optimization. Discussions between A. Lewis and P. Parrilo led them and coauthor M. Ramana to pursue connections with work of Helton and Vinnikov. Their joint paper, entitled *The Lax Conjecture is True* appeared this year in the Proceedings of the American Mathematical Society.

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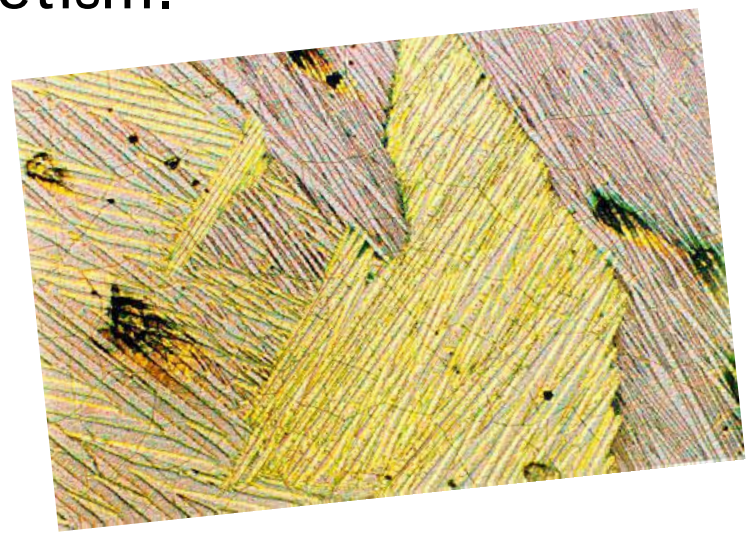
Microstructure has macro impact!

A mathematical theory pioneered at the IMA led to the development of alloys whose shapes can be modified with magnetism.

This revolutionary technology is at the foundation of a new industry, creating tiny pumps, valves, and actuators for medical, transportation, and military applications.



Microstructure in FMSA Ni_2MnGa.

The science of the *ferromagnetic shape-memory alloys* can be traced directly back to a 1990 IMA workshop where R. James and D. Kinderlehrer set out to explain the beautiful domain patterns observed in Terfenol and presented there. Their mathematical models introduced a new kind of free energy and led to the design of nickel-magnesium-gallium alloys exhibiting field-induced strains up to 50 times larger than those found in Terfenol, and paved the way for this important new technology.

Math outside the ivory tower

The IMA's Mathematical Modeling in Industry workshops are intensive ten-day programs in which teams of graduate students work under the guidance of a mentor from industry. The workshops give students an exceptional opportunity to experience the excitement and challenges of confronting—and often solving—actual industrial problems.

> *It shows clearly what industrial research is* really *like! With just the right amount of guidance, not letting us hang there by ourselves but also not solving the problem for us, our mentor led us through an exciting ten days of discovery.*
> —workshop participant Sonja Petrovic

> *This workshop will be one of the high points of the year for me in terms of excitement and enthusiasm. I returned to my own job with a renewed commitment to exploring new ideas and new mathematical techniques in our area. Most of all, the students left me with a sense that the future of the world is indeed very bright.*
> —mentor Tom Grandine, Boeing

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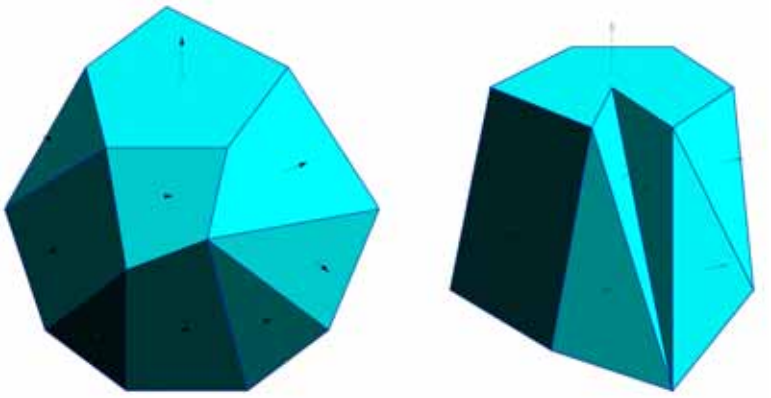
Toppling barriers

New ideas and results can take far too long to reach the scientists who need them most. The IMA breaks through the barriers created by the vast scale, complexity, and variety of contemporary scientific research.

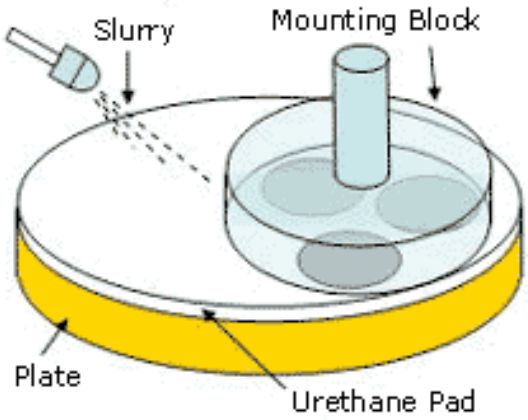


From the work of Brezzi, Shashkov and Lipnikov on mimetic finite differences.

