ISSN 0002-9920 (print)
ISSN 1088-9477 (online)

Notices

of the American Mathematical Society

November 2016

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Notices
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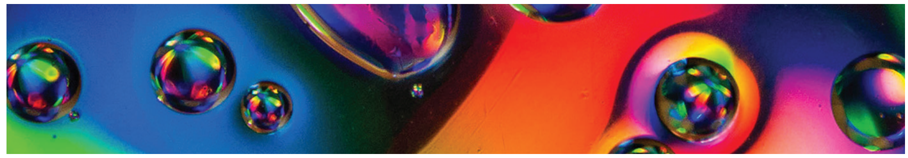
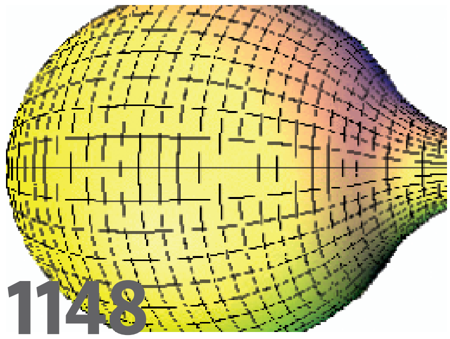
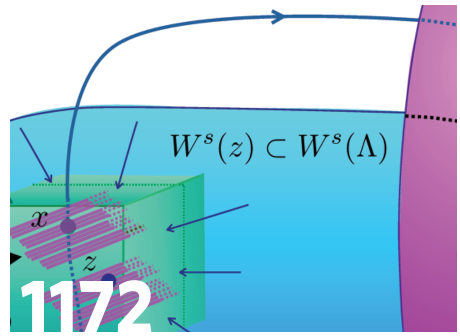


November 2016

FEATURES





Start with the latest on modeling flows and our sampler of the November AMS Southeastern Sectional Meeting, and for the American Thanksgiving this month, be glad we've got math and each other. —Frank Morgan, Editor-in-Chief

FROM THE SECRETARY'S OFFICE

JMM 2017

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ALSO IN THIS ISSUE, CONT'D.

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IN EVERY ISSUE

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Modified from the original by enlarging and cropping to measure 8.25" x 10.75"—final size.
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Level Set Method

For Motion by Mean Curvature

Tobias Holck Colding and William P. Minicozzi II

ABSTRACT. *Modeling of a wide class of physical phenomena, such as crystal growth and flame propagation, leads to tracking fronts moving with curvature-dependent speed. When the speed is the curvature this leads to one of the classical degenerate nonlinear second-order differential equations on Euclidean space. One naturally wonders, "What is the regularity of solutions?" A priori solutions are only defined in a weak sense, but it turns out that they are always twice differentiable classical solutions. This result is optimal; their second derivative is continuous only in very rigid situations that have a simple geometric interpretation. The proof weaves together analysis and geometry. Without deeply understanding the underlying geometry, it is impossible to prove fine analytical properties.*

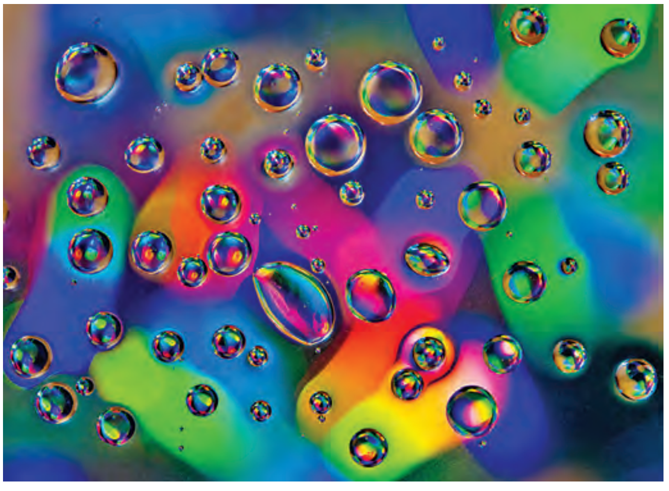

Figure 1. Oil droplets in water can be modeled by the level set method.

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DOI: http://dx.doi.org/10.1090/noti1439

The spread of a forest fire, the growth of a crystal, the inflation of an airbag, and a droplet of oil floating in water can all be modeled by the level set method. See Figure 1. One of the challenges for modeling is the presence of discontinuities. For example, two separate fires can expand over time and eventually merge to one, as in Figure 2, or a droplet of liquid can split as in Figure 3. The level set method allows for this.

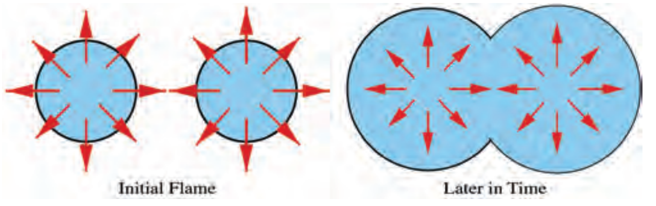

Figure 2. After two fires merge the evolving front is connected.

Figure 3. Water separates into droplets.

The level set method has been used with great success over the last thirty years in both pure and applied mathematics. Given an initial interface or front M_0 bounding a region in $\mathbf{R}^{n+1}$, the level set method is used to analyze its subsequent motion under a velocity field. The idea is to represent the evolving front as a level set of a function $v(x,t)$, where x is in $\mathbf{R}^{n+1}$ and t is time. The initial front M_0 is given by

$$M_0 = \{x \mid v(x,0) = 0\},$$

and the evolving front is described for all later time t as the set where $v(x,t)$ vanishes, as in Figure 4. There are many functions that have M_0 as a level set, but the evolution of the level set does not depend on the choice of the function $v(x,0)$.

In mean curvature flow, the velocity vector field is the mean curvature vector, and the evolving front is the level

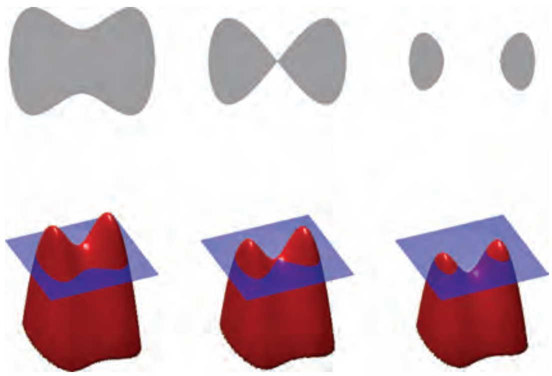

Figure 4. The gray areas represent trees that a forest fire has not yet reached. The edge is the burning fire front that is moving inward as time propagates left to right in the upper part of the figure. The propagation of the fire front is given as a level set of an evolving function in the second line.

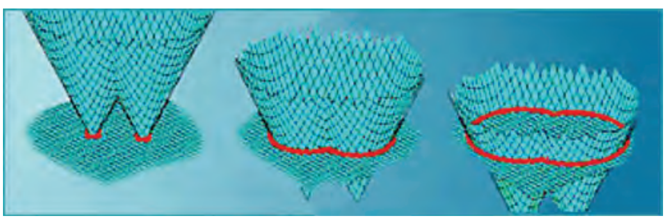

Figure 5. The red curves represent the evolving front at three different times. Each is the zero level set of the evolving function. The front here is moving outward as in Figure 2. In Figures 3 and 4, the front is moving inward.

set of a function that satisfies a nonlinear degenerate parabolic equation. Solutions are defined in a weak, so-called "viscosity," sense; in general, they may not even be differentiable (let alone twice differentiable). However, it turns out that for a monotonically advancing front viscosity solutions are in fact twice differentiable and satisfy the equation in the classical sense. Moreover, the situation becomes very rigid when the second derivative is continuous.

Suppose $\Sigma \subset \mathbf{R}^{n+1}$ is an embedded hypersurface and $\mathbf{n}$ is the unit normal of Σ. The **mean curvature** is given by $H = \operatorname{div}_\Sigma(\mathbf{n})$. Here

$$\operatorname{div}_\Sigma(\mathbf{n}) = \sum_{i=1}^{n} \langle \nabla_{e_i}\mathbf{n}, e_i \rangle,$$

where e_i is an orthonormal basis for the tangent space of Σ. For example, at a point where $\mathbf{n}$ points in the x_{n+1} direction and the principal directions are in the other axis directions,

$$\operatorname{div}_\Sigma(\mathbf{n}) = \sum_{i=1}^{n} \frac{\partial \mathbf{n}_i}{\partial x_i}$$

is the sum (n times the mean) of the principal curvatures. If $\Sigma = u^{-1}(s)$ is the level set of a function u on $\mathbf{R}^{n+1}$ and s is a regular value, then $\mathbf{n} = \frac{\nabla u}{|\nabla u|}$ and

$$H = \sum_{i=1}^{n} \langle \nabla_{e_i}\mathbf{n}, e_i \rangle = \operatorname{div}_{\mathbf{R}^{n+1}} \left(\frac{\nabla u}{|\nabla u|} \right).$$

The last equality used that $\langle \nabla_{\mathbf{n}}\mathbf{n}, \mathbf{n} \rangle$ is automatically 0 because $\mathbf{n}$ is a unit vector.

A one-parameter family of smooth hypersurfaces $M_t \subset \mathbf{R}^{n+1}$ flows by the **mean curvature flow** if the speed is equal to the mean curvature and points inward:

$$x_t = -H\,\mathbf{n},$$

where H and $\mathbf{n}$ are the mean curvature and unit normal of M_t at the point x. Our flows will always start at a smooth embedded connected hypersurface, even if it becomes disconnected and nonsmooth at later times. The earliest reference to the mean curvature flow we know of is in the work of George Birkhoff in the 1910s, where he used a discrete version of this, and independently in the material science literature in the 1920s.

Two Key Properties

- H is the gradient of area, so mean curvature flow is the negative gradient flow for volume (Vol M_t decreases most efficiently).
- Avoidance property: If M_0 and N_0 are disjoint, then M_t and N_t remain disjoint.

The avoidance principle is simply a geometric formulation of the maximum principle. An application of it is illustrated in Figure 6, which shows that if one closed hypersurface (the red one) encloses another (the blue one), then the outer one can never catch up with the inner one. The reason for this is that if it did there would be a first point of contact and right before that the inner one would contract faster than the outer one, contradicting that the outer was catching up.

Curve Shortening Flow

When $n = 1$ and the hypersurface is a curve, the flow is the curve shortening flow. Under the curve shortening flow, a round circle shrinks through round circles to a point in finite time. A remarkable result of Matthew Grayson from 1987 (using earlier work of Richard Hamilton and Michael Gage) shows that any simple closed curve in the plane remains smooth under the flow until it disappears

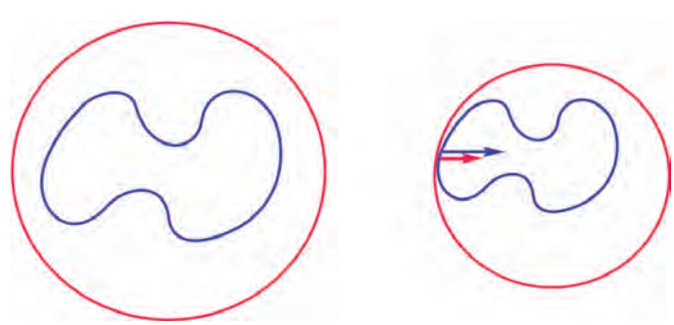

Figure 6. Disjoint surfaces avoid each other; contact leads to a contradiction.

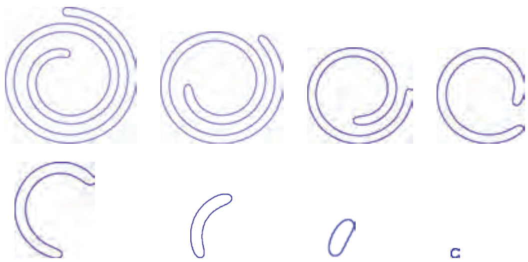

Figure 7. Grayson proved that even a tightly wound region becomes round under curve shortening flow.

in finite time in a point. Right before it disappears, the curve will be an almost round circle.

The evolution of the snake-like simple closed curve in Figure 7 illustrates this remarkable fact. (The eight figures are time shots of the evolution.)

Level Set Flow

The analytical formulation of the flow is the level set equation that can be deduced as follows. Given a closed embedded hypersurface $\Sigma \subset \mathbf{R}^{n+1}$, choose a function $v_0 : \mathbf{R}^{n+1} \to \mathbf{R}$ that is zero on Σ, positive inside the domain bounded by Σ, and negative outside. (Alternatively, choose a function that is negative inside and positive outside.)

- If we simultaneously flow $\{v_0 = s_1\}$ and $\{v_0 = s_2\}$ for $s_1 \neq s_2$, then avoidance implies they stay disjoint.
- In the level set flow, we look for $v : \mathbf{R}^{n+1} \times [0, \infty) \to \mathbf{R}$ so that each level set $t \to \{v(\cdot, t) = s\}$ flows by mean curvature and $v(\cdot, 0) = v_0$.
- If $\nabla v \neq 0$ and the level sets of v flow by mean curvature, then

$$v_t = |\nabla v| \operatorname{div}\left(\frac{\nabla v}{|\nabla v|}\right).$$

This is degenerate parabolic and undefined when $\nabla v = 0$. It may not have classical solutions.

In a paper cited more than 12,000 times from 1988, Stanley Osher and James Sethian studied this equation numerically. The analytical foundation was provided by Craig Evans and Joel Spruck in a series of four papers in the early 1990s and, independently and at the same time, by Yun Gang Chen, Yoshikazu Giga, and Shunichi Goto. Both of these two groups constructed (continuous) viscosity solutions and showed uniqueness. The notion of viscosity solutions had been developed by Pierre-Louis Lions and Michael G. Crandall in the early 1980s. The work of these two groups on the level set flow was one of the significant applications of this theory.

Examples of Singularities

Under mean curvature flow a round sphere remains round but shrinks and eventually becomes extinct in a point. A round cylinder remains round and eventually becomes extinct in a line. The marriage ring is the example of a thin torus of revolution in $\mathbf{R}^3$. Under the flow the marriage ring shrinks to a circle, then disappears. See Figure 8.

Dumbbell

Figure 9 shows the evolution of a rotationally symmetric mean convex dumbbell in $\mathbf{R}^3$. If the neck is sufficiently thin, then the neck pinches off first, and the surface disconnects into two components. Later each component (bell) shrinks to a round point. This example falls into a larger category of surfaces that are rotationally symmetric around an axis. Because of the symmetry, the solution reduces to a one-dimensional heat equation. This was analyzed in the early 1990s by Sigurd Angenent, Steven Altschuler, and Giga; cf. also with work of Halil Mete Soner and Panagiotis Souganidis from around the same time. A key tool in the arguments of Angenent-Altschuler-Giga was a parabolic Sturm-Liouville theorem of Angenent that holds in one spatial dimension.

Singular Set

Under mean curvature flow closed hypersurfaces contract, develop singularities, and eventually become extinct. The **singular set** S is the set of points in space and time where the flow is not smooth.

In the first three examples—the sphere, the cylinder, and the marriage ring—S is a point, a line, and a closed curve, respectively. In each case, the singularities occur only at a single time. In contrast, the dumbbell has two singular times with one singular point at the first time and two at the second.

Mean Convex Flows

A hypersurface is convex if every principal curvature is positive. It is mean convex if $H > 0$, i.e., if the sum of the principal curvatures is positive at every point. Under the mean curvature flow, a mean convex hypersurface moves inward, and, since mean convexity is preserved, it will continue to move inward and eventually sweep out the entire compact domain bounded by the initial hypersurface.

In many applications, the speed of the moving interface does not change sign and the front moves monotonically. This corresponds to positive mean curvature in our case. Monotone movement can be modeled particularly

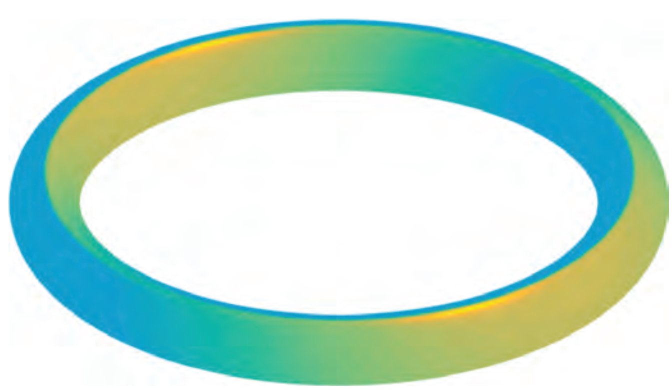

Figure 8. The marriage ring shrinks to a circle under mean curvature flow.

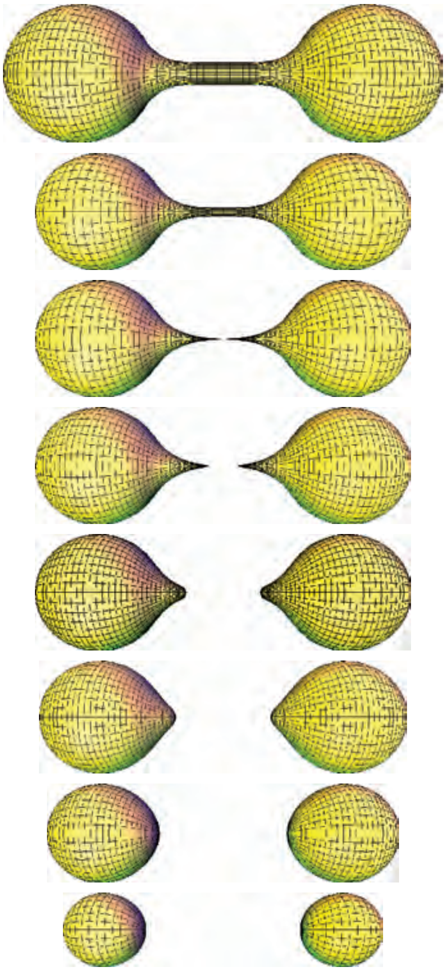

Figure 9. A narrow neck on a dumbbell pinches off, and then each half shrinks to a point.

efficiently numerically by the Fast Marching Method of James Sethian.

Level Set Flow for Mean Convex Hypersurfaces

When the hypersurfaces are mean convex, the equation can be rewritten as a degenerate elliptic equation for a function u defined by

$$u(x) = \{t \mid x \in M_t\}.$$

We say that u is the **arrival time**, since it is the time the hypersurfaces M_t arrive at x as the front sweeps through the compact domain bounded by the initial hypersurface. The arrival time has a game theoretic interpretation by work of Robert Kohn and Sylvia Serfaty. It follows easily that if we set $v(x,t) = u(x) - t$, then v satisfies the level set flow. Now the level set equation $v_t = |\nabla v| \operatorname{div}(\nabla v / |\nabla v|)$ becomes

$$-1 = |\nabla u| \operatorname{div}\left(\frac{\nabla u}{|\nabla u|}\right).$$

This is a degenerate elliptic equation that is undefined when $\nabla u = 0$. Note that if u satisfies this equation, then so does u plus a constant. This just corresponds to shifting the time when the flow arrives by a constant. A particular example of a solution to this equation is the function $u = -\frac{1}{2}(x_1^2 + x_2^2)$, which is the arrival time for shrinking round cylinders in $\mathbf{R}^3$. In general, Evans-Spruck (cf. Chen-Giga-Goto) constructed Lipschitz solutions to this equation.

Singular Set of Mean Convex Level Set Flow

The singular set of the flow is the critical set of u. Namely, $(x, u(x))$ is singular if and only if $\nabla_x u = 0$. For instance, in the example of the shrinking round cylinders in $\mathbf{R}^3$, the arrival time is given by $u = -\frac{1}{2}(x_1^2 + x_2^2)$, and the flow is singular in the line $x_1 = x_2 = 0$, that is, exactly where $\nabla u = 0$.

We will next see that even though the arrival time was only a solution to the level set equation in a weak sense, it turns out to be always a twice differentiable classical solution.

Differentiability

From [CM2]:

- u is twice differentiable everywhere, with bounded second derivatives, and smooth away from the critical set.
- u satisfies the equation everywhere in the classical sense.
- At each critical point the Hessian is symmetric and has only two eigenvalues, 0 and $-\frac{1}{k}$; $-\frac{1}{k}$ has multiplicity $k+1$.

This result is equivalent to saying that at a critical point, say $x = 0$ and $u(x) = 0$, the function u is (after possibly a rotation of $\mathbf{R}^{n+1}$) up to higher-order terms equal to the quadratic polynomial

$$-\frac{1}{k}\left(x_1^2 + \cdots + x_{k+1}^2\right).$$

This second-order approximation is simply the arrival time of the shrinking round cylinders. It suggests that the level sets of u right before the critical value and near the origin should be approximately cylinders (with an $n-k$ dimensional axis). This has indeed been known for a long time and is due to Huisken, White, Sinestrari, Andrews, and Haslhofer-Kleiner. It also suggests that those cylinders should be nearly the same (after rescaling to unit size). That is, the axis of the cylinders should not depend on the value of the level set. This last property, however, was only very recently established in [CM1] and is the key to proving that the function is twice differentiable.[1] The proof that the axis is unique, independent on the level set, relies on a key new inequality that draws

This kind of uniqueness is a famously difficult problem in geometric analysis

[1] *Uniqueness of the axis is parallel to the fact that a function is differentiable at a point precisely if on all sufficiently small scales at that point it looks like the same linear function.*

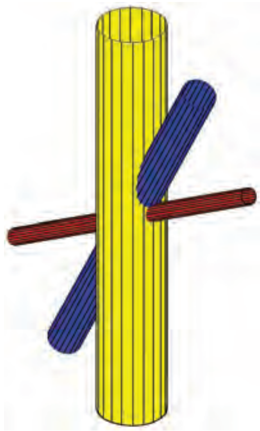

Figure 10. The figure illustrates a situation that turns out to be impossible, where the axes of the cylinders for three different level sets near the critical point are radically different. Instead, as the level sets approach the critical point, the axes go to a unique limit.

its inspiration from real algebraic geometry, although the proof is entirely new. This kind of uniqueness is a famously difficult problem in geometric analysis, and no general case had previously been known.

Regularity of Solutions

We have seen that the arrival time is always twice differentiable, and one may wonder whether there is even more regularity. Gerhard Huisken showed already in 1990 that the arrival time is C^2 for *convex* M_0. However, in 1992 Tom Ilmanen gave an example of a rotationally symmetric *mean convex* M_0 in $\mathbf{R}^3$ where u is not C^2. This result of Ilmanen shows that the above theorem about differentiability cannot be improved to C^2. We will see later that in fact one can entirely characterize when the arrival time is C^2. In the plane, Kohn and Serfaty (2006) showed that u is C^3, and for $n > 1$ Natasa Sesum (2008) gave an example of a *convex* M_0 where u is not C^3. Thus Huisken's result is optimal for $n > 1$.

The next result shows that one can entirely characterize when the arrival time is C^2.

Continuous Differentiability

[CM3]: u is C^2 if and only if:

- There is exactly one singular time (where the flow becomes extinct).
- The singular set S is a k-dimensional closed connected embedded C^1 submanifold of cylindrical singularities.

Moreover, the axis of each cylinder is the tangent plane to S.

When u is C^2 in $\mathbf{R}^3$, the singular set S is either:

(1) a single point with a spherical singularity or
(2) a simple closed C^1 curve of cylindrical singularities.

The examples of the sphere and the marriage ring show that each of these phenomena can happen, whereas the example of the dumbbell does not fall into either case, showing that in that case the arrival time is not C^2.

We can restate this result for $\mathbf{R}^3$ in terms of the structure of the critical set and Hessian: u is C^2 if and only if u has exactly one critical value and the critical set is either:

(1) a single point where Hess_u is $-\frac{1}{2}$ times the identity or
(2) a simple closed C^1 curve where Hess_u has eigenvalues 0 and -1 with multiplicities 1 and 2, respectively.

In case (2), the kernel of Hess_u is tangent to the curve.

Concluding Remarks

We have seen that for one of the classical differential equations, in order to understand the analysis it is necessary to understand the underlying geometry. There are many tantalizing parallels to other differential equations, both elliptic and parabolic.

For references about mean curvature flow, see the survey [CMP] and [CM1]–[CM3].

References

[CM1] T. H. Colding and W. P. Minicozzi II, Uniqueness of blowups and Łojasiewicz inequalities, *Annals of Math.* **182** (1) (2015), 221–285. MR 3374960

[CM2] ______, Differentiability of the arrival time, *Comm. Pure Appl. Math.*, DOI: 10.1002/cpa.21635.

[CM3] ______, Regularity of the level set flow, submitted, `https://arxiv.org/abs/1606.05185`.

[CMP] T. H. Colding, W. P. Minicozzi II, and E. K. Pedersen, Mean curvature flow, *Bull. Amer. Math. Soc.* (N.S.) **52** (2015), no. 2, 297–333. MR 3312634

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AMS FALL SOUTHEASTERN SECTIONAL SAMPLER

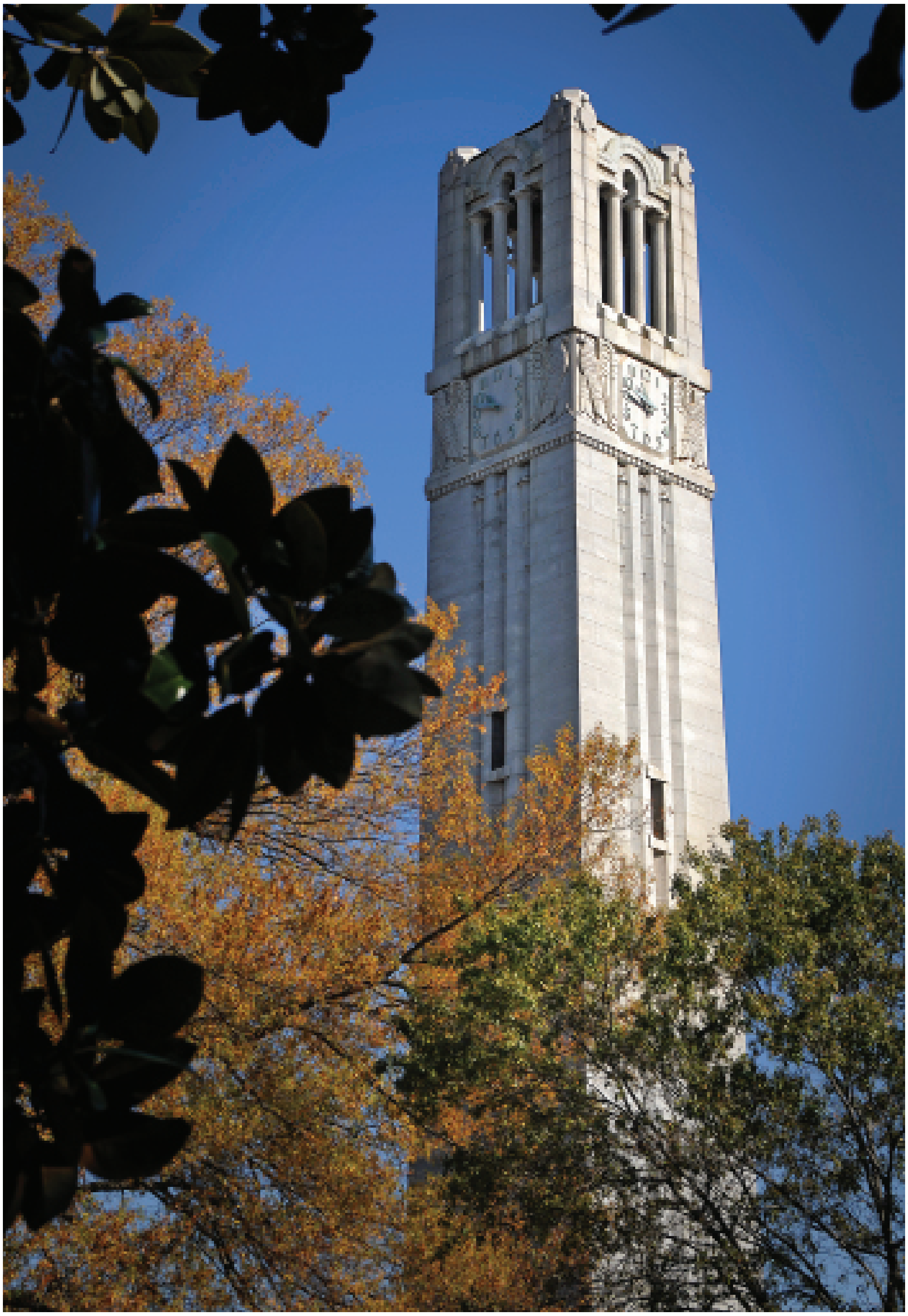


Photo courtesy of NC State University.

North Carolina State University, Raleigh.

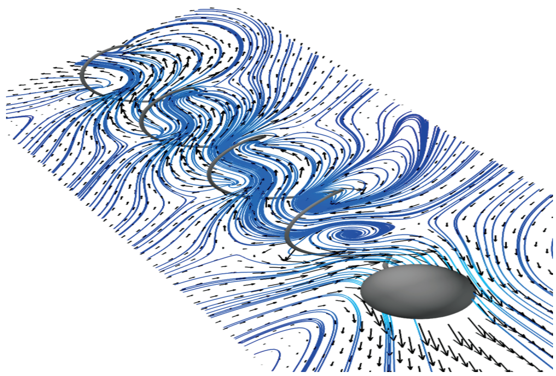
The AMS Fall Southeastern Sectional (North Carolina, November 12–13, 2016) Invited Address speakers kindly provide the following introductions to their presentations. (*Notices* did not have information on the AMS–NZMS Maclaurin Lecture by Gaven Martin in time for him to contribute, but he has graciously written an introduction to his *Siegel's Problem on Small Volume Lattices* presentation, which will appear in the December issue of *Notices*.)

RICARDO CORTEZ, Tulane University, *Mathematical and Computational Modeling of Microorganism Swimming*

JASON METCALFE, University of North Carolina, *Local Energy Decay for the Wave Equation*

AGNES SZANTO, North Carolina State University, *Certification of Approximate Roots of Exact Polynomial Systems*

Mathematical and Computational Modeling of Microorganism Swimming



Ricardo Cortez

Equations that describe the motion of fluids in three-dimensional spaces, much like the planar flow around the helical swimmer of Figure 1, are based on Newton's second law where the forces include those from pressure gradients, friction due to viscosity, inertia, and external forces exerted on the fluid. Depending on the application, some of these

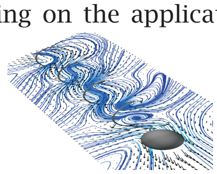


Figure 1. A computational helical swimmer and fluid flow pattern (velocity field and streamlines) on a plane.

forces may be negligibly small. On tiny scales, as in the case of biological flows around microorganisms, the inertial forces can often be omitted leading to the Stokes equations for incompressible flows:

$$0 = -\nabla p + \mu \Delta \mathbf{u} + \mathbf{F}, \qquad 0 = \nabla \cdot \mathbf{u},$$

where p is the pressure in the fluid, μ is the viscosity, $\mathbf{u}$ is the fluid velocity, and $\mathbf{F}$ is an external force density, which can be time-dependent and drives the flow.

Since the fluid velocity depends linearly on the external force, numerical methods for computing the solution of the Stokes equations can be designed based on their fundamental solution. At the Fall Southeastern Sectional meeting (November 12–13, NCSU), I will focus on the development and application of the method of regularized Stokeslets, which is based on a systematic derivation of nonsingular versions of the fundamental solution of the Stokes equations. Given a smooth function ϕ_ϵ (e.g., a Gaussian) that approximates a delta function as a distribution, we derive the exact solution $(p, \mathbf{u})$ of the Stokes equations for the forcing $\mathbf{F}(\mathbf{x}) = \mathbf{f}\phi_\epsilon(\mathbf{x} - \mathbf{x}_0)$. The resulting formula for $\mathbf{u}$, called a regularized Stokeslet, has no singularities and thus can be used to compute flows where the force density $\mathbf{F}$ is distributed over surfaces, curves, or even scattered points.

The regularization parameter ϵ represents roughly the radius of a ball where a force is spread so that $\epsilon \to 0$ reduces $\mathbf{u}$ to the (singular) fundamental solution. In studying the flow generated by beating or pulsating flagella we use this notion to set the value of ϵ based on physical parameters. My presentation will include examples of the usefulness of the method of regularized Stokeslets (and some variants) in biological applications.

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DOI: http://dx.doi.org/10.1090/noti1436

Credits

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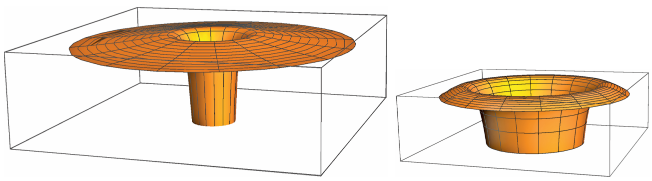
Photo of Ricardo Cortez and student, courtesy of Omid Forouzan.

Ricardo Cortez

ABOUT THE AUTHOR

Ricardo Cortez is an applied mathematician working on the development and analysis of numerical methods for the computation of fluid motion with applications to biology. Here he is shown with his student Ellie Ahmadi, who finished her PhD in 2016.

Local Energy Decay for the Wave Equation



Jason Metcalfe

We want to understand how waves spread out in spaces that look like Minkowski space-time as you go to infinity. This is the Lorentzian analog of being asymptotically Euclidean. To begin, we consider solutions to the Minkowski wave equation on $\mathbb{R} \times \mathbb{R}^3$:

$$\Box u := \frac{\partial^2}{\partial t^2} u - \Delta u = 0,$$

where Δ denotes the Laplacian

$$\Delta u = \frac{\partial^2 u}{\partial x_1^2} + \frac{\partial^2 u}{\partial x_2^2} + \frac{\partial^2 u}{\partial x_3^2}.$$

Such solutions enjoy a conserved energy $E(t) = E(0)$,

$$E(t) = \frac{1}{2} \int_{\mathbb{R}^3} (\partial_t u)^2 + |\nabla_x u|^2 \, dx.$$

This energy is the same for all times; it does not decay.

On the other hand, if the domain of integration is restricted to a compact set, say $B_R = \{|x| \leq R\}$, we expect the energy $E_{B_R}(t)$ within that set eventually to decrease in time. Imagine a stone thrown into the center of an infinite still ocean. After an initial splash, the waves move away, the center calms, and the energy within that set decreases. For some absolute constant C, if the total energy $E(0)$ is finite, say 1, then $E_{B_R}(t)$ has a finite integral with respect to t; indeed, its integral is bounded by CR. Such estimates originated in work of Cathleen Morawetz.

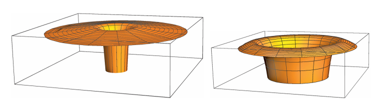
Imagine a stone thrown into the center of an infinite still ocean

In joint works with Christopher Sogge and with Daniel Tataru, we proved that such estimates continue to hold for small perturbations of Minkowski space-time that decay as $|x| \to \infty$. Once such estimates are known, several other common measures of dispersion have been shown to follow in such spaces, including the so-called Strichartz estimates and pointwise decay estimates.

We now turn our attention to wave operators on such asymptotically flat backgrounds but where the size of the perturbation may not be universally small. Moreover, lower-order perturbations such as potentials are also allowed. Motivated by, e.g., Maxwell's equations, these lower-order perturbations are permitted to be complex valued.

We will describe two immediate obstructions to local energy decay. Recent work with Jacob Sterbenz and Tataru demonstrates that these are the only relevant obstructions. The first obstructions are certain possible eigenfunctions and resonances of the elliptic portion of the operator. The second obstruction is trapping, when a geodesic, and hence energy from a disturbance, can remain in a compact set for all time.

One place where trapping occurs is in black hole space-times from general relativity. In the simplest example, Schwarzschild space, as depicted in Figure 1, photons can orbit the black hole along the so-called photon sphere. Under magnification as in Figure 1(B), this appears as a ridge about the black hole. Recent work shows that because the trapped geodesics are unstable—nearby



(A) Schwarzschild (B) Schwarzschild zoomed around the photon sphere

Figure 1. Photons orbit a black hole in Schwarzschild space along what appears as a ridge under magnification.

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This research is supported by the NSF CAREER award DMS-1054289.

DOI: http://dx.doi.org/10.1090/noti1437

geodesics go off to infinity or into the black hole—local energy decay can be recovered with a small loss. Stable trapping, however, eliminates most local energy decay. Interesting examples of in-between scenarios have recently been discovered, and a more general theory remains to be examined.

Photo Credit

Photo of Jason Metcalfe, courtesy of Anita Hepditch.

THE AUTHOR

Jason Metcalfe

Certification of Approximate Roots of Exact Polynomial Systems

At the 2016 AMS Fall Southeastern Sectional Meeting I will talk about my joint work with Jonathan Hauenstein and our student Tulay Ayyildiz Akoglu on the certification of solutions of polynomial systems.

Agnes Szanto

In the past fifty years, since the development of Buchberger's algorithm for computing Gröbner bases, symbolic computation has seen an explosion in development and applications for solving systems of polynomial equations. More recently, the combination of numerical analysis and algebraic geometry, yielding the field of numerical algebraic geometry, has produced new approaches and extended the limits of solving systems of polynomial equations. In general, these numerical methods are parallelizable and are producing solutions to large-scale systems. For example, the `Bertini` software package, a general-purpose numerical solver for polynomial systems, has recently been used to solve a system of seventy quadratics in seventy variables [4]. An overview of numerical algebraic geometry with a focus on using the software `Bertini` can be found in [2].

Sophisticated numerical algebraic geometry techniques are also able to solve problems that were once thought to be purely symbolic in nature, corresponding to noncontinuous properties of the input polynomial system. Some of the surprising problems that can be handled using numerical methods include finding primary decompositions, the genus of irreducible curves, or intersection numbers of Chern classes. However, many of the results produced by numerical algebraic geometry are not certified, as they are generated using heuristic methods that relax noncontinuous properties into continuous ones. The aim of our work is to give certification techniques for these noncontinuous problems and to demonstrate that certificates can be computed with not too much extra work, given numerical data.

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Agnes was partially supported for this research by NSF Grant CCF-1217557.

DOI: http://dx.doi.org/10.1090/noti1440

As mentioned above, typically the output of numerical algebraic geometry computations are not certified, with one notable exception being the special case of nonsingular roots of well-constrained systems. Before explaining our contributions, let me describe *α-theory*, one of the certification techniques from the extended body of literature for this special case.

Let $f : \mathbb{C}^n \to \mathbb{C}^n$ be a system of analytic functions and $\mathbf{z} \in \mathbb{C}^n$. Introduced by Smale in 1986, α-theory guarantees quadratic convergence of the Newton iteration from $\mathbf{z}$ to a fixed point if an associated invariant $\alpha(f, \mathbf{z})$ is smaller than a universal constant. Thus, in the case of a nonsingular root of a well-constrained system, α-theory gives a certificate that $\mathbf{z}$ is an *approximate zero* of f, i.e., that Newton's iteration starting from $\mathbf{z}$ quadratically converges to a root $\xi \in \mathbb{C}^n$ of f. Moreover, α-theory also gives a bound on the distance of $\mathbf{z}$ from ξ and certifies the uniqueness of the root within that distance. This last property allows α-theory to certify that $\mathbf{z} \in \mathbb{R}^n$ approximates a *real root* of a real polynomial system, which is used in many applications.

The invariant $\alpha(f, \mathbf{z})$ depends on all derivatives of f evaluated at $\mathbf{z}$. If f is a polynomial system, an upper bound for $\alpha(f, \mathbf{z})$ can be efficiently evaluated, which is implemented in the software `alphaCertified` [5]. A fascinating application is a computerized proof of a conjecture by John Edensor Littlewood, who asked the following question:

> *Is it possible in 3-space for seven infinite circular cylinders of unit radius each to touch all the others? Seven is the number suggested by constants.*

Bozóki, Lee, and Rónyai [3] proved this conjecture by setting up a well-constrained polynomial system over $\mathbb{Z}$ with real roots corresponding to solutions of the Littlewood conjecture. They approximated the roots using a numerical homotopy continuation method and certified that some roots are real using `alphaCertified`. A model of a cylinder arrangement solving Littlewood's conjecture that they found is shown in Figure 1.

Figure 1. Bozóki, Lee, and Rónyai proved that seven cylinders can all touch each other.

Motivated by such applications, we turned our attention to polynomial systems that are overdetermined or have singular roots. Note that consistency of an overdetermined polynomial system is not a continuous property of the input, and similarly the multiplicity structure of a given root is destroyed by perturbations of the input system. Existing approaches to certify solutions to such systems permit small perturbations of the input system, transforming the problem into a continuous one, allowing the use of α-theory or interval arithmetic or other continuous certification methods. However, for applications such as the computerized mathematical proof above, this is not sufficient: the polynomial system is given exactly with coefficients from $\mathbb{Z}$ or $\mathbb{Q}$, and we need to certify approximate zeroes of the given exact system without any perturbation.

Certifying the above noncontinuous properties posed completely new challenges and needed new ideas. Let me demonstrate the difficulties in a very simple example: Consider the overdetermined system $f : \mathbb{C} \to \mathbb{C}^2$ defined for any $a \in \mathbb{C}$ by

$$f(x) = \begin{pmatrix} x \\ x^2 + a \end{pmatrix}.$$

Dedieu and Shub developed an α-theory for overdetermined systems using the so-called *Gauss-Newton iteration*, but this only certifies fixed points which may not be roots; e.g., $x = 0$ is a fixed point of the Gauss-Newton iteration but not a root of f, unless $a = 0$. In particular, roots and local minima of $\|f\|$ are indistinguishable when using continuous certification methods.

To overcome this problem, Hauenstein and Sottile considered using universal lower bounds for the minimum of positive polynomials over $\mathbb{Z}$ on a disk. They concluded that all known bounds were "too small to be practical." For example, the overdetermined system

$$f_1 := x_1 - \frac{1}{2}, f_2 := x_2 - x_1^2, \ldots, f_n := x_n - x_{n-1}^2, f_{n+1} := x_n$$

has no common roots, but the value of f_{n+1} on the common root of $f_1, \ldots, f_n$ is doubly exponentially small in n. Since universal lower bounds have to cover these artificial cases, we cannot expect much improvement using universal bounds.

This led to the idea of constructing some individualized witness for our input polynomial system f instead of using universal lower bounds that are often very pessimistic. In our approach we use the so-called *Rational Univariate Representation* (RUR) as our witness, and we reconstruct this exact representation from approximate data. The advantage of our approach, as we shall see, is the ability to terminate early in cases when the witness for our input instance is small.

The main idea of our symbolic-numeric method to certify overdetermined polynomial systems over $\mathbb{Q}$ is as follows: Consider $f = (f_1, \ldots, f_m) \in \mathbb{Q}[x_1, \ldots, x_n]^m$ for some $m > n$, and assume for now that all roots are isolated and nonsingular. Under these assumptions, the RUR for the common roots of f exists, and the polynomials in the RUR also have rational coefficients. Thus we can compute them exactly, unlike the possibly irrational coordinates of the common roots of f. With the exact RUR, which is a well-constrained system of polynomials, we can use `alphaCertified` to certify that a given point is an approximate root for the RUR and thus for our original system f.

In principle, one can compute such an RUR using purely algebraic techniques, for example, by solving large linear systems corresponding to resultant or subresultant matrices. However, this purely symbolic method would again lead to running times close to the worst case complexity bounds. Instead, we propose a hybrid symbolic-numeric approach using interpolation on the approximate roots of f, rational number reconstruction, as well as exact univariate polynomial remaindering over $\mathbb{Q}$. Our hope is that our method will make the certification of roots of overdetermined systems practical for cases when the actual size of the RUR is significantly smaller than in the worst case.

The details of this hybrid symbolic-numeric method are described in our paper [1], which also contains detailed complexity analysis, demonstrating that in the case of successful certification the complexity is polynomial in the input plus the output size. This is a significant improvement over purely symbolic methods, which always have comparable complexity to our worst-case scenario when the certification fails. In other words, our method returns certification in many instances very quickly, but in some cases it terminates with failure.

Once we successfully certified nonsingular roots of overdetermined systems over $\mathbb{Q}$, we considered certifying isolated singular roots of rational polynomial systems. Due to the behavior of Newton's method near singular roots, standard techniques in α-theory cannot be applied to certify such roots even if the polynomial system is well constrained. The key tool to handle such multiple roots is called *deflation*. Deflation techniques "regularize" the system, thereby creating a new polynomial system which has a simple root corresponding to the multiple root of the original system. In our work, we focus on using a determinantal form of the *isosingular deflation*, in which one simply adds new polynomials to the original system without introducing new variables. The new polynomials are certain subdeterminants of the Jacobian matrix of the polynomial system, constructed using exact information that one can obtain from a numerical approximation of the multiple root. In particular, if the original system had rational coefficients, the new polynomials which remove the multiplicity also have rational coefficients. Thus, this technique provides a reduction to the case of an overdetermined system over $\mathbb{Q}$ in the original set of variables that has a simple root.

We demonstrate our method on a common benchmark system, the Caprasse system, which has 24 regular roots and 8 roots of multiplicity 4, namely,

$$g = \begin{bmatrix} x_1^3x_3 - 4x_1^2x_2x_4 - 4x_1x_2^2x_3 - 2x_2^3x_4 - 4x_1^2 - 4x_1x_3 + 10x_2^2 + 10x_2x_4 - 2 \\ x_1x_3^3 - 4x_1x_3x_4^2 - 4x_2x_3^2x_4 - 2x_2x_4^3 - 4x_1x_3 + 10x_2x_4 - 4x_3^2 + 10x_4^2 - 2 \\ 2x_1x_2x_4 + x_2^2x_3 - 2x_1 - x_3 \\ x_1x_4^2 + 2x_2x_3x_4 - x_1 - 2x_3 \end{bmatrix}.$$

Since the system is well constrained, numerical approximations for the 24 regular roots can be certified using standard α-theory. Here, we consider certifying the multiple roots. When evaluated at each of these multiple roots, the 4×4 Jacobian matrix $J_g = \left[\frac{\partial g_i}{\partial x_j}\right]_{i,j=1}^4$ has rank 2, with the lower right 2×2 block having full rank, which property can be obtained using approximate roots and numerical rank computations. Thus, we construct the new polynomial system f by appending g with the four 3×3 minors of J_g containing the lower right block. Now f is an overdetermined polynomial system over $\mathbb{Q}$ that completely deflates all 8 roots; i.e., they become nonsingular roots of f.

From the numerical approximations of the eight points that we computed using `Bertini`, we see that $T = x_1 - x_2 + 3x_3 - 3x_4$ separates the roots. Using interpolation on the numerical approximations of the roots correct to six digits we constructed the following exact RUR, which we certified to be correct using exact univariate polynomial remaindering:

$$\begin{aligned} q &= (T^2+4/3)(T^2+12)(T^2-16T+76)(T^2+16T+76), \\ r_1 &= (224/3)T^6 - (15232/3)T^4 - 6656T^2 + 505856/3, \\ r_2 &= -(80/3)T^6 - 1856T^4 - 41216T^2 + 97280/3, \\ r_3 &= (160/3)T^6 - 2944T^4 - (363008/3)T^2 - 972800/3, \\ r_4 &= (80/3)T^6 + 1856T^4 + 41216T^2 - 97280/3. \end{aligned}$$

This RUR corresponds to a well-constrained system $q, q'x_1r_1, \ldots, q'x_4 - r_4) \in Q[T, x_1, x_2, x_3, x_4]^5$ defining the 8 roots, now with multiplicity one. Thus we can use `alphaCertified` to certify that a given point is an approximate root for the RUR and thus for our original systems f and g.

References

[1] T. A. Akoglu, J. D. Hauenstein, and A. Szanto, Certifying solutions to overdetermined and singular polynomial systems over $\mathbb{Q}$, arXiv:1408.2721, 2014.

[2] D. J. Bates, J. D. Hauenstein, A. J. Sommese, and C. W. Wampler, *Numerically solving polynomial systems with Bertini*, volume 25 of Software, Environments, and Tools, Society for Industrial and Applied Mathematics (SIAM), Philadelphia, PA, 2013. MR 3155500

[3] S. Bozóki, T.-L. Lee, and L. Rónyai, Seven mutually touching infinite cylinders. *Comput. Geom.* **48** (2015), no. 2, 87–93. MR 3260249

[4] J. Hauenstein and J. McCarthy, Biologically-inspired linkage design: computing form from function. *SIAM News* **48** (2015), no. 8.

[5] J. D. Hauenstein and F. Sottile, Algorithm 921: alpha Certified: certifying solutions to polynomial systems, *ACM Trans. Math. Software* **38** (2012), no. 4, Art. ID 28, 20 pp. MR 2972672

Credits

Figure 1, courtesy of Peter Gal.
Photo of Agnes Szanto, courtesy of Scott Hellmann.

Agnes Szanto

ABOUT THE AUTHOR

Research interests of Agnes Szanto include symbolic-numeric computation, computational algebraic geometry, and differential algebra.

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COMMUNICATION

Todos Cuentan: Cultivating Diversity in Combinatorics

Federico Ardila-Mantilla

In nine years the Combinatorics Initiative between San Francisco State University (SFSU) and the nation of Colombia has built an active community of more than two hundred mathematicians, most of whom are members of underrepresented groups in mathematics. More than fifty have pursued PhDs in mathematics, while others continue to be mathematics users, enthusiasts, and ambassadors in other fields and to encourage and inspire the next generation of scientists in their communities. This article tells our story and shares some lessons we have learned about broadening and deepening representation in mathematics.

We begin by stating our axioms in the first section. We then outline our work in "SFSU-Colombia Combinatorics Initiative" and discuss our underlying sociopolitical framework and pedagogical strategies in "Deepening Representation."

I. The Axioms

Let me begin with some axioms. I firmly believe in them, and I build my work upon them.

Axiom 1. *Mathematical talent is distributed equally among different groups, irrespective of geographic, demographic, and economic boundaries.*

Axiom 2. *Everyone can have joyful, meaningful, and empowering mathematical experiences.*

Axiom 3. *Mathematics is a powerful, malleable tool that can be shaped and used differently by various communities to serve their needs.*

Axiom 4. *Every student deserves to be treated with dignity and respect.*

These statements should not sound revolutionary, but considering the current practices of the mathematical society, they are a pressing call to action.

"Todos cuentan" means "Everybody counts."

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DOI: http://dx.doi.org/10.1090/noti1434

Figure 1. A diverse group of more than two hundred mathematicians comprises the SFSU-Colombia Combinatorics Initiative.

II. SFSU-Colombia Combinatorics Initiative

The SFSU-Colombia Combinatorics Initiative is a research and training collaboration that seeks to offer every interested student a challenging and supportive mathematical experience while planting seeds for the broader and deeper representation of different groups in mathematics.

The Partners

The Universidad de Los Andes is an elite private university in Colombia. Its math department is one of the country's strongest, and through scholarships it attracts some of the best-prepared students in the country. Most Los Andes participants in the program are undergraduates with very solid mathematics backgrounds but little understanding of what research looks like. About one fifth of them were members of the Colombian math olympiad team, which I coached for fifteen years.

SFSU is a large public four-year university with a diverse population: over 60 percent of the students come from ethnic minority groups, and almost half are first-generation college students. The Masters program welcomes and serves a student body with a wide range of demographics and academic preparation. SFSU is home to an active research group in combinatorics, including about fifteen research students at a time.

I was born and raised in Colombia, discovering mathematics through the Olimpiadas Colombianas de Matemáticas. I came to the US twenty-two years ago as an undergraduate on a scholarship to MIT and have been here ever since while remaining in close contact with Colombia and its mathematics. In the US I am usually counted as a minority mathematician, and I have often felt in the minority. Though I was treated well, most of my training in the US took place alone, avoiding mathematical spaces where I felt uncomfortable. However, unlike most students from marginalized groups in mathematics, I never had to overcome the structural inequalities of our educational system. In particular, I never had a teacher or peer who doubted my abilities or told me that I was not good enough to succeed.

How it All Started (2005)

Felipe Rincón, then an undergraduate at Los Andes, had taken my Algebraic Combinatorics course there in 2003 and was writing his thesis under my supervision. In view of his classmates' interest and the relative lack of activity in this field in Colombia, he volunteered to teach an unofficial combinatorics course for free. The course was a great success, attracting more than twenty of the approximately one-hundred twenty math majors.

I had recently begun an assistant professorship at San Francisco State University and was very interested in contributing to mathematics in Colombia. Felipe's course exposed a great need, so I decided to offer a follow-up topics course on matroid theory, offered jointly at SFSU in person and at Los Andes electronically. Internet courses were still not in fashion, and this was exactly the kind of wild, uncertain experiment that Colombians love to embark upon.

SFSU/Los Andes, Matroid Theory (2007)

I taught the class at SFSU and filmed it using my colleague Arek Goetz's wonderfully low-budget artisanal setup, modeled after the one used by his figure-skating sister: heat sensors across the front of the room detected where I was standing and told the camera in the back where to point. With practice I learned to use large and clear handwriting and to move around less so I would not make the viewers dizzy. Arek also improved his algorithm so the camera would not follow me when I walked across the room and back to get the eraser.

Los Andes students watched the lecture together in a classroom, where I was present virtually to answer questions. We could not meet simultaneously due to time zone differences and the limits of the technology available to us. I visited Bogotá early in the semester to meet the students in person. PhD students from UC Berkeley also took the class, some in person and some on video.

We made great efforts for US and Colombian students to feel that they were in the same class. Students created mini-bios, including their photos, personal background, and mathematical interests; they were not afraid to let their personalities shine through. I also created an online forum where students from US and Colombia got to "meet," discuss the course material and the assignments, and find future collaborators.

Figure 2. Student profiles from the 2007 matroid theory joint course, the first course offered as part of the SFSU-Colombia Combinatorics Initiative.

In the first half of the course I assigned homework that ranged from reasonably straightforward exercises, accessible to anyone in the class, to approachable but challenging recent results in the matroid theory literature which required extensive (sometimes international) teamwork. Occasionally I assigned unannounced open problems. Posting student solutions while trying to represent everyone in the class raised the quality of the work and the writing. Most but not all Colombians were proficient in English, and some took the opportunity to write mathematics in English for the first time. Others didn't, and SFSU students got to read mathematics in Spanish; this was especially exciting for some of the US Latinas/os, many of whom spoke Spanish at home but not in their mathematical life.

In the second half, students did final projects in pairs; I suggested projects ranging from surveys of classic topics to current open problems of interest. Most students tried to do original research; see Figure 3.

• *Results.* The eleven projects in the class led to five papers in international journals (three coauthored internationally) and eight theses. Nine years later, of the twenty-one students in the class, eleven have completed PhDs in mathematics. Currently,
– four are university professors in mathematics,
– six are postdoctoral researchers in mathematics,
– four are community college faculty in mathematics,
– two are PhD students in economics, and
– five are working in industry.

• *Observations and lessons learned*
– Every student did deep work, especially in their final projects. Students with substantial mathematical gaps learned what they needed along the way.
– A strong sense of teamwork and collaboration helped most students lift one another up, though a few struggled with having to do mathematics in groups.