In 2004, at an IMA workshop convened to foster communication between groups of researchers pioneering different approaches to numerical simulations, F. Brezzi—one of the world's leading researchers in finite element methods—met M. Shashkov and K. Lipnikov—top scientists in the area of finite difference methods (and, as such, members of a scientific community nearly disjoint from Brezzi's). Intense and sometimes heated discussions at the IMA grew into a remarkably fruitful collaboration that has already yielded several important papers.

Students to the rescue!

Motorola had a problem. Graduate students at an IMA workshop found a solution that saves the company $300K per year. And they enjoyed an unforgettable lesson in the power of mathematics.



Chemical-mechanical planarization

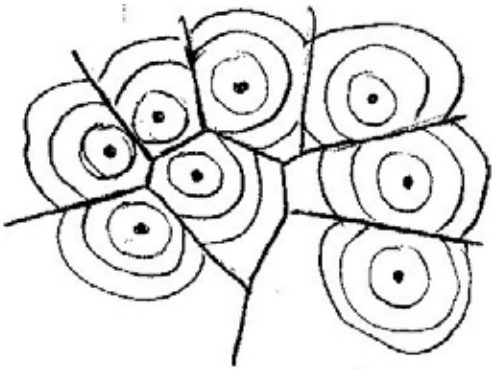
The pads used to polish silicon wafers in their chemical-mechanical planarization systems were wearing down too quickly and the impact on production was very costly. At the 1998 Industrial Mathematics Modeling workshop, Motorola scientist Len Borucki asked six graduate students in his assigned team to try to get a handle on pad wear through mathematical modeling. During the ten-day workshop, the students worked together to develop a simple mathematical model which incorporates the relevant physical processes, and created a prototype computer implementation. Impressed with the results, Borucki had the model refined at Motorola where it is now deployed company-wide to minimize pad changes.

Confronting new challenges

The *New Directions* program, introduced in 2003, is designed to help mid-career mathematicians move into new interdisciplinary research areas.

> It's very easy to just keep doing what I've been doing, but it can get stale. The New Directions program really has made me think in new ways and encouraged me to branch out.
>
> —Kevin Knudson

New Directions Visiting Professorships involve participation in the full academic year program, while the annual New Directions Short Course is an intensive two-week summer program in a developing area of application that shows particular promise for innovative mathematical investigation.



α-Complex from the 2004 New Directions short course on computational topology.

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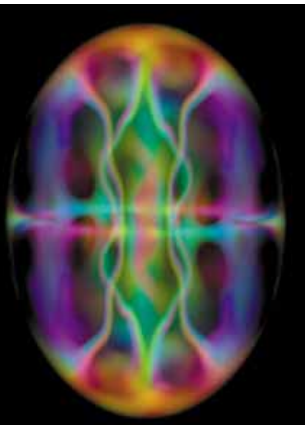
Conquering the critical case

A team of mathematicians gathered at the IMA to attack the nonlinear Schrödinger equation, a model for particles in a Bose-Einstein condensate. They managed to tame the most difficult case, that of critical nonlinearity.

Background

Bose-Einstein condensates, a new state of matter, were realized experimentally in the 1990s. At extremely low temperatures, elementary particles synchronize their probabilistic behavior in a common wave function, which, in the simplest case, can be described by a nonlinear Schrödinger equation.



Vortices in a BE condensate.

Their surprising results shows that even when interaction between particles is strong, a collections of particles in a Bose-Einstein condensate avoids collisions and collapse of the condensate and the collections eventually moves like a single free particle.

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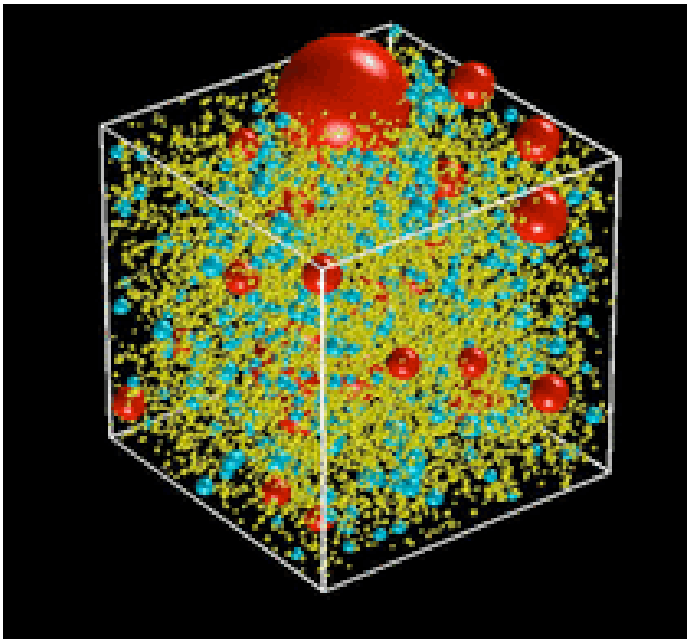
It is rocket science!



A sphere packing strategy that John Buckmaster and Thomas Jackson learned at the IMA became the starting point to devise a new modeling strategy for solid propellants in rockets. They devised a powerful tool to simulate rocket fuels such as those used in the space shuttle. *"We credit the IMA for helping make this breakthrough possible,"* says Buckmaster.