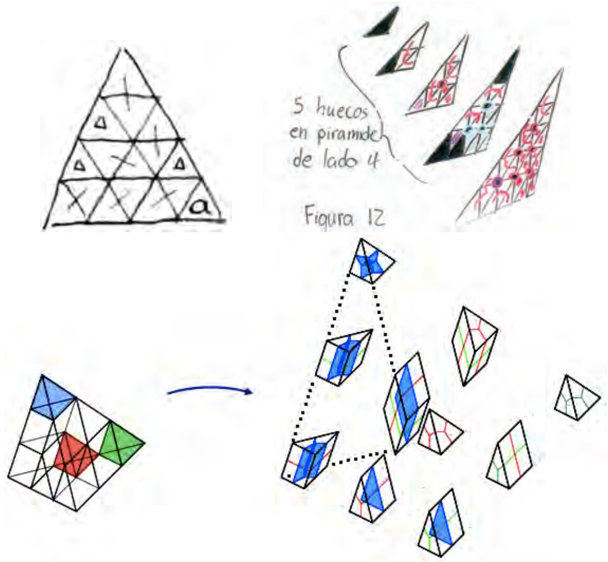


Figure 3. Cesar Ceballos's research, motivated by work of Billey and Vakil on the Schubert calculus of the flag variety, progresses from a homework solution to a final project and a publication about the triangulations of a product of two simplices $\Delta_m \times \Delta_n$.[1]

– Most projects were international, and those were most productive. Students' curiosity towards and accountability to strangers played a useful role.
– Generally speaking, SFSU students were impressed with the knowledge and problem-solving skills of Los Andes students. Los Andes students were impressed by the work ethic and determination of SFSU students, particularly in their research projects.
– Asynchronicity was far from ideal; it made classes lecture-centric. Creating a coherent shared experience took hard work, and it was still not a great substitute for personal interaction.

Figure 4. Ardila-Mantilla with some of the Colombian researchers presenting their work at the FPSAC 2011 combinatorics conference in Iceland.

[1]*For a list of publications of students in the SFSU-Colombia Combinatorics Initiative, visit* `math.sfsu.edu/federico/SFSUColombia/papers.html`.

Some Guiding Principles for the Course Design

The Matroid Theory class became the blueprint for eight topics courses over the last nine years; six of them were offered jointly at SFSU and Los Andes. As I continued to design these courses, I identified a few key principles that I always attempted to implement.
– Choose a deep topic of current interest that is accessible to students with different backgrounds.
– Hold students to extremely high standards and match that expectation with a solid support system.
– Devise challenging, interesting, and inspiring assignments, including a final project in pairs that students have the freedom to design themselves.
– Give students the time they need: allow two weeks for each homework and two months for the final project.
– Create a course structure that builds a strong community through a shared mathematical purpose.
Several student evaluations mentioned this sense of community, and some took it to social media:

Online Resources

I made all materials for my six SFSU-Colombia courses freely available, including more than 240 hours of videos on the YouTube channel `federicoelmatematico`. According to the channel's statistics, users in 155 countries have viewed more than 10,000 hours of combinatorics videos. More meaningful to me, I have personally heard from active users in places like Colombia, Germany, India, Iran, Sudan, Turkey, and the United States.

Technology offers exciting possibilities to increase access to education, but we should be cautious in interpreting the numbers above. For example, the average view duration for these 50–75-minute videos was 8:33. Of the viewers who divulged their gender, 81 percent were men. The last few lectures of each course were watched between 60 and 300 times each, with viewers concentrated in the US and Western Europe and including several of my students and colleagues. These online resources have certainly been helpful to people, but I do not believe they have had a significant effect in closing the gap for access to quality mathematics resources.

Encuentro Colombiano de Combinatoria (ECCO)

It soon became clear that US and Colombian students wanted to build closer ties and collaborate in person. I organized the Encuentro Colombiano de Combinatoria to benefit young mathematicians first and foremost, especially those who do not have easy access to such an opportunity. Now organized by a committee of former participants, ECCO meets bi-yearly. We do our best to build an atmosphere that is equally professional, welcoming, inclusive, and joyful. The reader may find Viviane Pons's personal account of her experience at ECCO 2016 in the AMS blog *On Teaching and Learning Mathematics*.[2]

Figure 5. MIT professor Richard Stanley as he is about to zipline across the Chicaque Cloud Forest with US and Colombian students during ECCO 2014: "I hope I don't have a heart attack right now; I still have to go to my birthday conference next week!"

ECCO features minicourses by international experts. Each minicourse lecture is followed by a problem session in randomly chosen groups that include mathematicians of varying levels of experience; see Figure 6. This forces every participant to engage with every topic and allows young people to meet and work with many experienced researchers and see how they approach unfamiliar topics. It also gives the lecturers immediate feedback on their course and allows them to adapt accordingly. ECCO also features research talks by students, open problem presentations, mentoring sessions, a visit to a salsa dance club, a hike, and (inevitably it seems) an impromptu street party.

ECCO 2016 was a CIMPA Research School and hosted 130 participants from over twenty countries, mostly from Latin America. Now that ECCO has gained some international notoriety, several combinatorics experts have asked to attend. We welcome them with care, reminding them that this is a school and an *encuentro*,[3] not a regular conference. We ask these experts to do problem sets with the students, to present open problems that they would like help with, to serve as mentors, and probably to join the dance floor at some point. They have been

Figure 6. A team of mathematicians from Universidad del Amazonas, Universidad del Cauca, University of Kentucky, and Fundación Universitaria Konrad Lorenz working on a problem set in discrete geometry during ECCO 2016.

wonderfully helpful and inspiring mentors, and several have mentioned that their experiences at ECCO have influenced their work at their home institutions.

I consider it a success that I am no longer on the ECCO organizing committee; sharing the decision making has brought new energy, ideas and perspectives, and has given many people a sense of ownership of this project. More importantly, I believe it has fostered their agency as members of the mathematical society and empowered them to pursue their own initiatives.

Funding

The Matroid Theory class and ECCO 2008 were generously funded by seed grants from SFSU and Los Andes. With those results in hand, I applied for the NSF CAREER and Combinatorics grants that have funded our activities since then.

The cost of tuition and living in San Francisco is a real challenge for our students, most of whom have significant workloads while they study. We have supported some of them using other NSF and NIH grants at SFSU, such as Matt Beck's GK-12 grant in mathematics and Frank Bayliss's SEO grants in science. We plan to implement a more sustainable funding infrastructure that will allow our students to better focus their efforts on their academic preparation.

Some Statistics

Approximately 200 students have officially enrolled in the classes offered by this initiative, and approximately 50 of them have pursued PhDs in the mathematical sciences.

The initiative has had 40 thesis students (4 PhD, 27 MS, 12 BS): 28 in the US (14 women, 15 URMs)[4] and 12 in Colombia (3 women, 12 URMs), who authored more than 20 publications, which appeared in journals such as *Duke Mathematical Journal, Advances in Mathematics, International Mathematics Research Notices*, and *Journal of Combinatorial Theory, Series A.*

[2] Viviane Pons, *"An Inclusive Maths Conference, ECCO 2016," AMS blog* On Teaching and Learning Mathematics, *August 22, 2016.*

[3] *gathering, usually of people with shared experiences*

[4] *underrepresented minorities*

Of these 40 students, 28 have entered math PhD programs (19 US, 11 women, 21 URMs), and 25 have finished or are current students, including all 21 URMs.[5]

III. Deepening Representation

The underrepresentation of women, Latinas/os, and African Americans in US mathematics is well documented.[6] These groups constituted respectively:

- 50.8 percent, 17.4 percent, 13.2 percent of the 2014 population [10];
- 31 percent, 3.5 percent, 2.5 percent of the 2014 new math PhDs [11];
- 18 percent, 3 percent, 1 percent of the full-time math faculty at PhD-granting institutions in 2005 [2].

Underrepresentation is more drastic further along the academic career. Among the science, engineering, and health faculty in 2008, Latinas/os and African Americans constituted 4.8 percent and 5 percent of assistant professors, 3.6 percent and 4.8 percent of associate professors, and 3.3 percent and 2.3 percent of full professors [1].

These numbers naturally lead to further underrepresentation in positions of leadership and decision-making power, slowing down the changes necessary to reverse this trend. Within the AMS, all sixty-three presidents have been white and sixty-one have been men. The situation is improving: the twelve current officers include four women and two foreign-born Latinos. A new Directorship of Education and Diversity was instituted in 2016, and at a more grassroots level, many excellent Mathematics Programs That Make a Difference have been recognized since 2006. However, the mathematical society at large still has a lot of work to do.

To truly broaden representation we must deepen representation

It appears that, now more than ever, US society recognizes the importance of building a scientific workforce that reflects and represents our diverse demographics. It is less clear how this will be achieved, but we have learned a few things: it is not enough to wait for the occasional lone "geniuses" from unlikely places to make it against all odds; it is not enough to say that we don't see gender or race in our classrooms; it is not enough to offer a few different kinds of people entrance to the same old house and expect them to come in and to thrive. To truly broaden representation we must deepen representation. We must be prepared to truly accept the structural inequalities that led to the current state of affairs, both within our mathematical population and in society at large, and to do the deep, hard work that is required to overcome them. As a mathematician with rather limited knowledge and expertise, I find this a daunting challenge.

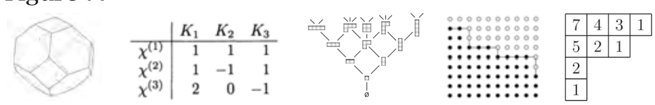
As scientists do when faced with a seemingly intractable problem, I have focused on a smaller problem for the moment: building nurturing environments where different people can thrive and do excellent mathematics. I certainly don't have a recipe for how to do this, and I know we still have a long way to go, but I do think the SFSU-Colombia Combinatorics Initiative has achieved some success. Along the way, by listening to students, teachers, organizers, and scholars, I have learned a few things about the larger structural obstacles to be overcome. I believe the following factors have been crucial to the small successes we've had so far.

The Mathematics

To succeed in mathematics, one must do high-quality mathematics. This is especially true for students without elite credentials, for whom the bar to success is often set higher. It is crucial to involve mentors with active research programs in areas of current interest.

Todos Cuentan (Everybody Counts)

Our activities are designed to serve **every** interested student by building an inclusive environment that everyone contributes to and benefits from. We aim to increase students' sense of belonging and responsibility to their mathematical community; see the "Agreement" section in Figure 7.



math 850 . representation theory

san francisco state university — federico ardila

Agreement. The goal of this course is to offer a meaningful, rigorous, and rewarding experience to every student; you will build that rich experience by devoting your strongest available effort to the class. You will be challenged and supported. Please be prepared to take an active, patient, and generous role in your own learning and that of your classmates.

Diary. After class n you will discuss the material with a classmate, and turn in a very brief summary of the key points at the beginning of class $n+1$. We will begin class $n+1$ by discussing these. After class $n+1$, you will edit and transcribe your summary of class n into your "diary" in LaTeX. You will get extra credit if you write diary entries with $> 2/3$ of the students in the class.

Final Project. This is a chance to go much deeper into a topic that interests you, in pairs. It could be an expository paper, the beginning of an original research project, or (why not?) the solution to an open problem. I will suggest possible projects. For most of you, this is the first time you receive such an open-ended assignment in a mathematics class. Have fun with it! Don't be afraid to take a risk; this is an opportunity to try something intriguing that you don't know how to do.

Figure 7. Syllabus excerpt of our Representation Theory course. We make sure students know they will be challenged and supported.

Intentionally or not, most programs in higher mathematics are designed to select the "top" mathematicians at each stage and prepare them for the next stage. Such programs have certainly played a crucial role in the careers of many mathematicians, including mine. However, they have also played a role in excluding and discouraging others with great mathematical potential, particularly among underrepresented groups.

Equitable Spaces

We try to be mindful of how different students experience the same environment and find ways to make sure each

[5] *Numbers for US and women omitted for confidentiality.*

[6] *We focus for the moment on these three large groups for which data is available.*

one of them is actively involved and engaged within the spaces we provide.

Language matters. Many of the standard patterns of communication of mathematicians—like calling a fact "easy to see" when it isn't, or saying "I get it" when one doesn't—are harmless to some, but they feel exclusive to those who already feel like outsiders.

Structure matters. Without an explicit and mindful effort, classrooms easily turn into conversations between a professor and a handful of students. My current courses are organized so that every student participates in every class, either verbally, in writing, or in small groups; I use several of Kimberly Tanner's techniques for creating equitable learning environments [8].

The Support System

A challenging experience can easily become alienating if it is not presented mindfully and accompanied with abundant support. We do not shy away from the emotional side of this work. A career in mathematics requires balancing long periods of frustration with (sometimes too brief) moments of great joy, and students find it surprising and beneficial to learn that they are not the only ones struggling with that balance. Readings and discussions on the psychology of mathematics and science [7], [9], growth mindset [4], stereotype threat [6], and impostor syndrome [3] have been helpful.

At SFSU we collaborate with initiatives like SF BUILD, which works to create inclusive and supportive research environments across six science departments, and the Mathematistas student group for women in math, which builds community in our department through many informal activities. Outside SFSU we benefit from interacting with organizations such as SACNAS, the Math Alliance, USTARS, and Latin@s in Math.

We are aware that the crucial work of supporting students traditionally falls disproportionately on women and people of color [12]. We make every attempt to counter that tendency.

People Rise to High Expectations

Many of my students from marginalized groups have been told, often by well-meaning professors in positions of power over them, that they cannot do something or that they are not good enough to be mathematicians. I **never** say this to a student. I cannot possibly know that.[7]

I have worked with students whose mathematical potential is not immediately apparent to me, but I know they are here for a reason. My approach is to always treat them with respect, give them an intriguing project that suits their experience and interests, and support them along the way; I have seen most of them rise to that challenge.

[7] *Upon meeting Endre Szemerédi, Israel Gelfand told him, "Just try to find another profession; there are plenty in the world where you may be successful"* [5]. *Szemerédi went on to write his PhD thesis under Gelfand and win the 2012 Abel Prize.*

Figure 8. Celebrating Anastasia Chavez and Nicole Yamzon's new theorem on the Dehn–Sommerville relations, Carolina Benedetti's visit to San Francisco, and Nicole's birthday. L to R: Ardila-Mantilla, Chavez, Yamzon, Benedetti.

Unconscious Bias and Discrimination

The mathematical society at large is relatively homogeneous, and students who do not fit neatly within its dominant cultures are often faced with unspoken but real obstacles. This is especially true for many underrepresented minorities, women and gender minorities, parents, disabled, low-income, first-generation, and returning students among others. On a professional level, these students face skepticism, and their work is undervalued by professors and peers. On a personal level, many feel pressured to leave their true selves at the door to try to fit in.

These are deep problems that we are far from solving. When they do arise, we talk about them openly, learn from them, and try to improve. We also emphasize that this is not just a problem for marginalized groups to address; every member of the mathematical society plays a role.

The Bigger Picture

The SFSU-Colombia Combinatorics Initiative tries to instill an awareness of the tremendous power that mathematicians hold in today's society and a collective belief in using our part of that power to do positive work. Individuals get to decide what this means for them, whether or not they pursue careers in mathematics. For many of them it means planting the seeds for the next generation of scientists in their communities. Today's uneven representation in mathematics is largely, though not exclusively, a consequence of the uneven access to opportunities before students arrive in our college classrooms. Several of our students and alumni are doing powerful work with young people at various stages of their education. We are slowly integrating their initiatives through a network of mentorship that everyone contributes to and benefits from.

In Colombia several participants in the initiative supervise undergraduate research projects and lead math olympiad programs. Others partner with the Clubes de Ciencia Colombia and the interactive science museum Parque Explora; thanks to them, ECCO 2016 included a week-long workshop for students in Medellín public schools and a public math talk featuring the students' work that was broadcast by television and internet stream.[8]

In the United States participants direct the San Francisco Math Circles, making great efforts to reach the (88 percent ethnic minority) populations of the San Francisco Unified School District. Through the GK-12 program, fifty PhD-bound students spent ten hours a week supporting the mathematics departments of various local public high schools. Other alumni teach mathematics full-time in local community colleges and high schools; the school district claims that 70 percent of its teachers have received training at SFSU.

I am inspired to be surrounded by a family of mathematicians who are doing extremely interesting mathematics and see themselves as agents of change in our scientific culture and in our societies. We are working hard to train the next generation of scientists—a diverse, engaged, dynamic community that works to serve the needs of all—and we are having a lot of fun in the process.

Figure 9. Members and friends of the SFSU-Colombia combinatorics community in Medellín, Colombia.

More Information

Our webpage, containing additional information and resources, can be found at:

`math.sfsu.edu/federico/sfsucolombia.html`

Acknowledgments

I thank the AMS Committee on Education, AMS president Robert Bryant, and the editors of the *Notices of the AMS* for inviting me to organize and share my ideas around a topic that is very challenging to me, partly because it is also very personal to me.

I am just one of many people doing this work at San Francisco State University and in Colombia. I am indebted to my colleagues for their invaluable support of this project. This work has also been supported by the NSF CAREER Award DMS-0956178, the NSF Combinatorics Grants DMS-0801075 and DMS-1600609, and the NIH SF BUILD grant 5UL1GM118985-03.

If I have learned one thing, it is that I still have a lot to learn. I am extremely grateful to the teachers, colleagues, family members, friends, organizers, and futbolistas who have shaped this initiative; I must mention Natalia Ardila, Matthias Beck, Ben Braun, Dania Cabello, Jeff Duncan-Andrade, Piper Harron, May-Li Khoe, María de Losada, Amparo Mantilla de Ardila, Leticia Márquez-Magaña, Bob Moses, Ali Nesin, Gustavo Salazar, Kimberly Tanner, and Nicole Yamzon. Most importantly, I would like to thank my students, who teach me something new every day and give meaning to my mathematical career.

References

[1] Joan Burrelli, *Academic institutions of minority faculty with science, engineering, and health doctorates*, National Science Foundation InfoBrief, NSF 11-320, October 2011, `www.nsf.gov/statistics/infbrief/nsf11320/`.

[2] Richelle Blair, Ellen E. Kirkman, and James W. Maxwell, *Statistical Abstract of Undergraduate Programs in the Mathematical Sciences in the United States*, American Mathematical Society, 2013.

[3] Pauline Rose Clance and Suzanne Imes, The imposter phenomenon in high achieving women: Dynamics and therapeutic intervention, *Psychotherapy: Theory, Research and Practice* **15** (1978), 241–247.

[4] Carol Dweck, The secret to raising smart kids, *Scientific American Mind* **18** (2007), 36–43.

[5] Martin Raussen and Christian Skau, Interview with Endre Szemerédi, *Notices Amer. Math. Soc.* **60** (2013), 221–231. MR 3060028

[6] Claude Steele, *Whistling Vivaldi: And Other Clues to How Stereotypes Affect Us*, W. W. Norton and Company, New York, 2010.

[7] Martin A. Schwartz, The importance of stupidity in scientific research, *Journal of Cell Science* **121** (2008), 1771.

[8] Kimberly Tanner, Structure matters: Twenty-one teaching strategies to promote student engagement and cultivate classroom equity, *CBE-Life Sciences Education* **12** (2013), 322–331.

[9] William Thurston, On proof and progress in mathematics, *Bull. Amer. Math. Soc.* **30** (1994), 161–177. MR 1249357

[10] United States Census Bureau, `https://www.census.gov/quickfacts/table/PST045215/00`, 2014, accessed June 11, 2016.

[11] William Yslas Vélez, James Maxwell, and Colleen Rose, Report on the 2013–2014 new doctoral recipients, *Notices Amer. Math. Soc.* **62** (2015), 771–781.

[12] Audrey Williams June, The invisible labor of minority professors, *The Chronicle of Higher Education* (November 8, 2015).

Credits

Part of Figure 3 is courtesy of Cesar Ceballos.
Figure 5 is courtesy of May-Li Khoe.
Figure 9 is courtesy of Mark Skandera.
Screen shot image on matroids is courtesy of Jeff Doker.

[8] `livestream.com/ParqueExploraTV/Fisica/videos/127505227`

Colin Adams Interview

Colin Adams is Thomas T. Read Professor of Mathematics at Williams College. He is the author or co-author of many research articles, eight books, and the mathematical humor column "Mathematically Bent," which appears in the *Mathematical Intelligencer*. He is also known for his humorous math plays and for starring in "The Great Pi/e Debate" and "Derivative vs. Integral: The Final Smackdown" together with his colleague Tom Garrity.

DOI: http://dx.doi.org/10.1090/noti1448

***Diaz-Lopez**: When did you know you wanted to be a mathematician?*

Adams: Unlike most people, I found out relatively late in life. When I was a kid I wanted to be a writer, but I ended up getting into MIT and Oberlin, which are very different schools, and my father essentially said, "I'll pay for MIT but I won't pay for Oberlin." So I went to MIT and started out as a philosophy major. But I just couldn't get into philosophy because I would disagree with the professor, and if you disagree with the professor you don't get As. In math there is no such thing as disagreeing with the professor. You are right or you are wrong. I ended up really liking math, but it wasn't until graduate school, when I solved a problem nobody had solved before, that I really fell in love with mathematics. That was the moment when I said, "OK, this is what I am doing for the rest of my life."

***Diaz-Lopez**: Who encouraged or inspired you?*

Adams: It's interesting because it's related to what I just said. I was taking a graduate seminar at the University of Wisconsin and I was trying to decide if I wanted to work with Jim Cannon (who later became my advisor) or a different faculty member. One day in the seminar Cannon said, "I will give five dollars to the first person who finds the hyperbolic volume of the 5_2 knot." At the time the hyperbolic volume of only one knot was known (the figure 8 knot) and the 5_2 knot was the next knot in the table. I was a starving graduate student so I said, "Ok, I'm going to get those five dollars." I spent the next month trying to solve this problem, and I couldn't solve it. After a month I started to think, "Okay, five dollars is not worth it anymore," but I kept working at it. There was a postdoc who was in the seminar, Dennis Stowe, who actually solved the problem. I was crushed when I heard he had solved it, but when he presented his proof I realized what I had been doing wrong. The interesting thing is that his method only worked on that one knot, but I fixed my method and it worked on all the rest of the knots in the table. So he got the five dollars but I got a PhD, so I thought that was a pretty good deal.

***Diaz-Lopez**: How would you describe your research to a graduate student?*

Adams: I work in two areas and the intersection between the two, namely I work in knot theory and hyperbolic 3-manifolds. Knot theory is very tangible and very easy to describe in terms of knotted circles sitting in space, how

I came in on the ground floor of hyperbolic 3-manifolds, right after Thurston invented the field

they are related to each other, and the different ways to tell them apart. Hyperbolic 3-manifolds is an area where you have 3-dimensional manifolds with a metric of constant curvature -1. It turns out when a manifold has such constant curvature there is a theorem called the Mostow rigidity theorem, which says that there is only one possible metric on the manifold. Therefore, you can associate a volume to the manifold and make calculations. I was very lucky to come into the intersection of both topics, and since then I've worked in both areas. It has been a really exciting time because I came in on the ground floor of hyperbolic 3-manifolds, right after Bill Thurston invented the field. There were many problems to work on, and to this day it is still a really exciting field. Thurston conjectured (and Perelman later proved) that 3-manifolds can be cut up into pieces that come in eight varieties. One of those varieties is hyperbolic. All manifolds in the other seven classes have been classified. So all the excitement is in the eighth category, hyperbolic manifolds. That made it a really great area to be in.

Diaz-Lopez: *What theorem are you most proud of and what was the most important idea that led to this breakthrough?*

Adams: Let me tell you about the theorem I didn't get, which would have been my favorite if I would have gotten it. It was conjectured for many years that the figure 8 knot has the smallest hyperbolic volume among all knots, in fact among all cusped hyperbolic 3-manifolds. I really wanted to prove that theorem, and I spent fifteen years working on it. Eventually somebody else got it, Robert Meyerhoff and Chun Cao [Inventiones, 2001]. That was difficult, but a lot of the ideas and things I learned in the process of trying to prove that theorem allowed me to prove many other theorems; so in the end it actually worked out fine.

Colin with students in the knot theory group of SMALL, 2013, now all in graduate school (Michigan, Georgia Tech, Brown, Princeton, MIT, Duke, and Stanford).

And they used some ideas that I had come up with in order to prove the result.

Diaz-Lopez: *All mathematicians feel discouraged occasionally. How do you deal with discouragement?*

Adams: As long as you are excited about the problems you are working on, even when you feel you are not making any forward progress, you can't help but think about the problem. Eventually the results come. It's hard to come to that realization in the beginning of your career because you haven't yet had enough times when that has happened. But as you go on and it happens to you more and more, you become more confident in the fact that it will happen, even if it's not happening now. Eventually you may not solve the problem you set out to solve, but you will solve some other problem instead that is related to the problem you set out to solve.

Adams' "cousin," Sir Randolph Bacon III, gives a talk, "Blown Away: What Knot To Do When Sailing."

Which brings up another important point. Don't assume you pick a problem and you solve that problem. More often what happens is you pick a problem and you try to solve that problem and it doesn't work, but then you think of all these related things and you solve those instead.

Diaz-Lopez: *You have won several honors and awards. Which one has been the most meaningful and why?*

Adams: One I was really pleased by is the Robert Foster Cherry Teaching Award, because that's an award that's not just for math; it's a general award for someone in academics in the English-speaking world. It was an honor to have people beyond the mathematical community saying, "Wow this is interesting stuff that this person is doing." It was very nice.

Diaz-Lopez: *Apart from your mathematics you are well known for your humorous plays and articles. How did you get involved in such things?*

Adams: That actually goes all the way back to what I said before about wanting to be a writer when I was a kid. I didn't want to be a mathematician, but as I mentioned before, math won out. But then, when I came to Williams I started writing again, and I actually published my first story in the Williams Literary Review. I had so much fun doing it. So, I started to think, "What can I write about humorous mathematics?" It turns out that math humor is a niche market. There isn't a lot of competition. I could not succeed in the humor market but in the math humor market I had a shot. So I started writing math humor, and I got *always have some mathematical project to think about*

very lucky. I met Ina Mette, who was one of the editors at Springer at the time (and is now at the AMS), and I asked her, "Could I publish a book on this?" She said, "Why don't you start a math humor column in the *Mathematical Intelligencer*?" I started doing that, and then I started turning those columns into scripts, and then I started putting on productions. It has really been fun. For me this is my hobby. I work all day on math, and then I come home and I get to work on the expository fun stuff, so it's a good way to break up the day.

Diaz-Lopez: *You have given over 300 presentations, published over fifty papers, refereed for numerous journals, published eight books, and run a research program every summer. Given your many commitments, what techniques do you use to manage your time?*

Adams: Rule number one for me is that I don't watch TV, so when I go home at night the things you mentioned are what I do for fun. And it works for me because I enjoy them. I can get my teaching, research, and administrative commitments done during the day, and then I have time to do the fun stuff in the evenings. And that's the reason I do so many different things. For me it's fun to do different things; if I had to do just one thing I would burn out and be frustrated. Being able to switch gears a lot has helped to be more productive.

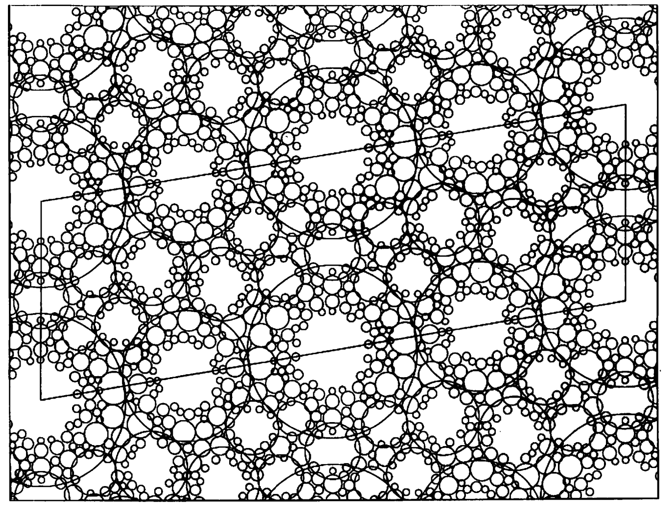
Diaz-Lopez: *If you could recommend one book to graduate students, what would it be?*

Adams: For people interested in knot theory, there is a book for graduate students that to me was really transformative: Knots and Links by Dale Rolfson. It has been around a while now but it's still an amazing book, and it has been a resource for me for many years.

Diaz-Lopez: *What advice do you have for graduate students?*

Adams: When I was near the end of my grad career, I went to my first research conference and met Joel Hass. He had graduated a couple of years ahead of me (from a different school), and one of the things he said to me that was really useful was, "Don't worry if you go to talks and you don't understand much of anything. Don't worry about it, it's okay. Many of the people in the room don't understand what's going on. Just let it wash over you, and after you let it wash over you enough times, eventually it starts to make sense." My advice is: don't feel like you are the only one in the room who doesn't understand what's going on. You are not. There are many people in the room who don't follow what is going on. You get the impression everyone does, because the ones who speak up and ask questions all do. But they are the experts in the area. If you see the speaker speak enough times, eventually it will make sense. So don't be intimidated by the fact that you don't grasp it all at the beginning.

Second, always have some mathematical project to think about. The most fruitful place for me to think about math is when I am at a conference in a talk that I don't understand. At some point I might give up on the talk, but I can't leave, so I think about mathematics.



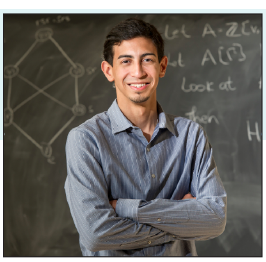
Because the complement of the 5_2 knot has a hyperbolic structure, maximal neighborhoods of the knot correspond to infinitely many tangent horoballs in hyperbolic space. In general, horoball diagrams can expose information about the symmetries, volumes, and other typical features of knots.

Credits

Photos of Colin Adams and Colin Adams with students are courtesy of Alexa Adams.

Photo of Colin Adams as Sir Randolph Bacon III is courtesy of Frank Morgan.

Horoball diagram was created by Jeffrey Weeks using SnapPea.



Alexander Diaz-Lopez, having earned his PhD at the University of Notre Dame, is now visiting assistant professor at Swarthmore College. Diaz-Lopez was the first graduate student member of the *Notices* Editorial Board.

WHAT IS...

a Blender?

Ch. Bonatti, S. Crovisier, L. J. Díaz, A. Wilkinson

Communicated by Cesar E. Silva

A blender is a compact, invariant set on which a diffeomorphism has a certain behavior. This behavior forces topologically "thin" sets to intersect in a robust way, producing rich dynamics. The term "blender" describes its function: to blend together stable and unstable manifolds. Blenders have been used to construct diffeomorphisms with surprising properties and have played an important role in the classification of smooth dynamical systems.

One of the original applications of blenders is also one of the more striking. A diffeomorphism g of a compact manifold is *robustly transitive* if there exists a point x whose orbit $\{g^n(x) : n \geq 0\}$ is dense in the manifold, and moreover this property persists when g is slightly perturbed. Until the 1990s there were no known robustly transitive diffeomorphisms in the isotopy class of the identity map on any manifold. Bonatti and Díaz (*Ann. of Math.*, 1996)[1] used blenders to construct robustly transitive diffeomorphisms as perturbations of the identity map on certain 3-manifolds.

To construct a blender one typically starts with a *proto-blender*; an example is the map f pictured in Figure 1. The function f maps each of the two rectangles, R_1 and R_2, affinely onto the square S and has the property that the vertical projections of R_1 and R_2 onto the horizontal direction overlap. Each rectangle contains a unique fixed point for f.

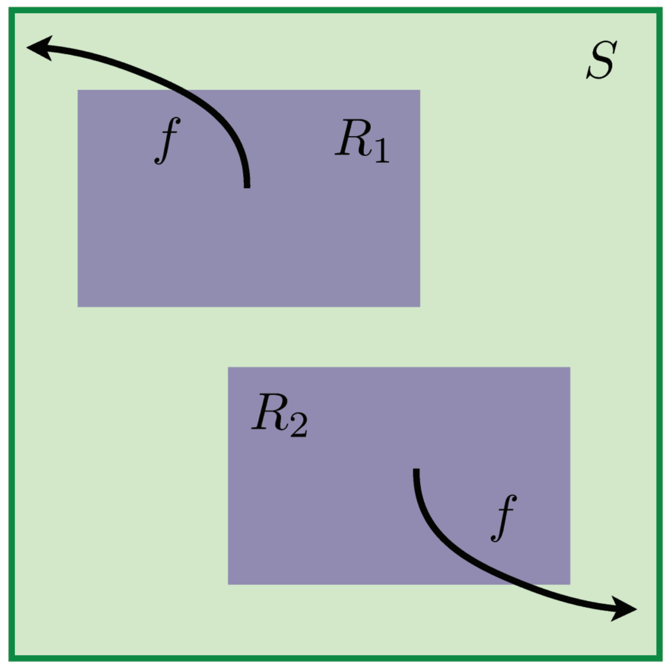


Figure 1. An example of a proto-blender. The map f is defined on the union of the two rectangles, R_1 and R_2, in the square S; f sends each R_i onto the entire square S affinely, respecting the horizontal and vertical directions, with the horizontal expansion factor less than 2. Note that f fixes a unique point in each rectangle R_i.

The compact set $\Omega = \bigcap_{n\geq 0} f^{-n}S$ is f-invariant, meaning $f(\Omega) = \Omega$, and is characterized as the set of points in S on which f can be iterated infinitely many times: $x \in \Omega$ if and only if $f^n(x) \in S$ for all $n \geq 0$. Ω is a Cantor set, obtained by intersecting all preimages $f^{-i}(S)$ of the square, which nest in a regular pattern, as in Figure 2.

Any vertical line ℓ between the fixed points in R_1 and in R_2 will meet Ω. To prove this, it is enough to see that for every i the vertical projection of the set $f^{-i}(S)$ (consisting

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[1] *This is also where the term "blender" was coined.*

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DOI: http://dx.doi.org/10.1090/noti1438

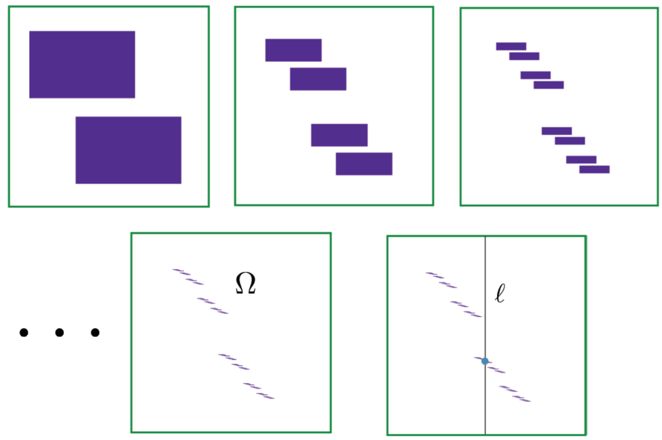

Figure 2. The invariant Cantor set Ω produced by the proto-blender f is the nested intersection of preimages of S under f. Any vertical line segment ℓ close to the center of the square intersects Ω in at least one point. The line segment can be replaced by a segment with nearly vertical slope or even a smooth curve nearly tangent to the vertical direction.

of 2^i horizontal rectangles) onto the horizontal is an interval. This can be checked inductively, observing that the projection of $f^{-i-1}(S)$ is the union of two rescaled copies of the projection of $f^{-i}(S)$, which overlap.

A more careful inspection of this proof reveals that the intersection is *robust* in two senses: First, the line ℓ can be replaced by a line whose slope is close to vertical or even by a C^1 curve whose tangent vectors are close to vertical; second, the map f can be replaced by any C^1 map $\hat{f}$ whose derivative is close to that of f. Such an $\hat{f}$ is called a *perturbation* of f.

The (topological) dimension of the Cantor set Ω is 0, the dimension of ℓ is 1, the dimension of the square is 2, and $0+1<2$. From a topological point of view, one would not expect these sets to intersect each other. But from a

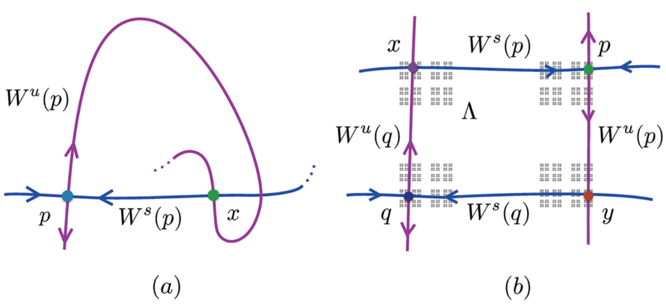

Figure 3. (a) A transverse homoclinic intersection of stable and unstable manifolds, first discovered by Poincaré in his study of the 3-body problem. (b) A horseshoe Λ produced by a pair of transverse heteroclinic points x and y. Every point in the Cantor set Λ can be approximated arbitrarily well both by a periodic point and by a point whose orbit is dense in Λ.

metric point of view, the fractal set Ω, when viewed along nearly vertical directions, appears to be 1-dimensional, allowing Ω to intersect a vertical line robustly. If the rectangles R_1 and R_2 had disjoint projections, the proto-blender property would be destroyed.

This type of picture is embedded in a variety of smooth dynamical systems, where it is a robust mechanism for chaos. The search for robust mechanisms for chaotic dynamics has a long history, tracing back to Henri Poincaré's discovery of chaotic motion in the three-body problem of celestial mechanics. Figure 3(a) depicts the mechanism behind Poincaré's discovery, a local diffeomorphism of the plane with a saddle fixed point p and another point x whose orbit converges to p both under forward and backward iterations (that is, under both the map and its inverse). Meeting at p are two smooth curves $W^s(p)$ and $W^u(p)$, the *stable and unstable manifolds* at p, respectively. $W^s(p)$ is the set of points whose forward orbit converges to p, and $W^u(p)$ is the set of points whose backward orbit converges to p.

In Figure 3(a), the intersection of $W^s(p)$ and $W^u(p)$ is *transverse* at x: the tangent directions to $W^s(p)$ and $W^u(p)$ at x span the set of all directions emanating from x—the tangent space at x to the ambient manifold, in this case the plane. The point x is called a *transverse homoclinic point* for p. In Figure 3(b) a slight variation is depicted: here there are two periodic saddles, p and q, such that $W^s(p)$ and $W^u(q)$ intersect transversely at a point x, and $W^u(p)$ and $W^s(q)$ intersect transversely at another point y. The points x and y are called *transverse heteroclinic points*, and they are arranged in a *transverse heteroclinic cycle*.

In the classification of the so-called *Axiom A diffeomorphisms*, carried out by Stephen Smale in the 1960s, transverse homoclinic and heteroclinic points play a central role. Any transverse homoclinic point or heteroclinic cycle for a diffeomorphism is contained in a special Cantor set Λ called a *horseshoe*, an invariant compact set with strongly chaotic (or unpredictable) dynamical properties (see [2] for a discussion). Two notable properties of a horseshoe Λ are:

(1) Every point in Λ can be approximated arbitrarily well by a periodic point in Λ.
(2) There is a point in Λ whose orbit is dense in Λ.

Horseshoes and periodic saddles are both examples of *hyperbolic sets*: a compact invariant set Λ for a diffeomorphism g is hyperbolic if at every point in Λ there are transverse stable and unstable manifolds $W^s(x)$ and $W^u(x)$ with $g(W^s(x)) = W^s(g(x))$ and $g(W^u(x)) = W^u(g(x))$. For a large class of diffeomorphisms known as Axiom A systems, Smale proved that the set of recurrent points can be decomposed into a disjoint union of finitely many hyperbolic sets on which (1) and (2) above hold. This theory relies on the most basic property of transverse intersections, first investigated by René Thom: robustness. A transverse intersection of submanifolds cannot be destroyed by a small perturbation of the manifolds; in the dynamical setting, a transverse intersection of stable and

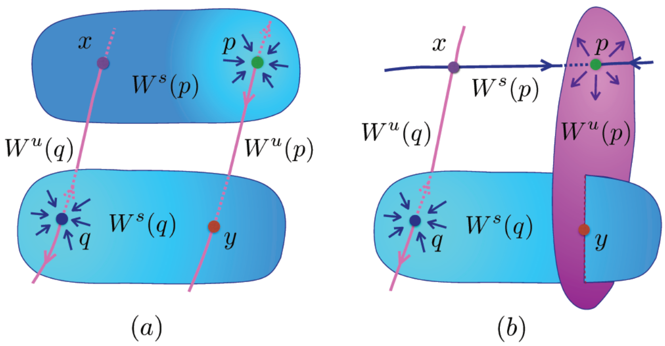

Figure 4. (a) Transverse cycle. (b) Nontransverse cycle.

unstable manifolds of two saddles cannot be destroyed by perturbing the diffeomorphism.

Classifying Axiom A systems was just the beginning. To illustrate the limitations of the existing theory, Abraham and Smale constructed diffeomorphisms that are *robustly nonhyperbolic*. These examples opened up the door for understanding a broader class of dynamics, and blenders have turned out to be a key player in this emerging classification.

Before constructing blenders and robust nonhyperbolic dynamics, we first illustrate (nonrobust) dynamics of *nonhyperbolic* type. To do so, let's return to our example of two periodic saddles p and q, but this time in dimension 3, where saddle points can have stable and unstable manifolds of dimension either 1 or 2. Suppose p and q are two fixed points in dimension 3 whose stable and unstable manifolds intersect. If, as in Figure 4(a), the stable manifolds of p and q have the same dimension, then both intersections can be transverse,[1] producing a horseshoe.

But quite another thing happens if the dimensions of the stable manifolds do not match up: the intersection between the 2-dimensional manifolds may be transverse, but the other, between 1-dimensional manifolds, is *never* transverse and thus cannot be robust. In the case depicted in Figure 4(b), the orbit of the point x accumulates on q in the past and on p in the future. The point x cannot be contained in a hyperbolic set, because $W^s(p)$ and $W^s(q)$ have different dimensions. On the other hand, this nonhyperbolicity is not robust, because this nontransverse intersection is easily destroyed by perturbation.

To obtain a robustly nonhyperbolic example, we will replace the point q in Figure 4(b) by a cube Q containing a special type of horseshoe Λ called a blender. To produce Λ, we use the proto-blender $f : R_1 \cup R_2 \to S$ of Figure 1. The map f has only expanding directions and is not injective; indeed, it has precisely two inverse branches, $f_1^{-1} : S \to R_1$ and $f_2^{-1} : S \to R_2$. In dimension three, we can embed these inverse branches into a local diffeomorphism by adding a third, expanded direction, as detailed in Figure 5, where the cube Q is stretched and folded across itself by a local diffeomorphism g.

The horseshoe Λ in Figure 5 is precisely the set of points whose orbits remain in the future and in the past in Q. The set $W^u(\Lambda)$ of points in the cube that accumulate on Λ in the past is the cartesian product of the Cantor set Ω with segments parallel to the third, expanded direction. $W^u(\Lambda)$ is the analogue of the unstable manifold of a saddle, but it is a fractal object rather than a smooth submanifold.

The set Λ is an example of a blender, and its main geometric property is that any vertical curve crossing Q close enough to the center intersects $W^u(\Lambda)$. In other words, this blender is a horseshoe whose unstable set behaves like a surface even though its topological dimension is one. This property is robust. While the definition of blender is still evolving as new constructions arise, a working definition is: *A blender is a compact hyperbolic set whose unstable set has dimension strictly less than one would predict by looking at its intersection with families of submanifolds.*

Figure 6 illustrates robust nonhyperbolic dynamics produced by combining Figure 4(b) with a blender. The connection between the stable manifold of p and $W^u(\Lambda)$ cannot be destroyed by perturbation, and the transverse intersection between the unstable manifold of p and the stable manifold of a point $z \in \Lambda$ is also robust. The orbit of the point z is contained in a compact invariant set with

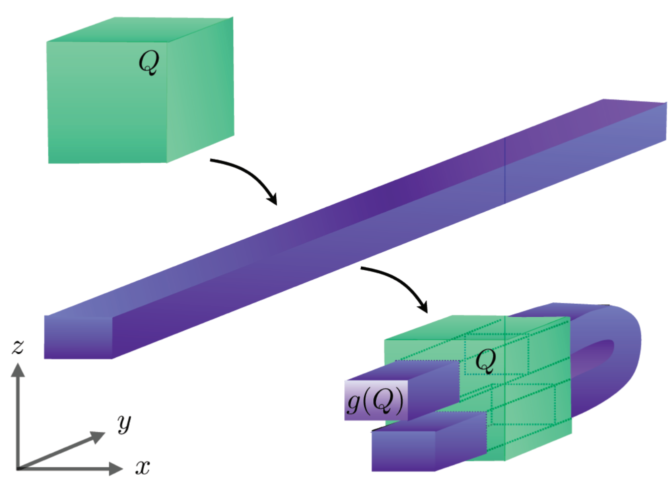

Figure 5. Constructing a blender, a type of horseshoe with a proto-blender built into its contracting directions. In the cube Q the local diffeomorphism g contracts the segments in the axial directions parallel to the front face (the xz-plane), elongates the cube into the third axial direction (the y-axis), and then folds this elongated piece across the original cube Q, as pictured. Each slice of $Q \cap g(Q)$ parallel to the xz-plane resembles exactly the picture of $R_1 \cup R_2$ in the square S. The restriction of g^{-1} to these rectangles in this slice is just a copy of the proto-blender f from Figure 1, whose image is another xz-slice of Q.

[1] *The intersections are generically transverse in this case, a consequence of the Kupka-Smale Theorem.*

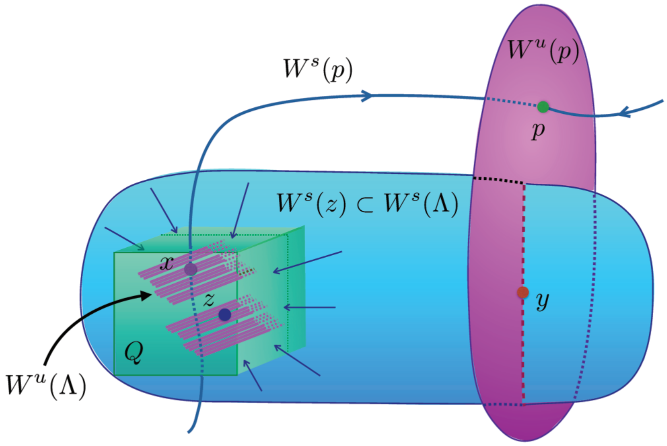

Figure 6. Replacing the periodic point q in Figure 4(b) with a cube Q containing the blender of Figure 5. The orbits of the points x and y accumulate both on the saddle p and the blender horseshoe Λ, producing an invariant subset of the dynamics with complicated, nonhyperbolic behavior.

complicated dynamics, in particular satisfying property (1) above.

Blenders are not just a tool to produce robust nonhyperbolic dynamics; they are in fact one of the two conjectured mechanisms responsible for robust nonhyperbolicity, the other being homoclinic tangencies. This is because, in contrast to the original Abraham-Smale construction, blenders appear in a natural way in local bifurcations. Indeed, whenever a diffeomorphism has two saddles p and q with different stable dimensions and they are dynamically related as in Figure 4(b), there is a perturbation that produces a blender.

Further Reading

[1] Christian Bonatti, Lorenzo Díaz and Marcelo Viana, *Dynamics beyond Uniform Hyperbolicity: A Global Geometric and Probabilistic Perspective*, Encyclopedia Math. Sci., 102, Springer, 2005. MR 2105774

[2] Michael Shub, “WHAT IS…a horseshoe?” *Notices Amer. Math. Soc.* **52** (2005), no. 5, 516–517. MR 2140094

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Photo of Amie Wilkinson, courtesy of the Institute for Pure and Applied Mathematics.

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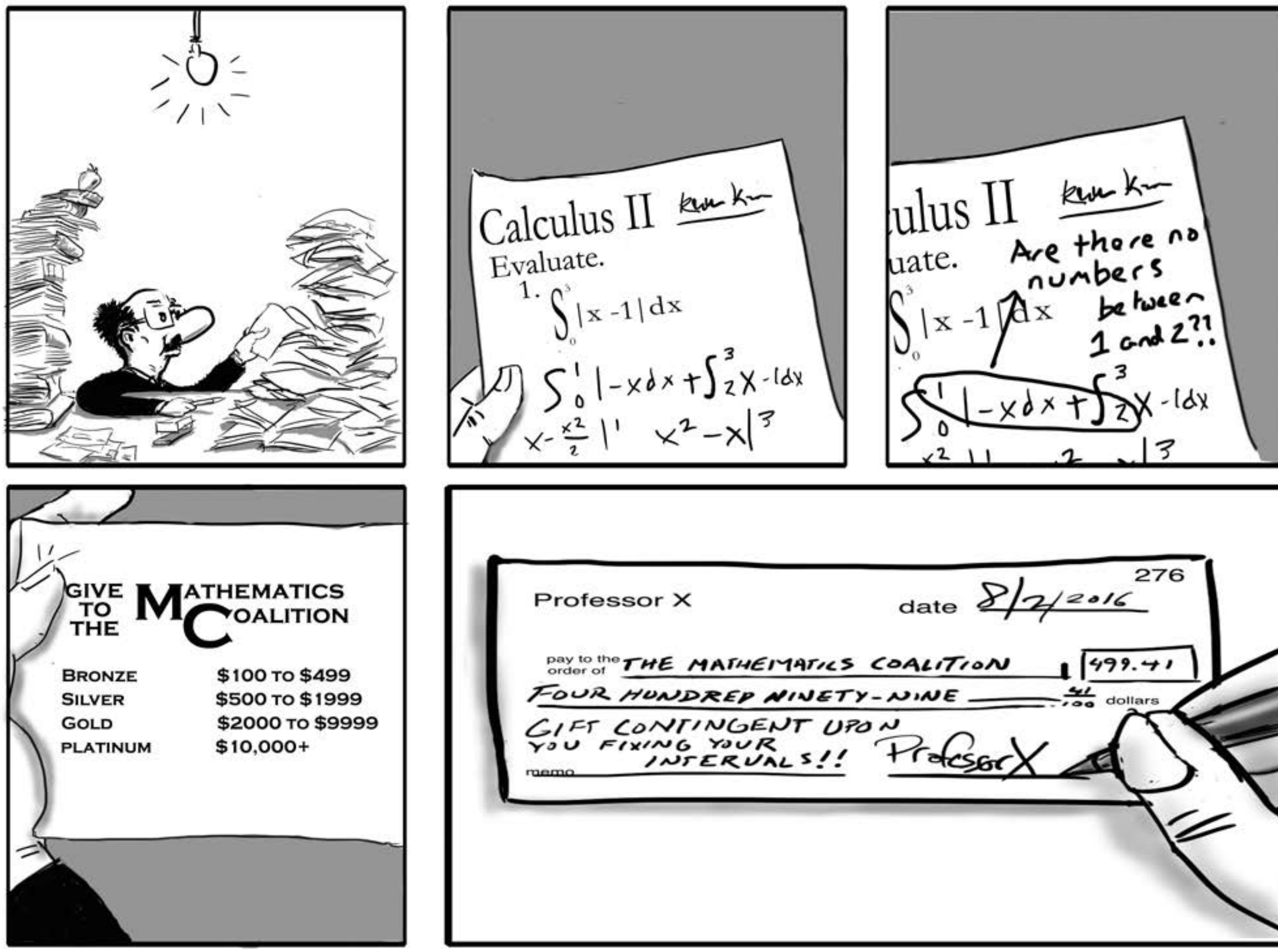
Amie Wilkinson

THE BACK PAGE

"Don't assume you pick a problem and you solve the problem. More often what happens is you pick a problem and you try to solve that problem and it doesn't work, but then you think of all these related things and you solve those instead."

—Colin Adams, Graduate Student Section interview, page 1172.

Fix Your Intervals



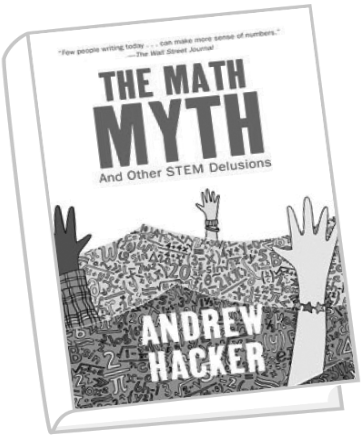
Concept by Katharine Merow.
Artwork by Sam White.

QUESTIONABLE MATHEMATICS

"But if the UK leaves, we will have this risk squared."

—Emmanuel Macron, France's economy minister, as noted by John M. Sullivan

What crazy things happen to you? Readers are invited to submit original short amusing stories, math jokes, cartoons, and other material to: `noti-backpage@ams.org`.



The Math Myth and Other STEM Delusions

A Review by David M. Bressoud

The Math Myth and Other STEM Delusions
Andrew Hacker
The New Press, 2016
US$15.57, 240 pages
Hardcover ISBN-13: 978-1-6209-7068-3

While there is much to dislike about Andrew Hacker's book, it is too easy, especially for the audience of these *Notices*, to dismiss it and ignore the underlying issues. This book and similar attacks on the role of algebra arise from real structural problems within mathematics education.

The fundamental problem is that the general population has a very poor conception of mathematics. Hacker plays on this by identifying algebra with words that sound scary: "azimuths and asymptotes" and "radical notations and elliptical equations." Building on painful memories of drill in rote procedures that made no sense, he finds a ready audience for his message that this is all a great conspiracy of the "math mandarins," those research mathematicians at top-tier universities who are subjecting the general population to their distorted view of what a proper education should be.

Issues of Access

After his chapter "Will plumbers need polynomials?" Hacker gives an unattributed quote that is quite insightful: "In other nations, such as Germany and Switzerland, it would be absurd to say that all sixteen-year-olds should have to learn the same stuff." It would be, because the European expectation is that university education is reserved for the elite. Their secondary schools distinguish between those they are preparing for university and those who receive skills training that prepares them for employment but blocks them from access to universities. Post-World War II, the American belief has been that university education should be available to all. A corollary of this belief is that everyone should enroll in the courses that will enable further study.

Hacker wants it all. He wants to see secondary programs that focus on targeted workplace skills while preparing everyone for postsecondary education. I am not willing to claim that this is a circle that cannot be squared, but building such an educational system is going to be far harder than he implies. The sad fact is that for many of our students our educational system delivers neither.

The blame cannot be placed entirely at the foot of mathematics. While over 60 percent of entering community college students need remediation in mathematics, about half of these also need remediation in reading, a far more serious impediment. Nevertheless, mathematics is a stumbling block for many students who could otherwise succeed. What high school mathematics do they really need?

This is an important question that requires a thoughtful response. On page 8, Hacker admits that "basic algebra is definitely necessary for everyone." Where he draws the line is at what he calls "advanced algebra," which is, in fact, Algebra 2. According to the Common Core State Standards for Mathematics, this is the course where, among other skills, students are expected to learn to perform arithmetic operations on polynomials and understand the connections between their zeros and factors; construct and compare linear, quadratic, and exponential models; understand the general role of functions in modeling a

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DOI: http://dx.doi.org/10.1090/noti1442

relationship between two quantities; and come to see trigonometric functions as models of periodic phenomena. These are all useful understandings, even for plumbers, and essential for those who would seek a STEM career.

Part of the problem is that a student's experience of high school mathematics is so often built on a poor comprehension of any mathematics. Mark Green has reflected on this problem in words that express my own ambivalence:

> You have a danger of people being limited throughout their lives by what math they got early on—or didn't. There's a lot of stuff that uses Algebra 2, and students who don't take it may be unaware that they are limiting their options later on. On the other hand, it's much better to have someone who genuinely understands modeling and quantitative reasoning and has a feeling for statistics than someone who took an Algebra 2 class but is totally bewildered by it. [1, p. 20]

The best solution seems to be an expectation that all students should take Algebra 2, combined with serious work to ensure that it is a meaningful experience, while recognizing that there will be students for whom an alternative would be more useful and merciful. It is in how we can make Algebra 2 more meaningful that I have my most violent disagreement with Hacker. He has totally mischaracterized the Common Core State Standards for Mathematics.

The True Core of the Common Core

Hacker presents the Common Core as a rigid set of lesson plans. In reality, the Common Core is not even a curriculum. It is a set of standards, a description of what students should understand and be capable of doing by the end of each grade through middle school. It is based on the best research available in mathematics education to determine what skills and abilities should be mastered by what grade if students are to be prepared for the next set of challenges and to stay on track to have completed Algebra 2 by the end of grade 12.

It is a framework that emphasizes flexibility. Nowhere is this clearer than in its treatment of high school mathematics, which is not laid out hierarchically. Common Core describes big domains of high school mathematics—Number and Quantity, Algebra, Functions, Modeling, Geometry, and Statistics and Probability—and then leaves it to the districts to figure out how to structure this instruction. The emphasis is not on a list of topics but on what it means to do mathematics. Absolutely essential are the Practice Standards: making sense of problems and persevering in solving them, reasoning abstractly and quantitatively, constructing viable arguments and criticizing those of others, modeling, using tools strategically, attending to precision, looking for and using structure, and looking for and expressing regularity in repeated reasoning. I cannot imagine that any of these are characteristics Hacker would not wish for his own numeracy course. It is because of this flexibility and recognition of what is truly essential that the National Council of Teachers of Mathematics, the professional society of and for pre K–12 teachers of mathematics, has so strongly endorsed and supported the Common Core.

This is not to say that the Common Core is without problems. Standards are useless without a means of assessing whether you are meeting them, hence the development of two national tests: Smarter Balanced and PARCC. Having worked for six years on the AP Calculus exams, I know how difficult it is even in that tightly constrained situation to come up with good questions that meaningfully assess student knowledge and abilities. To try to accomplish this across the varied scene of our national public education while honestly measuring student capabilities under the practice standards of the Common Core is nigh impossible.

I hate to see Smarter Balanced or PARCC used for high-stakes testing. That puts unneeded pressure on teachers and invites the very practice Common Core is trying to avoid, a mentality of drilling for the test. However, we will not be able to determine how effectively this program is being implemented without some form of accountability. Finding the right balance is one of the places where bright minds, patience, and nuance are required. Populist cries that Common Core is a big government (or big business) takeover of public education are not helpful.

Quantitative Literacy, a Point of Convergence

I now come to the place where I am closest to agreeing with Hacker, the question of what mathematics should be required at the postsecondary level. There is little point in forcing college students to retread the landscape of confusion that they left in high school unless these are skills and abilities needed for their chosen careers. I am proud that I was instrumental in the development of a successful quantitative literacy program at Macalester College for which the only mathematics course that fully satisfies this requirement is one in statistical modeling with emphasis on exploration and interpretation of real data. Quantitative literacy, or numeracy, is helpful for all students and may be our final opportunity to demonstrate that mathematics can make sense and be useful.

Hacker and I share an admiration for Lynn Steen and all that he has done to promote quantitative literacy, but there is one line of argument that Hacker picks up from Steen and then distorts beyond all recognition. In *Achieving Quantitative Literacy: An Urgent Challenge for Higher Education* [5], Steen expands on the problems inherent in an expectation that all students should be pushed down a track that is heading toward calculus. He despairs of the reluctance of many university mathematics departments to ease up on a graduation requirement of college algebra and places the blame on a select group of research mathematicians who insist that everyone should be "calculus-intending."

There is an enormous difference between desiring to see all students learn and appreciate the modeling power inherent in the tools of Algebra 2—which, after all, is an eleventh-grade course for nonaccelerated students—and requiring all students to continue down the line of college algebra, precalculus, and calculus until they either succeed or run off the rails.

Steen is correct that there have been prominent mathematicians with considerable influence on their departments who have insisted on maintaining traditional requirements, but I see the greatest impediments to changing current practice lying on the high school side of the transition, where they are shaped by societal pressures. Despite the freedom—bordering on encouragement—within the Common Core's high school standards to use an integrated curriculum, which would be better placed to emphasize the practice standards, few districts have adopted this approach. The fault lies with the dominance of traditional curricular materials, the difficulty of getting a teacher corps that is stretched thin and subject to intense scrutiny to shift its instructional practices, and the fear of the public that any movement away from what was done in the past will jeopardize the prospects of their sons and daughters.

The Real Dangers

This is my greatest concern over the possible influence of this book: while it feeds the flames that are devouring the Common Core, our best hope for improving pre K–12 mathematics education, it will do nothing to change the underlying dynamic of what Steen truly and rightly feared, the funneling of everyone toward calculus.

Hacker describes the fraction of high school students who take calculus as "only" 17 percent. From the latest NCES data [4], 19 percent of the class of 2012, or roughly 750,000 students, had completed a course in calculus while in high school. That is huge. Only twice that many, 1.5 million, matriculate each fall as full-time students in a four-year undergraduate program. The numbers of students who take an AP Calculus exam is still growing at 5 percent per year, while the number of those who take it before grade 12 has reached 120,000, growing at almost 9 percent per year [2] (examples of exponential growth that I would hope all Americans could appreciate). Calculus in high school is now the accepted norm for those who intend to go to college. This is not the work of a cabal of "math mandarins." In fact, most mathematicians deplore this trend.

What drives it is the fact that the best single predictor of successful completion of college is enrollment in calculus while in high school [3]. This is only an observation of a high degree of correlation. Nevertheless, in this age of increased competition for access to the best colleges and universities, getting calculus onto one's high school transcript is highly desirable. Those who can accelerate do. Those who cannot but who enroll in calculus when they get to college find themselves, even if they are academically talented, at a considerable disadvantage as they compete against those for whom the material has some familiarity. When this handicap is piled on top of lower socioeconomic status, the obstacles to successful completion of a STEM degree can be enormous.

We live in a time of wide and widening societal inequities. If the mathematics of Algebra 2 is eliminated from the desired accomplishments of a high school graduate, it is not the children of college-educated parents who will take advantage of the easier route this reveals. I am cheered by the honest work of so many research mathematicians who are engaged in improving instruction across all levels while wrestling with the real problems of equity and access. The solutions are not simple. Beware of those who think they are.

The solutions are not simple. Beware of those who think they are.

References

[1] Pamela Burdman, *Degrees of Freedom: Diversifying Math Requirements for College Readiness and Graduation*, Report 1 of a 3-part series from Policy Analysis for California Education, April 2015. www.edpolicyinca.org/publications/degrees-freedom-diversifying-math-requirements-college-readiness-and-graduation-report-1-3-part-series

[2] College Board, *AP Program Summary Reports*. Available at https://research.collegeboard.org/programs/ap/data

[3] Kasey Klepfer and Jim Hul, *High School Rigor and Good Advice: Setting Up Students to Succeed*, Center for Public Education of the National School Boards Association, October 2012. www.centerforpubliceducation.org/Main-Menu/Staffingstudents/High-school-rigor-and-good-advice-Setting-up-students-to-succeed

[4] National Center for Education Statistics, *High School Longitudinal Study of 2009 (HSLS:09)*, Institute of Education Science, US Department of Education. https://nces.ed.gov/surveys/hsls09/

[5] Lynn Arthur Steen, *Achieving Quantitative Literacy: An Urgent Challenge for Higher Education*, MAA Notes #62, Mathematical Association of America, Washington, DC, 2004.

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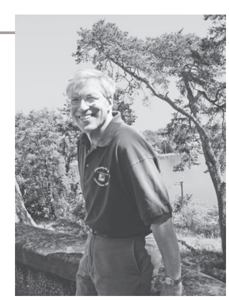
ABOUT THE REVIEWER

David Bressoud is former president of the Mathematical Association of America. In January 2017 he will take over the position of director of the Conference Board of the Mathematical Sciences.



David Bressoud

BOOKSHELF

A man is known by the books he reads. —Emerson

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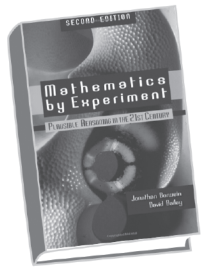
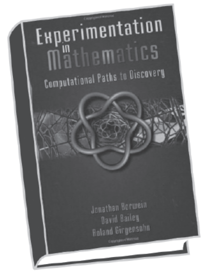
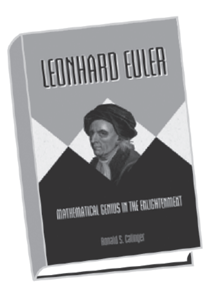
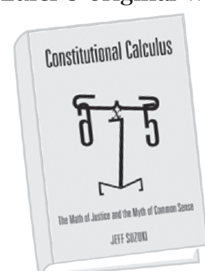




Mathematics by Experiment. Plausible Reasoning for the 21st Century, by Jonathan Borwein and David Bailey (AK Peters/CRC Press, second edition, 2008); *Experiments in Mathematics. Computational Paths to Discovery*, Jonthan Borwein, David Bailey, and Roland Girgensohn (AK Peters/CRC Press, 2004). In memory of Jonathan Borwein, who died on August 2 of this year (see page 1203 of this issue), the BookShelf draws readers' attention to two of his books, which were reviewed together by Jeffrey Shallit in the September 2005 issue of the *Notices*. Borwein was one of the world's most active and ardent proponents of the field of experimental mathematics. These two books "develop the value of [the experimental] approach in grand style," Shallit wrote. The emphasis is on number theory, algebra, and combinatorics, as these are areas where experimental mathematics has been most successful. *Mathematics by Experiment* is the more introductory of the two books and takes a more conversational approach, while *Experiments in Mathematics* is longer and provides more depth and detail. In his review, Shallit cautions against mindless or naive computation, and notes that one must acknowledge the limitations of the experimental approach. Nevertheless, he writes, "experimental mathematics is here to stay. The reader who wants to get an introduction to this exciting approach to doing mathematics can do no better than these interesting books."



Leonhard Euler: Mathematical Genius in the Enlightenment, by Ronald S. Calinger (Princeton University Press, 2015). The seventeenth century was a golden age for mathematics—so much so that at the start of the eighteenth century many believed there was little left in the field to pursue. Euler, who began his prodigiously productive career in St. Petersburg in 1720, showed how wrong that belief was. Calinger writes in the introduction to this new biography of Euler: "Driven by enormous energy, a passion for mathematics and the exact sciences, a commitment to building a strong institutional base for these fields, and an insistent defense of Reform Christianity, Euler diligently pursued an immense research, computational, and writing program across pure and applied mathematics and related technologies from his days in Basel onward except during a few bouts of severe fever." Based largely on original sources, this is the first book ever to treat the whole of Euler's life and his massive research output within the political, cultural, and religious context of his time. Unusually for a work of mathematics history, the book was reviewed in *The Economist*, which called it "an impressive work of scientific biography [that] gives a fascinating portrait of Euler, his work and the world around him." Calinger is the chancellor of The Euler Society, which is dedicated to encouraging scholarship about Euler. Another resource about this iconic mathematician is the Euler Archive (`eulerarchive.maa.org`), an online resource hosted by the Mathematical Association of America, which provides digital access to a library of Euler's original works and to modern Euler scholarship.



Constitutional Calculus: The Math of Justice and the Myth of Common Sense, by Jeff Suzuki (Johns Hopkins University Press, 2015). While social, judicial, and political decisions are often made on the basis of tradition and common sense, *Constitutional Calculus* shows that mathematics can help societies reach better and more just decisions. To make this point, Jeff Suzuki looks at a variety of topics, such as the US census, political gerrymandering, mandatory drug testing, the electoral college, and the surveillance program of the National Security Agency, as well as landmark legal rulings. He shows how mathematics offers powerful analytical tools that lead to greater fairness and better adherence to the ideals of the US Constitution. In a review on the website of the Mathematical Association of America, Charles Aschbacher wrote that his favorite section of the book was the one presenting an economic and statistical analysis of the "three strikes and you're out" legal principle, whereby if one commits three felonies, one goes to jail for life, regardless of the severity of the crimes committed. The book looks at an example in which a man went to prison for life for three instances of what was essentially petty theft. Aschbacher writes that "[Suzuki's] analysis demonstrates that this is a horribly flawed policy, both economically and in [terms of] ruined lives." Reading the book, he says, "was a breath of fresh air. It was a reaffirmation that mathematics should be used more often to make general public policy."

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OPINION

Are Mathematics Faculty Ready for Common Vision?

Marcus Jorgensen

Note: The opinions expressed here are not necessarily those of Notices. *Responses on the* Notices *webpage are invited.*

I find *A Common Vision for the Undergraduate Program in 2025* [1] a remarkable effort on the part of the various national associations with interests in college mathematics education. Tara Holm and Karen Saxe [2] made this comment:

> Change is coming, and the mathematical sciences community must come together to ensure that the change happens coherently and in a mathematically sound way. More mathematicians must become involved, working with colleagues from partner disciplines to modernize curricula and adopt evidence-based active learning strategies in mathematics classrooms. (p. 630)

I worry about colleagues who do not see a need to change or who believe in the traditional algebra for everyone.

I am writing this with a particular emphasis on general education mathematics for college freshmen and for those institutions that require college algebra for nearly all students. College algebra for freshmen has changed little in 150 years. As I look at my collection of nineteenth-century algebra textbooks, they are remarkably similar to what is taught today (with the major exception that they do not cover graphing). The similarity is either a testament to its enduring quality or to our inability to change and adapt to the times. I believe it is the latter, and change will only happen if it is supported by the faculty.

How do we know if the faculty are ready for the types of changes in Common Vision such as alternate pathways for students? Through my research and observations, I have concluded that you can tell how ready a faculty member is for change by asking four questions. These questions get to the heart of some basic tenets and beliefs that show either a willingness or reluctance to change. The questions are whether or not one agrees with the following statements:

- Algebra students should memorize the quadratic formula.
- Intermediate and college algebra have broad relevance in the "real world."
- Algebra, like no other subject, improves the brain's ability to think critically.
- Creating customized undergraduate pathways for students amounts to lowering standards.

Memorizing the Quadratic Formula and the Mathematics Attic

As heretical as this may seem to some, but not all, why do we insist on students memorizing the quadratic formula? Don't get me wrong; I have nothing against memorization. But if we made a prioritized list of information that students should memorize, would this be high on the list? It seems more important that they know what it is, where to find it, and how to use it. Better yet, why not use modern tools to do the quadratic formula calculations?

May I suggest that finding i to the nth power, rationalizing denominators, long division of polynomials, or any number of similar college algebra concepts would not stand the scrutiny of developing a truly modern and relevant curriculum for nonmath majors.

The attic analogy is an important one

I attended an interesting session at the 2012 AMATYC conference presented by a father and son team, Tom and Scott Adamson. The session title was "The Mathematics Attic." They suggested that there are a number of things that we do not use but do not want to throw away either, such as an abacus. So we put them in the mathematics attic. They went on to suggest a number of current items that could probably go into the attic. They asked the audience for other suggestions for the attic, and there was no shortage of ideas.

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DOI: http://dx.doi.org/10.1090/noti1441

The attic analogy is an important one. There are a number of interesting but outdated algebraic topics that we do not want to lose. So we could put them in the attic and bring them out for the mathematics majors to learn and appreciate. All freshmen do not need to see them. A faculty member willing to change is one who is open to consigning classics to the attic.

Relevance

This may not be a popular position with mathematics faculty, but I think that algebra in and of itself and as an end goal is not broadly relevant. By relevant I mean meaningful for a student's major, future employment, decision making in life, or citizenship in a democracy. Of course, there are algebraic skills that are important to follow-on math courses. However, when the traditional college algebra is the final destination, students are deprived of seeing how useful it can be, and they never get to see some other beautiful and relevant mathematics.

Defenders of algebra-for-all tend to cherry-pick algebraic concepts that are easy for students to see in their lives. Once, at a statewide education meeting with dozens of mathematics teachers from higher education institutions in the state, an instructor stood up and interrupted the meeting and said she was tired of everyone picking on mathematics. She asked the speaker, "How did you decide when to get up this morning and get to class on time?" She then added, "That's algebra." She explained that she uses that same example with her students and that algebra is used all the time in real life. She sat down to the loud ovation of her colleagues. I did not clap. While I suppose that example involved some low-level algebra, it seems disingenuous. A student does not simplify complex rational expressions or find the fifth root of a number as a matter of course in real life. Perhaps the most damning evidence against the relevance of algebra is the large proportion of traditional textbook word problems that are contrived and unrealistic.

The world, however, is often not black and white with one correct answer

Algebra and Thinking Critically

If you look for experimental evidence that learning algebra increases a student's ability to think more critically, you will find little. Yes, there is something to be learned by solving equations and problems using rules and logic. However, I can make the case that the traditional curriculum fosters almost the opposite of critical thinking. Students sit and listen to the instructor explain a concept and then get some chance to practice. Then the students are required to mimic that work on a test and try and get the one correct answer. The world, however, is often not black and white with one correct answer; it is complicated.

Secondly, word problems usually include exactly the information a student needs in the solution. Students can often memorize some type of formula, pattern, or algorithm to get the correct answer without really doing much critical thinking. If we really wanted to teach critical thinking, then we should do it intentionally and structure our teaching to encourage that type of thinking.

Some faculty believe there is something inherent about mathematics, and algebra specifically, that helps critical thinking. Faculty who believe in the inherent qualities of algebra without being able to articulate what that specifically means and provide evidence to support it are not ready for Common Vision. I believe that there is a level of numeracy that is vital to critical thinking, but the algebra-heavy, traditional curriculum often leaves that type of learning to chance. Faculty who are ready for change must be able to think critically and specifically about curriculum design and student learning rather than having vague notions of learning outcomes with nothing more than anecdotal supporting evidence.

Pathways and Rigor

An alternative path that does not go through college algebra or even intermediate algebra is seen by some faculty as watering down the curriculum. These faculty believe in the sanctity of algebra and its inherent rigor and benefits. Alternate pathways for them are attempts to weaken the curriculum in an effort to appease administrators and give in to the pressure to improve retention and graduation rates.

It is an interesting assumption that freshman mathematics courses other than algebra are not as rigorous as algebra. I fail to see why that has to be the case. An academic advisor once told me that his answer to students who questioned why they had to take College Algebra was that "you have to eat your broccoli before you eat your steak." In other words, you may not like it and it may be hard to eat, but—trust me—it will be good for you. I do not accept that as justification in itself for a course requirement. Surely there are many academically rigorous and challenging freshman mathematics courses other than College Algebra that are more relevant and stimulate critical thinking. Faculty who have the broccoli mindset are not ready for curricular change.

My hope is that this article can stimulate thinking on some key issues related to faculty beliefs and support of change to the freshman mathematics curriculum.

References

[1] *A Common Vision for the Undergraduate Mathematics Program in 2025: Project Overview for the White House Office of Science and Technology Policy*, January 22, 2015. Retrieved from: www.maa.org/sites/default/files/pdf/common-vision/cv_white_paper.pdf.

[2] T. Holm and K. Saxe, A Common Vision for undergraduate mathematics, *Notices Amer. Math. Soc.*, June/July 2016.

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Photo of Marcus Jorgensen is courtesy of Corey Peel.

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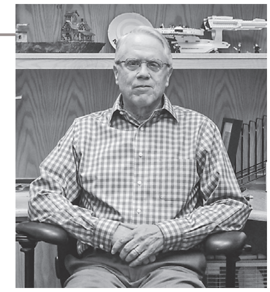
Marcus Jorgensen's research interests center on general education mathematics, quantitative literacy, curriculum design, and curricular change.



Marcus Jorgensen

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How to Help Students Understand Lectures in Advanced Mathematics

Keith Weber, Timothy P. Fukawa-Connelly, Juan Pablo Mejía-Ramos, and Kristen Lew

ABSTRACT. *We first provide evidence that even lectures of high quality are not always well understood by students. Second, we discuss four ideas to help instructors and students in proof-based mathematics courses.*

As part of a recent research study [1], [2], we videotaped and analyzed a real analysis lecture by the highly respected "Dr. A" and investigated how well six of his students understood it. We focused on his ten-minute proof of the following proposition:

> If a sequence x_n has the property that there exists a constant r with $0<r<1$ such that $|x_n-x_{n-1}|< r^n$ for any two consecutive terms in the sequence, then x_n is convergent.

Dr. A identified for us five ideas that he was trying to convey:

1. Cauchy sequences can be understood as sequences that "bunch up."
2. If one does not have a limit candidate for a convergent sequence, one can show that it is convergent by showing that it is Cauchy.
3. The proof illustrates how to set up a proof to show a sequence is Cauchy.
4. The triangle inequality is useful in proving series in absolute value formulae are small.
5. The geometric formula should be part of one's mathematical toolbox to keep some desired quantities small.

Our team felt that Dr. A clearly conveyed points 2, 3, 4, and 5. Two weeks later, after a mid-term examination, we showed three pairs of students from Dr. A's class the ten-minute proof video, along with a transcript of what Dr. A wrote on the blackboard, and asked them what Dr. A was trying to convey. After watching the video, one pair noted point 3 and another pair noted point 4. None noted point 2, which Dr. A emphasized three times during his proof. Together with additional research findings, this study leads us to believe that the following four ideas explain this student behavior and can contribute to improved student learning.

Idea #1: Students prioritize written work over oral comments, so we should write down the key points that we want students to learn.

When giving lectures in advanced mathematics, mathematics professors want to (i) help their students realize what constitutes an acceptable proof and (ii) teach their students how to construct a proof. A common way that professors manage this tension is to present the proof on the blackboard and supplement this presentation with commentary describing the thought processes used to produce it. The students' job in a mathematics lecture is also challenging. They are grappling with new abstract ideas. As the professor is speaking at a faster pace than the students can write, the students must prioritize certain ideas over others. It is natural for the students to focus on what is written on the blackboard; this is a traditional way by which teachers emphasize importance, and written comments have a permanence that oral comments lack.

Research shows that students forget things they don't write down and that instructors talk faster than students can write. Dr. A expressed four of his main points orally but did not write them down. Five of the six students did not record any of Dr. A's oral comments when reviewing the video. Their notes generally consisted of a

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DOI: http://dx.doi.org/10.1090/noti1435

verbatim copy of what Dr. A wrote on the blackboard. This suggests an intriguing hypothesis for why students might not learn in their advanced mathematics lectures: professors state their most important points orally, while students focus on what is being written down. Professors almost always record the formal parts of their lectures—definitions, theorems, and proofs—on the blackboard but often do not record mathematical methods or conceptual explanations on the blackboard. Since students' notes consist largely of what is on the blackboard, they do not record most of their professors' mathematical methods or conceptual explanations in their notes.

Professors state their most important points orally, while students focus on what is being written down.

Our subsequent investigation of student understanding in eleven proof-based mathematics lectures across a variety of mathematical domains provides strong evidence that this hypothesis is accurate. We see no reason to fault mathematics professors or their students for their actions. What we suggest is that mathematicians' habits while lecturing and students' focus of attention do not mesh well together; students do not prioritize the mathematicians' oral commentary and consequently do not record some of the most important ideas in the lectures. We recommend that for each portion of a lecture (e.g., introducing a new concept, presenting a proof), the professor identify one to three main ideas that they wish to convey and explicitly write these ideas on the blackboard.

Idea #2: Mathematicians and students have differing views on understanding advanced mathematics, so we should clearly communicate expectations about lectures from the outset.

Kristen Lew presenting a proof and writing the main points of the proof on the blackboard.

In our research, we have found that mathematics professors and students usually share the same broad goals of mathematics lectures, namely that students will develop a better understanding of the course content by paying attention to the lectures. Where the two groups differ is on their perceptions of what it means to understand advanced mathematics [4]. For mathematicians, understanding a proof involves understanding why a proof is valid. However, mathematicians also feel that it is important to have a holistic understanding of a proof. A holistic understanding includes being able to summarize a proof, as well as recognizing the overarching methods employed in the proof and being able to apply these methods in new situations.

Students view things differently. They want to understand the proofs that they see in lecture and read in their textbook. However, to gain this understanding, many students focus exclusively on justifying how each new assertion follows from previous assertions. In high school geometry courses, proofs are often written in a two-column format where assertions are presented in the left column and an explicit justification for each assertion is presented in the right column. High school students subsequently view the purpose of proof not as providing explanation (or even verification) but as a test to demonstrate their ability to reason. Transition-to-proof courses often reinforce this by placing emphasis on how proofs can and should be structured. As students continue studying proof in their content-based proof-oriented mathematics courses, these beliefs become counterproductive, as an exclusive focus on the deductive logic in a proof can lead students to ignore the larger conceptual points that the professor is making.

Another discrepancy between mathematics professors' and students' expectations of lectures in mathematics is that these expectations are rarely the topic of explicit conversation. Lectures in advanced mathematics are a new experience for students; they can use ongoing guidance about the nature of this process and what their role in this process should be. We believe it is critical that professors clearly communicate expectations about lectures beginning early in the semester. We recommend that the professor be explicit about what they expect students to learn from the lecture and how they should engage in the material to learn it. Clearly such a conversation does not guarantee that students will engage in lectures productively, but it does provide students direction and the opportunity to understand the importance of doing so.

Idea #3: When hearing a proof in a lecture, students often focus on calculation and logical detail, so we should shift what students attend to by assessing their understanding of other aspects of proofs.

In our interview with Dr. A, he highlighted the following excerpt in his lecture as a point where he was conveying an important mathematical point:

Dr. A: Now once again we ask the question. If we were to show this is small, we must represent it in terms of what we know is small. Well, what do you know is small? For n large enough [*gestures toward the statement of the theorem*], the difference between two consecutive terms is small. [*Turns and faces the blackboard*] So what we must do is represent that as a sum of consecutive terms.

In this excerpt, Dr. A is giving an overview of the proof, emphasizing that what he must do is to show one quantity can be made sufficiently small when one knows that another quantity can be made arbitrarily small. By stating, "now once again we ask the question," he was conveying that this is a question that one should often ask oneself when writing such proofs. In our interview with Dr. A, he emphasized the importance of this clip:

Dr. A: Once you get into the area where you're doing approximations, you can't do equal, equal, equal. You have to have bounds, bounds, bounds. The objective is to show how bounds, using the triangle inequality, can be used to show that something is small using information that they're given is small. And this instance turns out that the information which is small is given in a form that allows us to use the geometric series as a bound.

Dr. A's intended point in the lecture excerpt above was obvious to us. When the three pairs of students were asked what Dr. A was trying to convey after rewatching the proof in its entirety, none of the students mentioned these ideas.

After showing the students the proof in its entirety, we showed students the specific short clip containing the transcript above and asked the students what Dr. A was trying to convey in this clip. Again, the students did not mention anything about keeping quantities small. Rather, all of the students focused on the algebraic manipulations and the logical details in the proof. For instance, one pair of students mentioned "basically manipulating the information that we're given so that we can show that a sequence fits the definition." Another pair said, "Given on the problem to see like what we could, how we can manipulate the problem statement. Just how we can start the proof in general." Dr. A made his meta-comments prior to presenting a string of algebraic manipulations to provide meaning and context to the manipulations that he would perform. To students who view understanding as tantamount to justifying the calculations, Dr. A's comments would seem to be superfluous and unnecessary to understand the proof that was presented.

Advanced mathematics lecturers strive to engage students with high-level or intuitive ways to understand the course content, but students are typically assessed on their ability to produce formal mathematics, such as stating definitions, applying procedures, or writing proofs. These assessments send a message to students that the formal aspect of mathematics is what is important and the other aspects of mathematics are superfluous. This likely contributes to students' propensity to focus on calculations and derivations while not prioritizing high-level summaries of the proof. We recommend assessing students on high-level and informal aspects of mathematical proofs as well. Of course, this will motivate students to understand the material, but there are two other benefits as well. First, the types of questions that students are asked can give them a better sense of *how* the material should be understood. Second, students' responses to these questions will provide the instructor with a better sense of how the students are interpreting his or her lecture. We provide in [3] a template for how proof comprehension can be assessed. Discussing the meaning of specific proofs with students can help the students understand what the professor is trying to convey.

Keith Weber working with students to help them understand a proof.

Idea #4: Seek data on how students understand your lectures.

Ordinarily, in university mathematics instruction professors do not receive direct or immediate feedback on how students are interpreting their lectures. Rather, they rely on indirect measures such as their students' performance on exams and their comments on student evaluations, where it is difficult to posit causal links between specific actions of the instructor and the responses of students. We believe that it is important for the professor to seek more direct feedback. One method that is commonly used in K–12 mathematics instruction is the notion of an "exit ticket," in which students are required to answer a short series of questions about their mathematics lesson before exiting the classroom. Asking students to say what they consider the three most important ideas of a lecture can provide valuable insight for the professor on how they interpreted a proof. This information can be used to shape subsequent lectures if students' interpretations of the lecture are different from what the professor intended.

Acknowledgment

This material is based upon the work supported by the National Science Foundation under grants DUE-1245626 and DRL-0643734. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

[1] D. Bressoud, *What they say/what we hear*. Downloaded from: `launchings.blogspot.com/2016/02/what-we-saywhat-they-hear.html`. Last downloaded April 4, 2016.

[2] K. Lew, T. Fukawa-Connelly, J.P. Mejía-Ramos, and K. Weber, Lectures in advanced mathematics: Why students might not understand what the professor is trying to convey, *J. Res. Math. Ed.*, **47 (2016)**, 162–198.

[3] J. P. Mejía-Ramos, E. Fuller, K. Weber, K. Rhoads, and A. Samkoff, An assessment model for proof comprehension in undergraduate mathematics, *Educational Studies in Mathematics* **79** (2012), 3–18.

[4] K. Weber, *Mathematics professors and mathematics majors' expectations of lectures in advanced mathematics*," AMS Blog on Teaching and Learning Mathematics. Retreived from blogs.ams.org/matheducation/2015/02/10/mathematics-professors-and-mathematics-majors-expectations-of-lectures-in-advanced-mathematics/

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Backlog of Mathematics Research Journals

Journal (Print and Electronic)	Number issues per Year	Approximate Number Pages per Year	2015 Median Time (in Months) from: Submission to Final Acceptance	Acceptance to Print	Acceptance to Electronic Posting	Current Estimate of Waiting Time between Submission and Publication (in Months): Print	Electronic
Acta Inform.	8	640	10	13	11	13	11
Adv. in Appl. Math.	10	1639	8	3	1	9	7
Adv. Math.	18	12696	13	2	1.1	17	16
Algebr. Geom. Topol.	6	3750	9	11	9	21	20
Algebra Number Theory	10	2560	10	4	3	16	15
Algorithmica	12	1800	12	12	1	18	9
Amer. J. Math.	6	1728	NR	11.4	10.4	18	16
Anal. PDE	8	2050	9	5	4	15	14
Ann. Appl. Probab.	6	3900	12	12.75	11.75	22	22
Ann. Inst. H. Poincare Anal. Lineaire	6	1351	7	16	2.5	27	13
Ann. Mat. Pura Appl. (4)	6	1680	7	22	8	22	8
Ann. of Math. (2)	6	2100	16	10	7	10	5
Ann. Polon. Math	9	912	5.3	5.8	5.8	8	6
Ann. Probab.	6	4100	9.75	17	17	28	28
Ann. Pure Appl. Logic	12	1354	14	3	2.3	15	14
Ann. Statist.	6	3000	8	5	4.75	13	12
Appl. Anal.	12	2800	4	11.4	1	15	5
Appl. Comput. Harmon. Anal.	6	1133	9	10	0.9	19	10
Appl. Math. Comput.	24	18306	8	3	1.2	9	8
Arch. Hist. Exact. Sci.	6	696	6	6	7	6	7
Arch. Math. Logic	8	2080	14	15	15	15	15
Arch. Ration. Mech. Anal.	12	4200	13	17	14	17	14
Automatica J. IFAC	12	3561	13	3	1.3	17	15
Balkan J. Geom. Appl.	2	220	5	5	3	8	6
Beitr. Algebra Geom.	4	800	7	19	8	19	8
Bernoulli	4	2600	12.5	16	15	24.5	24.5
Bull. Aust. Math. Soc.	6	1056	1.1	6	2.4	9	4
Bull. Lond. Math. Soc.	6	1632	7.2	2.9	1.8	10.2	8.9
Bull. Sci. Math.	8	939	6	10	2.3	18	10
Bull. Soc. Math. France	4	800	9	12	10	7	6
C. R. Math. Acad. Sci. Paris*	12	1056	5	2	1.2	0	8
Calc. Var. Partial Differential Equations	6	3000	10	17	11	17	11

The Backlog of Research Journals is reported each year in the November issue of the *Notices*. The report covers journals of publishers who have agreed to participate and who continue to provide backlog information. Publishers whose journals are not currently included can request that their journals be added. Such requests should be made in e-mail to Marcia Almeida, `backlogreport@ams.org`. To be eligible for inclusion in the backlog report, a journal must be on the list of journals receiving cover-to-cover treatment in *Mathematical Reviews* (`www.ams.org/msnhtml/serials.pdf`).

Once a publisher's journals are accepted for inclusion, the publisher must designate a contact person or persons to supply data about the journals to the AMS. While the AMS makes every effort to obtain the data from the designated contacts, if data about a journal is not supplied, then that journal will not appear in the backlog report.

Journal (Print and Electronic)	Number issues per Year	Approximate Number Pages per Year	2015 Median Time (in Months) from: Submission to Final Acceptance	Acceptance to Print	Acceptance to Electronic Posting	Current Estimate of Waiting Time between Submission and Publication (in Months): Print	Electronic
Canad. J. Math.	6	1440	6	12	5	17	13
Canad. Math. Bull.	4	896	4	8	3	13	6
Combinatorica	6	750	8	26	14	30	12
Comm. Math. Phys.	24	7200	10	13	11	13	11
Commun. Appl. Math. Comput. Sci.	2	225	11	6	3	18	16
Commun. Pure Appl. Anal.	6	2500	4	3	2	8	7
Complex Var. Elliptic Equ.	12	1800	4.4	6.7	1.2	9.6	6.9
Compos. Math.	12	2688	11.3	9.6	5.4	18.3	16.6
Comput. Aided Geom. Design	9	829	5	3	1.2	5	4
Comput. Geom.	9	602	15	3	2.1	19	17
Comput. Math. Appl.	24	4568	8	2	1.2	9	8
Comput. Methods Funct. Theory	4	720	7	13	8	13	8
Computing	12	2496	11	19	12	19	12
Constr. Approx.	6	1000	10	11	4	16	11
Des. Codes Cryptogr.	12	1800	9	12	1	18	9
Differential Geom. Appl.	6	1170	8	3	0.9	13	11
Discrete Appl. Math	18	3013	13	6	1.1	17	13
Discrete Comput. Geom.	8	2000	9	3	1	12	9
Discrete Contin. Dyn. Syst.	12	6200	5	4	3	10	9
Discrete Contin. Dyn. Syst. Ser. B	10	3600	6	3	2	10	9
Discrete Math.	12	3326	11	3	1	13	11
Discrete Optim.	4	520	12	3	1.7	12	10
Duke Math. J.	15	3000	12	10	10	19	16
Dyn. Syst.	4	590	5.8	5.4	1.2	9.8	7.4
European J. Combin.	8	2101	10	3	1.1	11	10
Expo. Math.	4	557	11	8	3.4	15	6
Finite Fields Appl.	6	1811	8	3	1.4	11	9
Found. Comput. Math.	6	1200	6	12	1	18	7
Geom. Dedicata	6	2400	4	7	0.5	11	3
Geom. Topol.	6	3750	12	12	10	24	23
Graphs Combin.	6	2500	4	2	1	6	5
Historia Math.	4	503	9	8	1.3	15	8
Homology Homotopy Appl.	2	800	6.4	7	5.2	12	10
Houston J. Math.	4	1400	6	18	16	21	19
Illinois J. Math.	4	1200	6	4	3	10	9
Indag. Math. (N.S.)	5	601	5	3	1.2	10	7
Indiana Univ. Math. J.	6	1900	6	13	13	17	17
Infor. Process. Lett.	12	800	11	2	0.8	12	10
Inform. and Comput.	6	1652	16	9	5.5	30	28
Invent. Math.	12	3000	17	24	18	24	18
Inverse Probl. Imaging	4	1200	5	3	2	8	7
Involve	5	900	9	12	11	19	18
Israel J. Math.	8	4000	5	15	14	22	19
J. Algebra	24	11160	9	3	1.3	13	12
J. Algebraic Geom.	4	800	12	16	2	16	12
J. Amer. Math. Soc.	4	1200	19.7	13.1	2.1	31.6	20.3
J. Anal. Math.	3	1200	5	22	22	NR	NR
J. Appl. Log.	6	881	4	7	1.7	11	8
J. Approx. Theory	12	2046	8	6	1	13	12
J. Aust. Math. Soc.	6	864	6.5	8.5	3	14.5	11

Journal (Print and Electronic)	Number issues per Year	Approximate Number Pages per Year	2015 Median Time (in Months) from: Submission to Final Acceptance	Acceptance to Print	Acceptance to Electronic Posting	Current Estimate of Waiting Time between Submission and Publication (in Months) Print	Electronic
J. Combin. Theory Ser. A	8	2265	12	2	0.8	14	13
J. Combin. Theory Ser. B	6	1809	24	4	1	32	30
J. Complexity	6	872	7	4	1.2	10	7
J. Comput. Appl. Math.	18	7069	9	4	1.3	11	7
J. Comput. System Sci.	8	1655	12	6	3.3	19	17
J. Convex Anal.	4	1260	9	12	1	14	7
J. Difference Equ. Appl.	12	2000	3.4	3.5	1.8	12	6.6
J. Differential Equations	24	14336	9	2	0.8	8	7
J. Differential Geom.	9	1625	8	21	20	18	17
J. Discrete Algorithms	6	782	12	5	1.3	11	8
J. Eur. Math. Soc. (JEMS)	12	3000	9	18	17	20	19
J. Funct. Anal.	24	8291	8	2	0.8	13	12
J. Geom. Anal.	4	2800	6.7	18.4	2.6	12	8
J. Geom. Phys.	12	2693	8	3	1.2	11	6
J. Ind. Manag. Optim.	4	1500	5	8	3	12	8
J. Integral Equations Appl.	4	600	7	11	8	10	7
J. Lie Theory	4	1200	5	10	1	15	6
J. Log. Algebr. Program.	6	965	13	4	1.2	15	10
J. Lond. Math. Soc. (2)	6	1632	8.3	3.7	1.9	14.3	10.1
J. Math. Anal. Appl.	24	17386	7	1	0.6	8	8
J. Math. Biol.	14	3500	9	18	10	18	10
J. Math. Ecom.	6	835	10	3	1.3	11	10
J. Math. Phys.	12	4000	5	1	0.7	5	5
J. Math. Pures Appl. (9)	12	2569	7	6	2	13	12
J. Math. Soc. Japan	4	1700	8.7	14.5	14.5	26.6	26.6
J. Mod. Dyn.	**	400	6	6	1	12	7
J. Multivariate Anal.	10	2655	9	5	1.1	16	9
J. Number Theory	12	4819	7	3	2.3	10	8
J. Operator Theory	4	1200	6	10	9	7	6
J. Pure Appl. Algebra	12	6087	9	4	0.9	11	9
J. Statist. Plann. Inference	12	1501	9	4	1.4	11	10
J. Symbolic Comput.	6	1586	9	6	1.8	13	10
J. Symbolic Logic	4	1440	12	8	8	18	15
J. Théor. Nombres Bordeaux	3	800	8	12	8	27	23
J. Theoret. Probab.	4	1762	9.5	NA	0.5	NA	NA
J. Topol.	6	1120	10.5	6	2.9	15.5	13.3
Kodai Math. J.	3	700	4	7	7	9	9
Kyoto J. Math.	4	900	5	13	13	18	18
Linear Algebra Appl.	24	8670	7	3	0.8	11	7
Linear Multilinear Algebra	12	2500	4.7	9.2	1.3	12.8	4.6
Lobachevskii J. Math.	4	450	3.6	5.2	8.8	5.2	5.2
Manuscripta Math.	12	3264	8	13	9	13	9
Math. Ann.	12	6720	7	13	8	13	8
Math. Comp.	6	3000	9.9	18.7	12.6	27.9	20
Math. Program.	12	2760	16	25	17	25	17
Math. Res. Lett.	6	1300	7	9	9	9	9
Math. Social Sci.	6	630	11	3	1.4	14	13
Math. Z.	12	7200	11	14	12	14	12
Mathematika	3	960	5.7	10	3.7	13.7	10.3

Journal (Print and Electronic)	Number issues per Year	Approximate Number Pages per Year	2015 Median Time (in Months) from: Submission to Final Acceptance	Acceptance to Print	Acceptance to Electronic Posting	Current Estimate of Waiting Time between Submission and Publication (in Months): Print	Electronic
Mem. Amer. Math. Soc.	6	3800	11.6	22.7	16.5	33.9	NA
Methods Appl. Anal.	4	400	5	4	4	7	7
Michigan Math. J.	4	896	7	7	6	9	8
Monatsh. Math.	12	1920	8	16	9	16	9
Multiscale Model. Simul.	4	1575	9.2	4.3	2.3	13.5	11.5
Nagoya Math. J.	4	850	10.5	13.8	13.8	14	9
Nonlinear Anal.	18	5932	4	3	1.2	7	5
Nonlinear Anal. Hybrid Syst.	4	627	11	3	1.1	13	11
Nonlinear Anal. Real World Appl.	6	1795	7	3	1.1	10	9
Notre Dame J. Form. Log.	4	600	9	28	28	31	27
Numer. Math.	12	2400	17	21	18	21	18
Pacific J. Math.	12	3075	7	7	6	13	12
Probab. Theory Related Fields	12	4800	12	24	13	24	13
Proc. Amer. Math. Soc.	12	5240	5.6	15.7	12.3	15.5	9.1
Proc. Lond. Math. Soc. (3)	12	2304	10.6	2.9	2.2	13.6	12.9
Publ. Math. de l'IHES	2	600	20	27	21	27	21
Quantum Topol.	4	800	11	12	11	12	11
Quart. Appl. Math.	4	800	1.7	20	18.3	19.3	16.8
Rocky Mountain J. Math.	6	2100	9	26	23	24	21
Semigroup Forum	6	1400	8.5	11	1	20	10
SIAM J. Appl. Math.	6	2635	7	4.4	2.4	11.4	9.4
SIAM J. Comput.	6	1850	15.6	4.7	2.7	20.3	18.3
SIAM J. Control Optim.	6	3690	12.4	4.6	2.6	17	15
SIAM J. Discrete Math.	4	2430	11.5	4.5	2.5	16	14
SIAM J. Math. Anal.	6	4750	9.1	3.6	2.6	12.7	11.7
SIAM J. Matrix Anal. Appl.	4	1720	8.7	4.5	2.5	13.2	11.2
SIAM J. Numer. Anal.	6	2850	11.1	3.5	2.5	14.6	13.6
SIAM J. Optim.	4	2615	11.4	4.4	2.4	15.8	13.8
SIAM J. Sci. Comput.	6	5430	8.7	3.5	2.5	12.2	11.2
SIAM Rev.	4	750	12.1	7.7	6.7	19.8	18.8
Stochastic Process. Appl.	12	4611	10	3	1.5	17	14
Theoret. Comput. Sci.	48	7300	10	5	1.1	15	13
Theory Comput. Syst.	8	1000	12	8	1	15	9
Topology Appl.	18	4178	7	6	3.9	12	10
Trans. Amer. Math. Soc.	12	8880	7.4	22.9	17.6	31.7	22.8

Journal (Electronic)	Number of Articles Posted in 2015	2015 Median Time (in days) from: Submission to Final Acceptance	Acceptance to Posting	Format(s)
Abstr. Appl. Anal. www.hindawi.com/journals/aaa/	195	68	51	html, pdf, ps, dvi, tex, ePUB
Acta Math. Acad. Paedagog. Nyházi. (N.S.) www.emis.de/journals/AMAPN/	28	510	120	pdf, ps
Adv. Difference Equ. link.springer.com/journal/13662	386	123	22	html, pdf
Adv. Math. Commun. aimsciences.org/journals/home.jsp?journalID=10	31	180	120	pdf
Appl. Math. E-Notes www.math.nthu.edu.tw/~amen/	31	123	135	pdf

Journal (Electronic)	Number of Articles Posted in 2015	2015 Median Time (in days) from: Submission to Final Acceptance	Acceptance to Posting	Format(s)
Bound. Value Probl. link.springer.com/journal/13661	244	127	17	html, pdf
Conform. Geom. Dyn. www.ams.org/journals/ecgd	15	200	33	tex
Differ. Geom. Dyn. Syst. www.mathem.pub.ro/dgds/	11	100	180	pdf
Differ. Uravn. Protsessy Upr. www.math.spbu.ru/diffjournal/EN/about.html	16	30	10	html, pdf, tex, doc
Discrete Math. Theor. Comput. Sci. dmtcs.episciences.org/	47	401	19	pdf
Electron. J. Combin. www.combinatorics.org	233	226	17	pdf
Electron. J. Differential Equations ejde.math.txstate.edu	317	116	8	pdf, tex
Electron. J. Qual. Theory Differ. Equ. www.math.u-szeged.hu/ejqtde/	100	139	18	pdf
Electron. Res. Announc. Math. Sci. eramath.s3-website-us-east-1.amazonaws.com/	10	60	14	pdf
Electron. Trans. Numer. Anal. etna.ricam.oeaw.ac.at/	25	213	77	pdf
ESAIM Control Optim. Calc. Var. www.esaim.cocv.org	42	241	243	html, pdf, tex
ESAIM Math. Model. Numer. Anal. www.esaim.m2an.org	84	240	183	html, pdf, tex
ESAIM Probab. Stat. www.esaim.ps.org	39	290	293	html, pdf, tex
Fixed Point Theory Appl. link.springer.com/journal/13663	237	118	18	html, pdf
Int. J. Math. Math. Sci. www.hindawi.com/journals/ijmms/	43	79	34	html, pdf, ps, dvi, tex, ePUB
Int. J. Stoch. Anal. www.hindawi.com/journals/ijsa/	10	75	70	html, pdf, ps, dvi, tex, ePUB
Integers www.integers-ejcnt.org/	73	368	24	pdf
J. Appl. Math. www.hindawi.com/journals/jam/	118	77	34	html, pdf, ps, dvi, tex, ePUB
J. Inequal. Appl. link.springer.com/journal/13660	418	128	16	html, pdf
J. Integer Seq. cs.uwaterloo.ca/journals/JIS/	88	117	10	html, pdf, ps, dvi, tex
Math. Biosci. Eng. aimsciences.org/journals/home.jsp?journalID=8	90	90	21	pdf
Netw. Heterog. Media aimsciences.org/journals/home.jsp?journalID=9	40	90	14	pdf
Open Math. www.openmathematics.com/	86	163	39	pdf
Proc. Amer. Math. Soc. Ser. B www.ams.org/journals/bproc	4	135	102	tex
Reliab. Comput. interval.louisiana.edu/reliable-computing-journal/RC.html	8	122.5	5	pdf, other***
Represent. Theory www.ams.org/journals/ert	15	249	33	tex

Journal (Electronic)	Number of Articles Posted in 2015	2015 Median Time (in days) from: Submission to Final Acceptance	Acceptance to Posting	Format(s)
Sém. Lothar. Combin. www.mat.univie.ac.at/~slc	12	228	40	pdf, ps, dvi, tex
SIAM J. Appl. Dyn. Syst. epubs.siam.org/journal/siads/	68	200	71	pdf
SIAM J. Financial Math. epubs.siam.org/journal/sifin/	43	336	71	pdf
SIAM J. Imaging Sci. epubs.siam.org/journal/siims	97	181	73	pdf
Theory Appl. Categ. www.tac.mta.ca/tac/	56	218	6	html, pdf
Theory Comput. theoryofcomputing.org/	20	416	189	html†, pdf, ps, tex
Trans. Amer. Math. Soc. Ser. B www.ams.org/journals/btran	4	225	24	tex

NR means no response received. NA means not available or not applicable.
* Starting in 2016, this is an electronic-only journal.
** Number of issues per year: paper by paper in a single volume, no issues.
*** Articles are submitted in LaTeX (TeX) but posted only in PDF.
† Applies to abstract, bibliography, author info, but not to full article.

Reciprocity Agreements

The American Mathematical Society has reciprocity agreements with a number of mathematical organizations around the world. A current list of the reciprocating societies appears here; for full details of the agreements, see www.ams.org/membership/individual/mem-reciprocity.

Allahabad Mathematical Society

Argentina Mathematical Society

Australian Mathematical Society

Austrian Mathematical Society

Azerbaijan Mathematical Society

Balkan Society of Geometers

Belgian Mathematical Society

Berliner Mathematische Gesellschaft

Bharata Ganita Parisad

Brazilian Mathematical Society

Brazilian Society of Computational and Applied Mathematics

Calcutta Mathematical Society

Canadian Mathematical Society

Catalan Society of Mathematicians

Chilean Mathematical Society

Columbian Mathematical Society

Croatian Mathematical Society

Cyprus Mathematical Society

Danish Mathematical Society

Dutch Mathematical Society

Edinburgh Mathematical Society

Egyptian Mathematical Society

European Mathematical Society

Finnish Mathematical Society

German Mathematical Society

German Society for Applied Mathematics and Mechanics

Glasgow Mathematical Association

Hellenic Mathematical Society

Icelandic Mathematical Society

Indian Mathematical Society

Indonesian Mathematical Society

Iranian Mathematical Society

Irish Mathematical Society

Israel Mathematical Union

Italian Mathematical Union

János Bolyai Mathematical Society

Korean Mathematical Society

London Mathematical Society

Luxembourg Mathematical Society

Macedonian Society Association Mathematics/Computer Science

Malaysian Mathematical Society

Mathematical Society of France

Mathematical Society of Japan

Mathematical Society of the Philippines

Mathematical Society of the Republic of China

Mathematical Society of Serbia

Mexican Mathematical Society

Mongolian Mathematical Society

Nepal Mathematical Society

New Zealand Mathematical Society

Nigerian Mathematical Society

Norwegian Mathematical Society

Palestine Society for Mathematical Sciences

Parana's Mathematical Society

Polish Mathematical Society

Portuguese Mathematical Society

Punjab Mathematical Society

Ramanujan Mathematical Society

Romanian Mathematical Society

Romanian Society of Mathematicians

Royal Spanish Mathematical Society

Saudi Association for Mathematical Sciences

Singapore Mathematical Society

Sociedad Matemática de la Republica Dominicana

Sociedad Uruguaya de Matemática y Estadística

Société Mathématiques Appliquées et Industrielles

Society of Mathematicians, Physicists and Astronomers of Slovenia

South African Mathematical Society

Southeast Asian Mathematical Society

Spanish Mathematical Society

Swedish Mathematical Society

Swiss Mathematical Society

Tunisian Mathematical Society

Turkish Mathematical Society

Ukrainian Mathematical Society

Union of Bulgarian Mathematicians

Union of Czech Mathematicians and Physicists

Union of Slovak Mathematicians and Physicists

Vietnam Mathematical Society

Vijnana Parishad of India

Mathematics People

Xu Awarded ICTP-IMU Ramanujan Prize

Chenyang Xu

Chenyang Xu of the Beijing International Center of Mathematical Research has been awarded the 2016 Ramanujan Prize of the Abdus Salam International Center for Theoretical Physics (ICTP), the International Mathematical Union, and the Department of Science and Technology of the Government of India. Xu was honored for his outstanding works in algebraic geometry, notably in the area of birational geometry, including works on both log canonical pairs and on *Q*-Fano varieties, and on the topology of singularities and their dual complexes.

The prize citation reads, in part: "Building his work in part on applications and ramifications of methods from the minimal model program, Xu has now demonstrated expertise over an impressively wide range of techniques in algebraic geometry and beyond to tackle a broad spectrum of geometric problems from birational geometry in characteristic 0 and characteristic p, topology of algebraic varieties, arithmetic geometry and Kähler geometry, and he has contributed to the strengthening of the subject of algebraic geometry in China."

Xu received his PhD from Princeton University in 2008 under the direction of János Kollár. He has been a Clay Liftoff Fellow (2008), a member of the Institute for Advanced Study (2008), and a Viterbi Endowed Postdoctoral Scholar at MSRI (2009). He held positions at the Massachusetts Institute of Technology and the University of Utah before moving to the Beijing International Center.

Xu tells the AMS, "I grew up in Sichuan Province, which is located in inland China. I started to consider having my career as a mathematician when I was a college student. That time I was thinking of doing a subject which there were not that many Chinese mathematicians working on, so I naturally chose algebraic geometry. About four years ago, I moved back to China after spending eight years in the US. I'm very glad to see the community of Chinese algebraic geometers has grown quickly in the recent years."

The Ramanujan Prize is awarded annually to a young researcher from a developing country. The prize carries a cash award of US$15,000, and the recipient is invited to deliver a lecture at ICTP.

—Elaine Kehoe

Juschenko Receives 2016 Duszenko Award

Kate Juschenko

Kate Juschenko of Northwestern University has been named the recipient of the second annual Kamil Duszenko Award. According to the prize citation, she "has been distinguished for her work exploring geometric, analytic, and probabilistic aspects of group theory, in particular for providing, with N. Monod, the first examples of finitely generated amenable simple groups." Juschenko was born in Kiev, Ukraine, and she received her PhD from Texas A&M University in 2011 under the direction of Gilles Pisier. She was a postdoctoral fellow at EPFL, Lausanne, and assistant professor at Vanderbilt University before joining the faculty at Northwestern.

The Duszenko Award is given by the Wrocław Mathematicians Foundation (WMF) for outstanding work or research that has significantly contributed to the deepening of knowledge and further progress in the field of mathematics. It was founded in honor of Kamil Duszenko, a young mathematician who died of acute lymphoblastic leukemia at the age of twenty-eight. It will be given at least every two years in the fields of mathematics and hematology.

—From a WMF announcement

Jeffrey Awarded Noether Lectureship

Lisa Jeffrey

Lisa Jeffrey of the University of Toronto has been awarded the 2017 Noether Lectureship by the Association for Women in Mathematics and the AMS. She was honored "for her contributions and leadership in symplectic and algebraic geometry, focused on connections with theoretical physics."

According to the prize citation, "Jeffrey is best known for her joint work with Frances Kirwan on localization and moduli spaces. They determined the structure of the cohomology ring of the moduli space of representations of the fundamental group of a surface. This was an application of their earlier work, developed to study the cohomology rings of symplectic quotients. More recently, Jeffrey's work has focused on the based loop group in *K*-theory. In joint work with Harada, Holm, and Mare, she showed the connectedness of the level sets of the moment map on the based loop group."

Jeffrey received her DPhil in mathematics from Trinity College, University of Cambridge, in 1992 under the direction of M. F. Atiyah. She held assistant professorships at Princeton University and McGill University before joining the faculty at Toronto. She has been the recipient of the Krieger–Nelson Prize (2000) and the Coxeter–James Lectureship (2001), both from the Canadian Mathematical Society. She was elected a Fellow of the AMS in 2010. Jeffrey will deliver the Noether Lecture at the 2017 Joint Mathematics Meetings in Atlanta, Georgia.

—From an AWM announcement

2016 CAV Award Announced

The 2016 CAV (Computer-Aided Verification) Award was given to:

- Josh Berdine, Facebook
- Cristiano Calcagno, Facebook
- Dino Distefano, Facebook and Queen Mary University of London
- Samin Ishtiaq, Microsoft Research Cambridge
- Peter O'Hearn, Facebook and University College London
- John Reynolds, Carnegie Mellon
- Hongseok Yang, University of Oxford

"for the development of Separation Logic and for demonstrating its applicability in the automated verification of programs that mutate data structures."

Separation Logic was developed in the early 2000s by O'Hearn, Reynolds, Ishtiaq, and Yang, building on earlier work by Burstall in the early 1970s and by O'Hearn and Pym in the late 1990s on Bunched Logic. Afterwards Berdine, Calcagno, Distefano, O'Hearn, and Yang developed tools such as Space Invader and Smallfoot to exploit Separation Logic for automated program verification in industrial-size case studies.

Many researchers are now working on both fundamental and practical issues related to Separation Logic and its use in efficient verification tools. Examples include the SLAyer tool for device drivers developed at Microsoft and the Infer tool for the verification of mobile applications developed at Facebook.

—From a CAV announcement

Seiberg Awarded 2016 Dirac Medal

Nathan Seiberg of the Institute for Advanced Study has been awarded a 2016 Dirac Medal by the International Centre for Theoretical Physics (ICTP). According to the prize citation, he "has made major contributions to supersymmetric field theories elucidating the power of holomorphy to establish the non-renormalisation theorems, deciphering the different phases of N=1 supersymmetric theories and uncovering a strong-weak coupling duality known as Seiberg duality. He (in collaboration with Edward Witten) also made major contributions towards a full non-perturbative understanding of N=2 theories that has led to many further developments in theoretical physics and mathematics." Also honored for their joint work were Mikhail Shifman and Arkady Vainshtein, both of the University of Minnesota. The medals are awarded to scientists who have made significant contributions to theoretical physics and carry a cash award of US$5,000.

—From an ICTP announcement

Donaldson Awarded Doctor Honoris Causa by Universidad Complutense de Madrid

Sir Simon K. Donaldson

Sir Simon K. Donaldson, professor in pure mathematics at Imperial College London, will be awarded the honorary degree Doctor Honoris Causa by Universidad Complutense de Madrid on January 20, 2017. Donaldson is a Fellow of the Royal Society, a permanent member of the Simons Center for Geometry and Physics at Stony Brook University, a foreign member of the US National Academy of Sciences, and a Fellow of the American Mathematical Society. The ceremony and a preceding colloquium are open to the general public.

—Vicente Munoz
Universidad Complutense de Madrid

Jonathan Borwein, 1951–2016

Jonathan Borwein

JONATHAN BORWEIN of the University of Newcastle, Australia, passed away on August 2, 2016. Borwein was renowned for his vast and far-ranging work in pure mathematics, applied mathematics, optimization theory, computer science, mathematical finance, and, of course, experimental mathematics, in which he has been arguably the world's premier authority. The Google Citation Tracker finds over 22,048 citations.

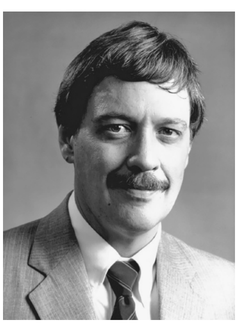
Jon tried at every turn to do research that is accessible and take it to a broad audience. He was famous for his popular work in the computation and analysis of pi. He wrote numerous articles for the Math Drudge blog, the *Conversation*, and the *Huffington Post*. He was a past president of the Canadian Mathematical Society.

Jon was a mentor par excellence, having guided thirty graduate students and forty-two postdoctoral scholars. Working with Jon was not easy—he was a demanding colleague (as the present author will attest)—but for those willing to apply themselves, the rewards have been great.

—David H. Bailey

Editor's Note: Two of Borwein's books are featured in this issue's BookShelf; see p. 1184.

Joseph L. Taylor, 1941–2016



Joseph L. Taylor

Joseph L. Taylor was a mathematician and professor at the University of Utah, who was awarded the 1975 Leroy P. Steele Prize for Seminal Contribution to Research for his paper "Measure Algebras." At Utah he served as department chair, dean, and Vice President for Academic Affairs.

Hugo Rossi, a colleague of Taylor's, said, "Joe's fearless insights, exceptional clarity of thought, and tirelessness while on the hunt, led him to tackle some of the most significant problems of his era, and if not resolve them, to bring new ideas and tools to the task."

Among his colleagues, friends, and family, Taylor was renowned for his sharp sense of humor and love of the outdoors. An avid hunter, hiker, and camper, he explored much of Utah's wilderness. He also trained bird dogs, including one national field champion.

—Based on the obituary in the Salt Lake Tribune, *July 31, 2016*

Mathematics Opportunities

Travel Grants for MCA 2017 July 24–28, 2017 Montreal, Canada

This travel grant program is contingent on receiving funding from the National Science Foundation (NSF).

This grant will permit partial travel support for up to 100 US mathematicians attending the Mathematical Congress of the Americas (MCA) that will take place July 24–28, 2017, in Montreal, Canada. The Society is preparing to administer the selection process.

Instructions on how to apply are available on the AMS website at www.ams.org/programs/travel-grants/mca. This travel grants program will be administered by the Membership and Programs Department, AMS, 201 Charles Street, Providence, RI 02904-2294. For questions or more information, contact Steven Ferrucci at sxf@ams.org, 800-321-4267, ext. 4113 or 401-455-4113.

This program is open to US mathematicians (those who are affiliated with a US institution, and must be affiliated with a US institution at the time of travel). It is expected that this travel grant program will provide travel support for both US-based invited speakers (senior mathematicians) and early career mathematicians. Early career mathematicians (those within six years of their doctorate), women, and members of US groups underrepresented in mathematics are especially encouraged to apply. Invited speakers to MCA 2017 who are from US institutions should submit applications, if funding is desired.

Applications will be evaluated by a panel of mathematical scientists under the terms of a proposal submitted to the National Science Foundation by the Society.

The following conditions will apply: Mathematicians accepting grants for partial support of the travel to MCA 2017 may not supplement them with any other NSF funds. Should NSF fund this program, it will be the intention of the NSF's Division of Mathematical Sciences to provide no additional funds on its other regular research grants for travel to MCA in 2017. However, an individual mathematician who does not receive a travel grant may use regular NSF grant funds, subject to the usual restrictions and prior approval requirements.

All information currently available about the MCA 2017 program, organization, and registration procedure is located on the MCA 2017 website: https://mca2017.org.

The deadine for applications is **October 31, 2016**.

—AMS Membership & Programs Department

American Mathematical Society Centennial Fellowship

Invitation for Applications for Awards for 2017–2018
Deadline December 1, 2016

Description: The AMS Centennial Research Fellowship Program makes awards annually to outstanding mathematicians to help further their careers in research. The number of fellowships to be awarded is small and depends on the amount of money contributed to the program. The Society supplements contributions as needed. At least one fellowship will be awarded for the 2017–2018 academic year. Specific information can be found at www. ams.org/programs/ams-fellowships/centennial-fellow/emp-centflyer.

Eligibility: The eligibility rules are as follows. The primary selection criterion for the Centennial Fellowship is the excellence of the candidate's research. Preference will be given to candidates who have not had extensive fellowship support in the past. Recipients may not hold the Centennial Fellowship concurrently with another research fellowship such as a Sloan or NSF Postdoctoral Fellowship. Under normal circumstances, the fellowship cannot be deferred. A recipient of the fellowship shall have held his or her doctoral degree for at least three years and not more than twelve years at the inception of the award (that is, received between September 1, 2005, and September 1, 2014). Applications will be accepted from those currently holding a tenured, tenure track, postdoctoral, or comparable (at the discretion of the selection committee) position at an institution in North America. Applications should include a cogent plan indicating how the fellowship will be used. The plan should include travel to at least one other institution and should demonstrate that the fellowship will be used for more than reduction of teaching at the candidate's home institution. The selection committee will consider the plan, in addition to the quality of the candidate's research, and will try to award the fellowship to those for whom the award would make a real difference in the development of their research careers. Work in all areas of mathematics, including interdisciplinary work, is eligible.

Deadline: The deadline for receipt of applications is **December 1, 2016**. The award recipient will be announced in February 2017 or earlier, if possible.

Application information: Find Centennial application information at www.ams.org/ams-fellowships. For questions, contact the Membership and Programs Department, American Mathematical Society, 201 Charles Street, Providence, RI 02904-2294; `prof-serv@ams.org`; 401-455-4096.

—AMS Membership & Programs Department

AMS Congressional Fellowship

The AMS, in conjunction with the American Association for the Advancement of Science, will sponsor a Congressional Fellow from September 2017 through August 2018. The Fellow will spend the year working on the staff of a Member of Congress or a congressional committee, as a special legislative assistant in legislative and policy areas requiring scientific and technical input. The fellowship is designed to provide a unique public policy learning experience to demonstrate the value of science–government interaction, and to bring a technical background and external perspective to the decision-making process in the Congress. An AMS Fellowship Committee will select the AMS Congressional Fellow. The fellowship stipend is US$77,490 for the fellowship period, with allowances for relocation and professional travel and a contribution towards health insurance. Applicants must have a PhD or an equivalent doctoral-level degree in mathematics by the application deadline. For information and to apply, go to `bit.ly/AMSCongressionalFellowship`. The deadline for applications is **February 15, 2017**.

—AMS Washington Office

AMS-AAAS Mass Media Summer Fellowships

The American Mathematical Society provides support each year for a graduate student in the mathematical sciences to participate in the American Association for the Advancement of Science (AAAS) Mass Media Science and Engineering Fellows Program. This summer fellowship program pairs graduate students with major media outlets nationwide, where they will research, write, and report on science news and use their skills to bring technical subjects to the general public.

The principal goal of the program is to increase the public's understanding of science and technology by strengthening the connection between scientists and journalists to improve coverage of science-related issues in the media. Past AMS-sponsored fellows have held positions at National Public Radio, *Scientific American*, Voice of America, *The Oregonian*, NOVA, the *Chicago Tribune*, and the *Milwaukee Journal Sentinel*.

Fellows receive a weekly stipend of US$500, plus travel expenses, to work for ten weeks during the summer as reporters, researchers, and production assistants in newsrooms across the country. They observe and participate in the process by which events and ideas become news, improve their ability to communicate about complex technical subjects in a manner understandable to the public, and increase their understanding of editorial decision making and of how information is effectively disseminated. Each fellow attends an orientation and evaluation session in Washington, DC, and begins the internship in mid-June. Fellows submit interim and final reports to AAAS. A wrap-up session is held at the end of the summer.

Mathematical sciences faculty are urged to make their graduate students aware of this program. The deadline to apply for fellowships for the summer of 2017 is **January 15, 2017**. Further information about the fellowship program and application procedures is available online at `www.aaas.org/programs/education/MassMedia`; or applicants may contact Rebekah Corlew, Program Director, AAAS Mass Media Science and Engineering Fellows Program, 1200 New York Avenue, NW, Washington, DC 20005; e-mail `rcorlew@aaas.org`. Further information is also available at `www.ams.org/programs/ams-fellowships/media-fellow/massmediafellow` and through the AMS Washington Office, 1527 Eighteenth Street, NW, Washington, DC 20036; telephone: 202-588-1100; e-mail: amsdc@ams.org.

—AMS Washington Office

Mathematics Research Communities 2017

The AMS invites mathematicians just beginning their research careers—those who are close to finishing their doctorates or have recently finished—to become part of Mathematics Research Communities (MRC), a unique and successful program that builds social and collaborative networks through which individuals inspire and sustain each other in their work. Women and underrepresented minorities are especially encouraged to participate. Supported by the National Science Foundation, the structured program engages and guides all participants as they start their careers. Those accepted into the program will receive support for the summer conference and will be partially supported for their participation in the Joint Mathematics Meetings that follow in January 2018. The summer conferences of the MRC are held at Snowbird Resort, Utah, where participants can enjoy the natural beauty and a collegial atmosphere. The program also includes discussion networks by research topic and a longitudinal study of early career mathematicians.

Three conferences will be held in summer 2017 on the following topics:

Week 1. June 4–10, 2017: Homotopy Type Theory. Organizers: J. Daniel Christensen (University of Western Ontario), Chris Kapulkin (University of Western Ontario), Daniel R. Licata (Wesleyan University), Emily Riehl (Johns Hopkins University), Michael Shulman (University of San Diego).

Week 2. June 11–17, 2017: Beyond Planarity: Crossing Numbers of Graphs. Organizers: Éva Czabarka (University of South Carolina), Silvia Fernández-Merchant (California State University, Northridge); Gelasio Salazar (Universidad

Autónoma de San Luis Potosí), Marcus Schaefer (DePaul University), László A. Székely (University of South Carolina).

Week 3. June 18–24, 2017: Dynamical Systems: Smooth, Symbolic, and Measurable. Organizers: Jon Chaika (University of Utah), Vaughn Climenhaga (University of Houston), Boris Hasselblatt (Tufts University), Bryna Kra (Northwestern University), Daniel Thompson (Ohio State University).

Individuals one to two years before receiving their PhDs or one to five years after receiving their PhDs are welcome to apply. The MRC program is open to individuals who are US citizens, as well as to those who are affiliated with US institutions. A few international participants may be accepted. All participants are expected to be active in the full MRC program. Detailed instructions and the online application will be available on September 1, 2016. Applications are due no later than **March 1, 2017**.

For further information on Mathematics Research Communities, visit www.ams.org/mrc or contact Steven Ferrucci at ams-mrc@ams.org.

—AMS announcement

AMS Epsilon Fund

The AMS Epsilon Fund awards grants to summer mathematics programs that support and nurture mathematically talented high school students in the United States. The deadline to apply for funding for summer 2017 programs is **December 15, 2016**. Applications are now taken online at www.mathprograms.org. For more information about the program and updated application information, go to www.ams.org/programs/edu-support/epsilon/emp-epsilon. For more information contact the AMS Membership and Programs Department by e-mail at prof-serv@ams.org or by telephone at 800-321-4267, ext. 4060.

—AMS announcement

*NSF Graduate Research Fellowships

The National Science Foundation's Graduate Research Fellowship Program recognizes and supports outstanding graduate students in NSF-supported science, technology, engineering, and mathematics disciplines pursuing research-based master's and doctoral degrees at US institutions. The NSF welcomes applications from all qualified students and strongly encourages underrepresented populations, including women, underrepresented racial and ethnic minorities, and persons with disabilities, to apply. Fellows benefit from a three-year annual stipend of US$34,000, along with a US$12,000 cost-of-education allowance to the institution for tuition and fees, and opportunities for international research and professional development. The deadline in the mathematical sciences is **October 28, 2016**. For further information, visit www.nsf.gov/funding/pgm_summ.jsp?pims_id=6201.

—From NSF announcements

*NSF East Asia and Pacific Summer Institutes for US Graduate Students

The National Science Foundation (NSF) and selected foreign counterpart agencies sponsor international research institutes for US graduate students in seven East Asia and Pacific locations (Australia, China, Japan, Korea, New Zealand, Singapore, or Taiwan) between June and August each year. The Summer Institutes (EAPSI) operate similarly, and the research visits to a particular location occur at the same time. Although applicants apply individually to participate in a Summer Institute, awardees become part of the cohort for each location. Applicants propose a location, host scientist, and research project appropriate for the host site and duration of the international visit. An EAPSI award provides students in science, engineering, and education with firsthand research experiences; an introduction to the science, science policy, and scientific infrastructure of the respective location; and an orientation to the society, culture, and language. It is expected that EAPSI awards will help students initiate professional relationships to enable future collaboration with foreign counterparts. International travel is provided, and awardees receive a summer stipend of US$5,000. The deadline for full proposals is **November 10, 2016**. See www.nsf.gov/funding/pgm_summ.jsp?pims_id=5284.

—From an NSF announcement

Call for Nominations for the Alan T. Waterman Award

The National Science Foundation (NSF) is soliciting nominations for the 2017 Alan T. Waterman Award, recognizing an outstanding young researcher in any field of science or engineering supported by the NSF. The award consists of a US$1,000,000 grant over a five-year period for research at the institution of the recipient's choice. The deadline for nominations is **October 21, 2016**. See www.nsf.gov/od/waterman/waterman.jsp for more details.

—From an NSF announcement

**The most up-to-date listing of NSF funding opportunities from the Division of Mathematical Sciences can be found online at:* www.nsf.gov/dms *and for the Directorate of Education and Human Resources at* www.nsf.gov/dir/index.jsp?org=ehr. *To receive periodic updates, subscribe to the DMSNEWS listserv by following the directions at* www.nsf.gov/mps/dms/about.jsp.

Jefferson Science Fellows Program

The Jefferson Science Fellows program at the US Department of State involves the American academic science, technology, and engineering communities in the formulation and implementation of US foreign policy. Each fellow spends one year at the US Department of State or the US Agency for International Development for an on-site assignment in Washington, DC, that may also involve extended stays at US foreign embassies and/or missions. Fellows receive a stipend of up to US$50,000 to cover living expenses for one year. An additional US$10,000 is awarded for travel. Following the fellowship year, the Jefferson Science Fellow returns to his or her academic career but remains available to the US Department of State for short-term projects. The deadline is **October 31, 2016**. For further information, e-mail `jsf@nas.edu`, telephone 202-334-2643, or see `sites.nationalacademies.org/PGA/Jefferson/PGA_046612`.

—From a National Academies announcement

AAUW Educational Foundation Fellowships and Grants

The American Association of University Women (AAUW) has programs for supporting women students and scholars at various stages of their careers. Selected Professions Fellowships support women students in areas in which women's participation has traditionally been low, including computer/information sciences and mathematics/statistics. For further information visit `www.aauw.org/what-we-do/educational-funding-and-awards`, call 202-785-7700, e-mail `connect@aauw.org`, or call the customer service center at 800-326-2289.

—From AAUW website

AWM Essay Contest

The Association for Women in Mathematics (AWM) and Math for America cosponsor an annual essay contest for biographies of contemporary women mathematicians and statisticians in academic, industrial, and government careers. Each essay is based primarily on an interview with a woman currently working in a mathematical sciences career. This contest is open to students in the following categories: Grades 6–8, Grades 9–12, and College Undergraduate. At least one winning submission is chosen from each category. Winners receive a prize, and their essays are published online at the AWM website. Additionally, a grand prize winner has his or her submission published in the AWM newsletter. The deadline is **January 31, 2017**. AWM is also currently seeking women mathematicians to volunteer as the subjects of these essays. For more information or to sign up as a volunteer, contact the contest organizer, Heather Lewis, at `hlewis5@naz.edu`. See `https://sites.google.com/site/awmmath/programs/essay-contest` for complete information.

—AWM announcement

PIMS Call for Nominations

The Pacific Institute for the Mathematical Sciences invites nominations of outstanding young researchers in the mathematical sciences for postdoctoral fellowships for the year 2017–2018. Candidates must be nominated by a scientist or a department affiliated with PIMS. The fellowships are intended to supplement support provided by the sponsor and are tenable at any of PIMS' Canadian member universities.

For more information and application procedures, visit: `www.pims.math.ca/scientific/postdoctoral` or contact: `assistant.director@pims.math.ca`.

Complete applications must be received by PIMS by **December 1, 2016**.

—PIMS announcement

For Your Information

IMU Committee on Women in Mathematics

The Committee on Women in Mathematics of the International Mathematical Union (IMU) aims to help establish worldwide networks of female mathematicians at the continental scale. The committee's objectives include promoting international contacts between national and regional organizations for women in the mathematical sciences; working with groups, committees, and commissions of IMU on topics pertaining to women mathematicians and their representation; and to help to promote equal treatment of women in the mathematical community and equal opportunities in universities and institutions. See the website www.mathunion.org/cwm.

—From IMU announcements

Twenty Years Ago in the *Notices*

November 1996

The Interpretation of Quantum Mechanics, by Roland Omnès.

This book review, by Bill Faris, provides a great deal of insight into the mysteries of quantum mehanics.
www.ams.org/notices/199611/faris.pdf

Inside the AMS

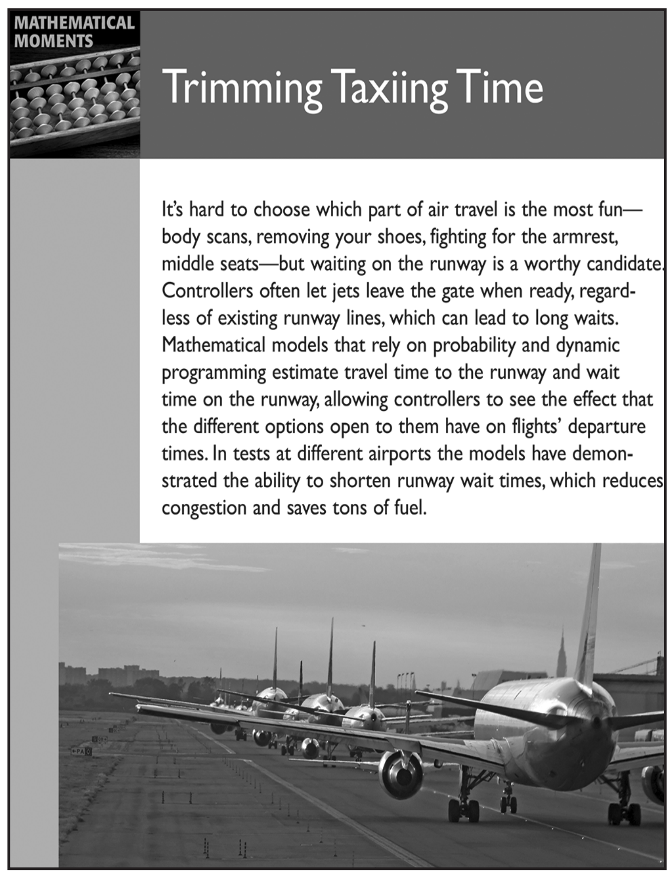
2017 Class of Fellows of the AMS Selected

A list of those who have been selected for the 2017 Class of Fellows of the AMS will appear on the AMS website beginning November 1, 2016. The list will be located at: www.ams.org/profession/new-fellows.

—AMS Membership and Programs Department

From the AMS Public Awareness Office

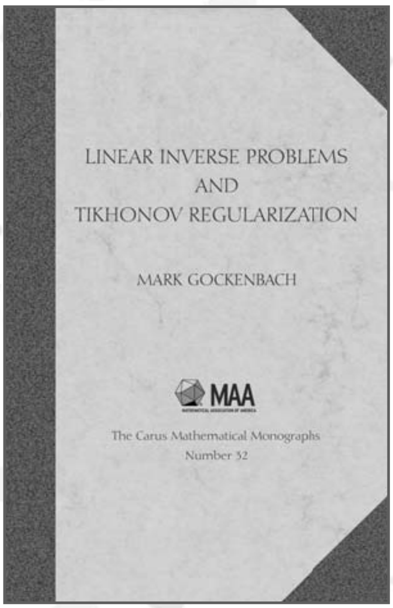
Mathematical Moments:



Thwarting Poachers, *Dis-playing the Game of Thrones*, *Trimming Taxiing Time*, *Making Art Work*, *Explaining Rainbows*, *Maintaining a Balance,* and *Farming Better*—new posters and podcasts at www.ams.org/mathmoments.

—Annette Emerson and Mike Breen
AMS Public Awareness Officers

Coming Soon from MAA Press



Linear Inverse Problems and Tikhonov Regularization

Mark Gockenbach

Carus Mathematical Monographs

Inverse problems occur frequently in science and technology, whenever we need to infer causes from effects that we can measure. Mathematically, they are difficult problems because they are unstable: small bits of noise in the measurement can completely throw off the solution. Nevertheless, there are methods for finding good approximate solutions.

Linear Inverse Problems and Tikhonov Regularization examines one such method: Tikhonov regularization for linear inverse problems defined on Hilbert spaces. This is a clear example of the power of applying deep mathematical theory to solve practical problems.

Beginning with a basic analysis of Tikhonov regularization, this book introduces the singular value expansion for compact operators, and uses it to explain why and how the method works. Tikhonov regularization with seminorms is also analyzed, which requires introducing densely defined unbounded operators and their basic properties. Some of the relevant background is included in appendices, making the book accessible to a wide range of readers.

Catalog Code: CAM-32
292 pp., Hardbound, 2016

ISBN: 978-0-88385-141-8
Price not yet set

To order, visit store.maa.org or call 1-800-331-1622.

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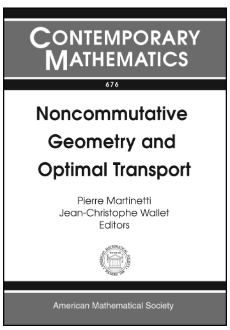
Algebra and Algebraic Geometry



Noncommutative Geometry and Optimal Transport

Pierre Martinetti, *Università di Genova, Italy*, and **Jean-Christophe Wallet**, *CNRS, Université Paris-Sud 11, Orsay, France*, Editors

This volume contains the proceedings of the Workshop on Noncommutative Geometry and Optimal Transport, held on November 27, 2014, in Besançon, France.

The distance formula in noncommutative geometry was introduced by Connes at the end of the 1980s. It is a generalization of Riemannian geodesic distance that makes sense in a noncommutative setting, and provides an original tool to study the geometry of the space of states on an algebra. It also has an intriguing echo in physics, for it yields a metric interpretation for the Higgs field. In the 1990s, Rieffel noticed that this distance is a noncommutative version of the Wasserstein distance of order 1 in the theory of optimal transport. More exactly, this is a noncommutative generalization of Kantorovich dual formula of the Wasserstein distance. Connes distance thus offers an unexpected connection between an ancient mathematical problem and the most recent discovery in high energy physics. The meaning of this connection is far from clear. Yet, Rieffel's observation suggests that Connes distance may provide an interesting starting point for a theory of optimal transport in noncommutative geometry.

This volume contains several review papers that will give the reader an extensive introduction to the metric aspect of noncommutative geometry and its possible interpretation as a Wasserstein distance on a quantum space, as well as several topic papers.

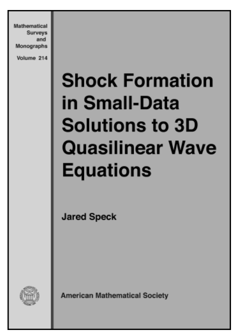
This item will also be of interest to those working in mathematical physics.

Contents: P. Martinetti, From Monge to Higgs: A survey of distance computations in noncommutative geometry; **F. Latrémolière**, Quantum metric spaces and the Gromov-Hausdorff propinquity; **M. Dubois-Violette**, Lectures on the classical moment problem and its noncommutative generalization; **N. Franco** and **J.-C. Wallet**, Metrics and causality on Moyal planes; **F. D'Andrea**, Pythagoras theorem in noncommutative geometry; **M. Guillemard**, An overview of groupoid crossed products in dynamical systems.

Contemporary Mathematics, Volume 676

November 2016, 222 pages, Softcover, ISBN: 978-1-4704-2297-4, LC 2016017993, 2010 *Mathematics Subject Classification:* 00B25, 46L87, 58B34, 53C17, 46L60, **AMS members US$86.40**, List US$108, Order code CONM/676

Differential Equations



Shock Formation in Small-Data Solutions to 3D Quasilinear Wave Equations

Jared Speck, *Massachusetts Institute of Technology, Cambridge, MA*

In 1848 James Challis showed that smooth solutions to the compressible Euler equations can become multivalued, thus signifying the onset of a shock singularity. Today it is known that, for many hyperbolic systems, such singularities often develop. However, most shock-formation results have been proved only in one spatial dimension. Serge Alinhac's groundbreaking work on wave equations in the late 1990s was the first to treat more than one spatial dimension. In 2007, for the compressible Euler equations in vorticity-free regions, Demetrios Christodoulou remarkably sharpened Alinhac's results and gave a complete description of shock formation.

In this monograph, Christodoulou's framework is extended to two classes of wave equations in three spatial dimensions. It is shown that if the nonlinear terms fail to satisfy the null condition, then for small data, shocks are the only possible singularities that can develop. Moreover, the author exhibits an open set of small data whose solutions form a shock, and he provides a sharp description of the blow-up. These results yield a sharp converse of the fundamental result of Christodoulou and Klainerman, who showed that small-data solutions are global when the null condition is satisfied.

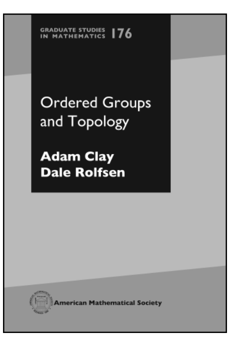
Readers who master the material will have acquired tools on the cutting edge of PDEs, fluid mechanics, hyperbolic conservation laws, wave equations, and geometric analysis.

Contents: Introduction; Overview of the two main theorems; Initial data, basic geometric constructions, and the future null condition failure factor; Transport equations for the Eikonal function quantities; Connection coefficients of the rescaled frames and geometric decompositions of the wave operator; Construction of the rotation vectorfields and their basic properties; Definition of the commutation vectorfields and deformation tensor calculations; Geometric operator commutator formulas and schematic notation for repeated differentiation; The structure of the wave equation inhomogeneous terms after one commutation; Energy and cone flux definitions and the fundamental divergence identities; Avoiding derivative loss and other difficulties via modified quantities; Small data, sup-norm bootstrap assumptions, and first pointwise estimates; Sharp estimates for the inverse foliation density; Square integral coerciveness and the fundamental square-integral-controlling quantities; Top-order pointwise commutator estimates involving the Eikonal function; Pointwise estimates for the easy error integrands and identification of the difficult error integrands corresponding to the commuted wave equation; Pointwise estimates for the difficult error integrands corresponding to the commuted wave equation; Elliptic estimates and Sobolev embedding on the spheres; Square integral estimates for the Eikonal function quantities that do not rely on modified quantities; A priori estimates for the fundamental square-integral-controlling quantities; Local well-posedness and continuation criteria; The sharp classical lifespan theorem; Proof of shock formation for nearly spherically symmetric data; Extension of the results to a class of non-covariant wave equations; Summary of notation and conventions; Bibliography; Index.

Mathematical Surveys and Monographs, Volume 214

December 2016, approximately 518 pages, Hardcover, ISBN: 978-1-4704-2857-0, LC 2016022109, 2010 *Mathematics Subject Classification:* 35L67; 35L05, 35L10, 35L72, 35Q31, 35L15, **AMS members US$88**, List US$110, Order code SURV/214

Geometry and Topology



Ordered Groups and Topology

Adam Clay, *University of Manitoba, Winnipeg, MB, Canada*, and **Dale Rolfsen**, *University of British Columbia, Vancouver, BC, Canada*

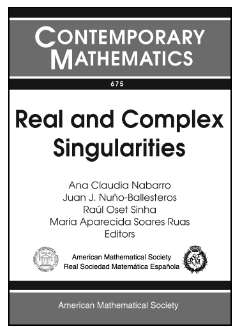
This book deals with the connections between topology and ordered groups. It begins with a self-contained introduction to orderable groups and from there explores the interactions between orderability and objects in low-dimensional topology, such as knot theory, braid groups, and 3-manifolds, as well as groups of homeomorphisms and other topological structures. The book also addresses recent applications of orderability in the studies of codimension-one foliations and Heegaard-Floer homology. The use of topological methods in proving algebraic results is another feature of the book.

The book was written to serve both as a textbook for graduate students, containing many exercises, and as a reference for researchers in topology, algebra, and dynamical systems. A basic background in group theory and topology is the only prerequisite for the reader.

Contents: Orderable groups and their algebraic properties; Hölder's theorem, convex subgroups and dynamics; Free groups, surface groups and covering spaces; Knots; Three-dimensional manifolds; Foliations; Left-orderings of the braid groups; Groups of homeomorphisms; Conradian left-orderings and local indicability; Spaces of orderings; Bibliography; Index.

Graduate Studies in Mathematics, Volume 176

December 2016, 154 pages, Hardcover, ISBN: 978-1-4704-3106-8, LC 2016029680, 2010 *Mathematics Subject Classification:* 20-02, 57-02; 20F60, 57M07, **AMS members US$63.20**, List US$79, Order code GSM/176



Real and Complex Singularities

Ana Claudia Nabarro, *Universidade de São Paulo, São Carlos, SP, Brazil*, **Juan J. Nuño-Ballesteros**, *Universitat de València, Burjassot, València, Spain*, **Raúl Oset Sinha**, *Universitat de València, Burjassot, València, Spain*, and **Maria Aparecida Soares Ruas**, *Universidade de São Paulo, São Carlos, SP, Brazil*, Editors

This volume is a collection of papers presented at the XIII International Workshop on Real and Complex Singularities, held from July 27–August 8, 2014, in São Carlos, Brazil, in honor of María del Carmen Romero Fuster's 60th birthday.

The volume contains the notes from two mini-courses taught during the workshop: on intersection homology by J.-P. Brasselet, and on non-isolated hypersurface singularities and Lê cycles by D. Massey. The remaining contributions are research articles which cover topics from the foundations of singularity theory (including classification theory and invariants) to topology of singular spaces (links of singularities and semi-algebraic sets), as well as applications to topology (cobordism and Lefschetz fibrations), dynamical systems (Morse-Bott functions) and differential geometry (affine geometry, Gauss-maps, caustics, frontals and non-Euclidean geometries).

Contents: **R. I. Baykur** and **K. Hayano**, Hurwitz equivalence for Lefschetz fibrations and their multisections; **R. R. Binotto**, **S. I. R. Costa**, and **M. C. Romero Fuster**, The curvature Veronese of a 3-manifold immersed in Euclidean space; **J.-P. Brasselet**, Introduction to intersection homology with and without sheaves; **D. Dreibelbis**, Gauss maps and duality of sphere bundles; **N. Dutertre** and **J. A. Moya-Pérez**, Topological formulas for closed semi-algebraic sets by Euler integration; **A. Honda**, On associate families of spacelike Delaunay surfaces; **S. Ichiki** and **T. Nishimura**, Generalized distance-squared mappings of $\mathbb{R}^{n+1}$ into $\mathbb{R}^{2n+1}$; **S. Izumiya**, Caustics of world hyper-sheets in the Minkowski space-time; **M. Kawashima**, On genericity of a linear deformation of an isolated singularity; **J. Martínez-Alfaro**, **I. S. Meza-Sarmiento**, and **R. Oliveira**, Topological classification of simple Morse Bott functions on surfaces; **R. Martins** and **J. J. Nuño-Ballesteros**, The link of a frontal surface singularity; **D. B. Massey**, Non-isolated hypersurface singularities and Lê cycles; **R. Mendes** and **J. J. Nuño-Ballesteros**, Knots and the topology of singular surfaces in $\mathbb{R}^4$; **A. J. Miranda** and **M. J. Saia**, A presentation matrix associated to the discriminant of a co-rank one map-germ from $\mathbb{C}^n$ to $\mathbb{C}^n$; **M. G. Monera** and **E. Sanabria-Codesal**, Critical points of the Gauss map and the exponential tangent map; **G. Reeve** and **F. Tari**, Minkowski medial axes and shocks of plane curves; **O. Saeki** and **T. Yamamoto**, Cobordism group of Morse functions on surfaces with boundary; **M. J. Saia** and **L. F. Sánchez**, Affine metric for locally strictly convex manifolds of codimension 2; **K. Saji**, Criteria for Morin singularities for maps into lower dimensions, and applications; **M. Takahashi**, Legendre curves in the unit spherical bundle over the unit sphere and evolutes.

Contemporary Mathematics, Volume 675

November 2016, approximately 359 pages, Softcover, ISBN: 978-1-4704-2205-9, LC 2016010844, 2010 *Mathematics Subject Classification:* 58Kxx, 32Sxx, 53Axx, 57Rxx, 14Pxx, 37Dxx, **AMS members US$86.40**, List US$108, Order code CONM/675

New AMS-Distributed Publications

Algebra and Algebraic Geometry

Development of Moduli Theory—Kyoto 2013

Osamu Fujino, *Osaka University, Japan*, **Shigeyuki Kondô**, *Nagoya University, Japan*, **Atsushi Moriwaki**, *Kyoto University, Japan*, **Masa-Hiko Saito**, *Kobe University, Japan*, and **Kōta Yoshioka**, *Kobe University, Japan*, Editors

This volume contains the proceedings of the 6th Mathematical Society of Japan Seasonal Institute—Development of Moduli Theory, which was held as the Seasonal Institute 2013, with support from the Mathematical Society of Japan and the 2013 Research Project of the Research Institute of Mathematical Science, Kyoto University.

This volume, dedicated to Shigeru Mukai on the occasion of his sixtieth birthday, consists of five survey articles and eight research articles.

This item will also be of interest to those working in number theory.

Published for the Mathematical Society of Japan by Kinokuniya, Tokyo, and distributed worldwide, except in Japan, by the AMS.

Advanced Studies in Pure Mathematics, Volume 69

July 2016, 537 pages, Hardcover, ISBN: 978-4-86497-032-7, 2010 *Mathematics Subject Classification:* 14-06; 11G50, 14C05, 14C22, 14C25, 14C30, 14D20, 14D21, 14D23, 14H10, 14H50, 14J10, 14J15, 14J26, 14J27, 14J28, 14J29, 14J50, 14J60, 14K10, 14K25, 14N35, 18E30, 32M15, 32N15, **AMS members US$136.80**, List US$171, Order code ASPM/69

Analysis

School on Real and Complex Singularities in São Carlos, 2012

Raimundo Nonato Araújo dos Santos, *Universidade de São Paulo, São Carlos, SP, Brazil*, **Victor Hugo Jorge Pérez**, *Universidade de São Paulo, São Carlos, SP, Brazil*, **Takashi Nishimura**, *Yokohama National University, Japan*, and **Osamu Saeki**, *Kyushu University, Fukuoka, Japan*, Editors

This volume is a collection of six lecture notes presented at the School on Singularity Theory, São Carlos, Brazil, July 16–21, 2012, or at the 12th International Workshop on Real and Complex Singularities, São Carlos, Brazil, July 22–27, 2012. Topics treated in the six lecture notes written by established authors cover a wide range, including topology and geometry of real singularities, singularities of holomorphic map-germs, singularities of complex algebraic sets, algorithms of the computer algebra "SINGULAR", singularities of maps and characteristic classes, and limit cycles of systems of ordinary differential equations.

Each lecture note is extremely well written with plenty of examples and may be considered excellent reading on the relevant topic. This book is suitable as a desktop reference and is widely recommended for graduate students studying singularity theory and researchers in various fields who would like to enjoy the world of singularities.

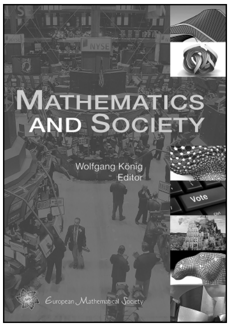
This item will also be of interest to those working in algebra and algebraic geometry.

Published for the Mathematical Society of Japan by Kinokuniya, Tokyo, and distributed worldwide, except in Japan, by the AMS.

Advanced Studies in Pure Mathematics, Volume 68

July 2016, 373 pages, Hardcover, ISBN: 978-4-86497-030-3, 2010 *Mathematics Subject Classification:* 32Sxx; 14Pxx, 14Bxx, 14Qxx, 57Rxx, 34Cxx, **AMS members US$100.80**, List US$126, Order code ASPM/68

General Interest



Mathematics and Society

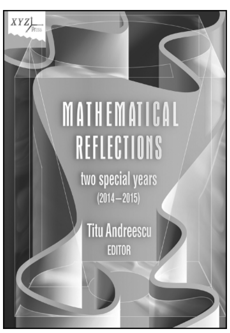
Wolfgang König, *Weierstrass Institute for Applied Analysis and Stochastics, Berlin, Germany, and Technical University of Berlin, Germany*, Editor

The ubiquity and importance of mathematics in our complex society is generally not in doubt. However, even a scientifically interested layperson would be hard pressed to point out aspects of our society where contemporary mathematical research is essential. The way mathematics comes into play in finance, engineering, weather and industry is widely unknown by the public. And who thinks of application fields such as biology, encryption, architecture, or voting systems?

This volume comprises a number of success stories of mathematics in our society—important areas being shaped by cutting-edge mathematical research. The authors are eminent mathematicians with a strong talent for public presentation, addressing scientifically interested laypersons as well as professionals in mathematics and its application disciplines.

July 2016, 314 pages, Hardcover, ISBN: 978-3-03719-164-4, 2010 *Mathematics Subject Classification:* 00-XX, **AMS members US$38.40**, List US$48, Order code EMSMATHSOC

Math Education



Mathematical Reflections: Two Special Years (2014–2015)

Titu Andreescu, *University of Texas at Dallas, TX*, Editor

This book, a compilation and revision of the 2014 and 2015 volumes from the online journal of the same name, is aimed at high school students, participants in math competitions, undergraduates, and anyone who has a fire for mathematics. Passionate readers submitted many of the problems, solutions, and articles and all require creativity, experience, and comprehensive mathematical knowledge.

This book is a great resource for students training for advanced national and international mathematics competitions such as USAMO and IMO.

A publication of XYZ Press. Distributed in North America by the American Mathematical Society.

XYZ Series, Volume 20

June 2016, 583 pages, Hardcover, ISBN: 978-0-9968745-3-3, 2010 *Mathematics Subject Classification:* 00A05, 00A07, 97U40, 97D50, **AMS members US$47.96**, List US$59.95, Order code XYZ/20

Classified Advertisements

Positions available, items for sale, services available, and more

CALIFORNIA

CALIFORNIA INSTITUTE OF TECHNOLOGY
Harry Bateman Research Instructorships in Mathematics

Description: Appointments are for two years with one-year terminal extension expected. The academic year runs from approximately October 1 to June 1. Instructors typically are expected to teach one course per quarter for the full academic year and to devote the rest of their time to research. During the summer months there are no duties except research.

Eligibility: Open to persons who have recently received their doctorates in mathematics.

Deadline: January 1, 2017.

Application information: Please apply online at `MathJobs.Org`. You can also find information about this position at `pma.caltech.edu/content/mathematics-postdoctoral-scholars`. To avoid duplication of paperwork, your application may also be considered for an Olga Taussky and John Todd Instructorship. Caltech is an Affirmative Action/Equal Opportunity Employer. Women, minorities, veterans, and disabled persons are encouraged to apply.

000024

CALIFORNIA INSTITUTE OF TECHNOLOGY
Olga Taussky and John Todd Instructorships in Mathematics

Description: Appointments are for three years. There are three terms in the Caltech academic year, and instructors typically are expected to teach one course in all but two terms of the total appointment. These two terms will be devoted to research. During the summer months there are no duties except research.

Eligibility: Offered to persons within three years of having received the PhD who show strong research promise in one of the areas in which Caltech's mathematics faculty is currently active.

Deadline: January 1, 2017.

Application information: Please apply online at `MathJobs.Org`. You can also find information about this position at `pma.caltech.edu/content/mathematics-postdoctoral-scholars`. To avoid duplication of paperwork, your application may also be considered for an Olga Taussky and John Todd Instructorship. Caltech is an Affirmative Action/Equal Opportunity Employer. Women, minorities, veterans, and disabled persons are encouraged to apply.

000026

CALIFORNIA INSTITUTE OF TECHNOLOGY
Senior Postdoctoral Scholar in Mathematics

Description: There are three terms in the Caltech academic year. The fellow is typically expected to teach one course in two terms each year, and is expected to be in residence even during terms when not teaching. The initial appointment is for three years with an additional three-year terminal extension expected.

Eligibility: Offered to a candidate within six years of having received the PhD who shows strong research promise in one of the areas in which Caltech's mathematics faculty is currently active.

Deadline: January 1, 2017.

Application information: Please apply online at `MathJobs.Org`. You can also find information about this position at `pma.caltech.edu/content/mathematics-postdoctoral-scholars`. To avoid duplication of paperwork, your application may also be considered for an Olga Taussky and John Todd Instructorship. Caltech is an Affirmative Action/Equal Opportunity Employer. Women, minorities, veterans, and disabled persons are encouraged to apply.

000025

Suggested uses for classified advertising are positions available, books or lecture notes for sale, books being sought, exchange or rental of houses, and typing services. The publisher reserves the right to reject any advertising not in keeping with the publication's standards. Acceptance shall not be construed as approval of the accuracy or the legality of any advertising.

The 2016 rate is $3.50 per word with a minimum two-line headline. No discounts for multiple ads or the same ad in consecutive issues. For an additional $10 charge, announcements can be placed anonymously. Correspondence will be forwarded.

Advertisements in the "Positions Available" classified section will be set with a minimum one-line headline, consisting of the institution name above body copy, unless additional headline copy is specified by the advertiser. Headlines will be centered in boldface at no extra charge. Ads will appear in the language in which they are submitted.

There are no member discounts for classified ads. Dictation over the telephone will not be accepted for classified ads.

Upcoming deadlines for classified advertising are as follows: January 2017—October 31, 2016; February 2017—November 23, 2016; March 2017—January 2, 2017; April 2017—January 30, 2017; May 2017—March 2, 2017; June 2017—April 28, 2017.

US laws prohibit discrimination in employment on the basis of color, age, sex, race, religion, or national origin. "Positions Available" advertisements from institutions outside the US cannot be published unless they are accompanied by a statement that the institution does not discriminate on these grounds whether or not it is subject to US laws. Details and specific wording may be found on page 1373 (vol. 44).

Situations wanted advertisements from involuntarily unemployed mathematicians are accepted under certain conditions for free publication. Call toll-free 800-321-4AMS (321-4267) in the US and Canada or 401-455-4084 worldwide for further information.

Submission: Promotions Department, AMS, P.O. Box 6248, Providence, Rhode Island 02904; or via fax: 401-331-3842; or send email to `classads@ams.org`. AMS location for express delivery packages is 201 Charles Street, Providence, Rhode Island 02904. Advertisers will be billed upon publication.

UNIVERSITY OF CALIFORNIA, LOS ANGELES
Department of Mathematics
Faculty Positions 2017–18

Tenured/Tenure-Track positions 2017–18 (subject to administrative approval)

The Department of Mathematics at the University of California, Los Angeles, invites applications for tenure-track or tenured faculty positions starting July 1, 2017. Outstanding candidates in all areas of mathematics may be considered.

Applicants must possess a PhD and should have outstanding accomplishments in both research and teaching. Duties include mathematical research, undergraduate and graduate teaching, and departmental and university service. Level of appointment will be based on qualifications, with appropriate salary per UC pay scales.

The department is especially interested in candidates who can contribute to the diversity & excellence of the academic community through teaching and service. Applications and supporting documentation for all positions must be submitted online via www.mathjobs.org.

Applications will be accepted until the position is filled. To guarantee full consideration, the application should be received by November 15, 2016.

Temporary Faculty Positions 2017–18 The Department of Mathematics at the University of California, Los Angeles, invites applications for temporary and visiting appointments in the categories 1–4 below. Depending on the level, candidates must give evidence of potential or demonstrated distinction in scholarship and teaching. Applicants must possess a PhD and should have outstanding accomplishments in both research and teaching. Postdoctoral Positions:

(1) E.R. Hedrick Assistant Professorships: Appointments are for three years. The teaching load is four one-quarter courses per year.

(2) Computational and Applied Mathematics (CAM) Assistant Professorships: Appointments are for three years. The teaching load is normally reduced by research funding to two one-quarter courses per year.

(3) Program in Computing (PIC) Assistant Adjunct Professorships: Applicants for these positions must show very strong promise in teaching and research in an area related to computing. The teaching load is four one-quarter programming courses each year and one additional course every two years. Initial appointments are for one year and possibly longer, up to a maximum service of four years.

(4) Assistant Adjunct Professorships and Research Postdocs: Appointments are normally for one year, with the possibility of renewal. Strong research and teaching background required. The teaching load is six one-quarter courses per year.

(5) RTG Assistant Adjunct Professorship in Analysis: Salary is $59,400, and appointments are for three years. This position is limited to US citizens or permanent residents who have received a PhD within 18 months of June 1, 2017. The successful recipient will receive a summer stipend of $10,000 for two summers and $9,000 over three years for travel, equipment, and supplies. The teaching load is three one-quarter courses per year.

Appointments will be effective July 1, 2017, or later. Applications will be accepted until all positions are filled. For fullest consideration, all application materials should be submitted on or before November 15, 2016.

Applications and supporting documentation must be submitted online via www.mathjobs.org.

All letters of evaluation are subject to UCLA campus policies on confidentiality. Refer potential reviewers to the UCLA statement of confidentiality at www.apo.ucla.edu/policies/the-call/summary-of-procedures/summary-10-statement-of-confidentiality.

Lecturer Positions in Mathematics

The UCLA Department of Mathematics receives on an ongoing basis applications for quarter positions (Fall/Winter/Spring or for Summer Session) for Lecturers to teach undergraduate Mathematics, Financial Actuarial Mathematics, or Math Education courses. Positions are very limited and temporary. Responsibilities include lecturing, conducting office hours, writing and grading exams and supervising teaching assistants. Previous teaching experience at the college level or extensive actuary experience is required and a PhD is preferred. Applications will be accepted until all positions are filled.

The University of California is an Equal Opportunity/Affirmative Action Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, national origin, disability, age or protected veteran status. For the complete University of California nondiscrimination and affirmative action policy see: UC Nondiscrimination and Affirmative Action Policy, policy.ucop.edu/doc/4000376/NondiscrimAffirmAct.

The University of California asks that applicants complete the Equal Opportunity Employer survey for Letters and Science at the following URL: cis.ucla.edu/facultysurvey/. Under Federal Law, the University of California may employ only individuals who are legally authorized to work in the United States as established by providing documents specified in the Immigration Reform and Control Act of 1986.

000039

UNIVERSITY OF CALIFORNIA, SAN DIEGO
Assistant Associate, or Full Professor, Mathematics and Statistics

The Department of Mathematics, within the Division of Physical Sciences at the University of California, San Diego (www.math.ucsd.edu), invites applications for up to four tenure-track positions and up to one tenured position. One of the tenure-track positions is expected to be filled in applied mathematics (including statistics), and the other positions are open to applicants from all areas of pure and applied mathematics and statistics. The tenured position is open to applicants from all areas of pure and applied mathematics and statistics with a preference for topology or a related field. All positions are subject to budgetary approval.

The University is committed to an excellent and diverse staff, faculty, and student body. Successful candidates will be evaluated on research and teaching accomplishments, as well as leadership in areas contributing to diversity, equity and inclusion.

Candidates must receive their PhD prior to their first quarter of teaching. Salary is commensurate with qualifications and based on UC pay scales. The starting date for the positions will be July 1, 2017. Review of applications will commence on November 1, 2016, and continue until the positions are filled.

Submit applications online through https://www.mathjobs.org.

For the Assistant Professor position apply here: https://www.mathjobs.org/jobs/jobs/8982.

For the Associate or Full Professor position apply here: https://www.mathjobs.org/jobs/jobs/8999.

EOE/AA

000045

UNIVERSITY OF CALIFORNIA, SAN DIEGO
Tenure-Track Faculty, Mathematics and Statistics

The Department of Mathematics, within the Division of Physical Sciences at the University of California, San Diego (www.math.ucsd.edu), invites applications for a tenure-track faculty position. This is a broad search that is open to applicants from all areas of pure and applied mathematics and statistics. Successful candidates must have a PhD and demonstrated potential for excellence in both teaching and research.

The University is committed to an excellent and diverse staff, faculty, and student body. Preferred candidates will have the potential for leadership in areas contributing to diversity, equity, and inclusion and will have a desire to play a future role in helping to shape and expand the University's diversity initiatives (diversity.ucsd.edu/). We especially welcome candidates who have experience with and wish to contribute to programs that increase the access and success of underrepresented students and faculty in mathematics. Positions are subject to availability of funding.

Candidates must receive their PhD prior to their first quarter of teaching. Salary is commensurate with qualifications and based on UC pay scales. The starting date for the position will be July 1, 2017. Review of applications will commence on November 1, 2016, and continue until the position is filled.

Submit applications online through https://www.mathjobs.org/jobs/jobs/8954.

EOE/AA

000044

ILLINOIS

UNIVERSITY OF CHICAGO
Department of Mathematics

The University of Chicago Department of Mathematics invites applications for the following positions:

1. L. E. Dickson Instructor: This is open to mathematicians who have recently completed or will soon complete a doctorate in mathematics or a closely related field, and whose work shows remarkable promise in mathematical research. The initial appointment is typically up to three years with the possibility of renewal. The teaching obligation is up to four one-quarter courses per year.

2. Assistant Professor: This is open to mathematicians who are further along in their careers, typically two or three years past the doctorate. These positions are intended for mathematicians whose work has been of outstandingly high caliber. Appointees are expected to have the potential to become leading figures in their fields. The appointment is generally for three years, with the possibility for renewal and a teaching obligation of up to three one-quarter courses per year.

Applicants will be considered for any of the positions above which seem appropriate. Complete applications consist of (a) a cover letter, (b) a curriculum vitae, (c) three or more letters of reference, at least one of which addresses teaching ability, and (d) a description of previous research and plans for future mathematical research. Applicants are strongly encouraged to include information related to their teaching experience, such as a teaching statement or evaluations from courses previously taught, as well as an AMS cover sheet. If you have applied for an NSF Mathematical Sciences Postdoctoral Fellowship, please include that information in your application, and let us know how you plan to use it if awarded.

Applications must be submitted online through MathJobs.Org. Questions may be directed to: apptsec@math.uchicago.edu. We will begin screening applications on November 1, 2016. Screening will continue until all available positions are filled. The University of Chicago is an Affirmative Action/Equal Opportunity/Disabled/Veterans Employer and does not discriminate on the basis of race, color, religion, sex, sexual orientation, gender identity, national or ethnic origin, age, status as an individual with a disability, protected veteran status, genetic information, or other protected classes under the law. For additional information please see the University's Notice of Nondiscrimination at www.uchicago.edu/about/non_discrimination_statement/. Job seekers in need of a reasonable accommodation to complete the application process should call 773-702-7328 or e-mail jgarza@math.uchicago.edu with their request.

000053

MASSACHUSETTS

BOSTON COLLEGE
The Department of Mathematics

The Department of Mathematics at Boston College invites applications for tenure-track positions at the level of Assistant Professor beginning in fall 2017. We are particularly interested in candidates in geometry, topology, number theory, and representation theory, but will consider candidates in other areas. In exceptional cases, a higher-level appointment may be considered. The teaching load for each position is three semester courses per year. Requirements include a PhD or equivalent in Mathematics awarded in 2015 or earlier, a record of very strong research combined with outstanding research potential, and demonstrated excellence in teaching mathematics. A completed application should contain a cover letter, a description of research plans, a statement of teaching philosophy, curriculum vitae, and at least four letters of recommendation. One or more of the letters of recommendation should directly comment on the candidate's teaching credentials. Applications completed by November 1, 2016, will be assured our fullest consideration. Please submit all application materials through MathJobs.Org. Applicants may learn more about the Department, its Faculty and its programs, and about Boston College at www.bc.edu/math. Electronic inquiries concerning these positions may be directed to math@bc.edu. Boston College is an Affirmative Action/Equal Opportunity Employer. Applications from women, minorities and individuals with disabilities are encouraged.

000051

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, MA

The Mathematics Department at MIT is seeking to fill positions in Pure and Applied Mathematics, and Statistics at the level of Assistant Professor or higher beginning July 2017 (for the 2017–2018 academic year, or as soon thereafter as possible). Appointments are based primarily on exceptional research qualifications. Appointees will be required to fulfill teaching duties and pursue their own research program. PhD in Mathematics or related field required by employment start date.

For more information and to apply, please visit www.mathjobs.org. To receive full consideration, submit applications by December 1, 2016. MIT is an Equal Opportunity, Affirmative Action Employer.

000036

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, MA

The Mathematics Department at MIT is seeking to fill positions in Pure and Applied Mathematics, and Statistics at the level of Instructor beginning July 2017 (for the 2017–2018 academic year). Appointments are based primarily on exceptional research qualifications. Appointees will be expected to fulfill teaching duties and pursue their own research program. PhD in Mathematics or related field required by employment start date.

For more information and to apply, please visit www.mathjobs.org. To receive full consideration, submit applications by December 1, 2016. MIT is an Equal Opportunity, Affirmative Action Employer.

000037

TUFTS UNIVERSITY
Department of Mathematics
Tenure-Track Position Complex Geometry

Applications are invited for a tenure-track Assistant Professor position in Complex Geometry, including complex algebraic geometry and complex differential geometry, to begin July 1, 2017. Applicants must hold a doctorate by the beginning of the appointment, must have an active research program, must show promise of outstanding research, and must exhibit a strong commitment to excellence in teaching. Preference may be given to candidates who show potential for interaction with mathematical researchers in the department. There are also many opportunities for interdisciplinary connections with faculty at Tufts beyond the Mathematics Department.

Applications should include a cover letter, curriculum vitae, a research statement, and a teaching statement. These documents should be submitted electronically through https://www.mathjobs.org/jobs/jobs/9043. In addition, applicants should arrange for three letters of recommendation to be submitted electronically on their behalf through www.mathjobs.org. If a recommender cannot submit online, we will also accept signed PDF attachments sent to loring.tu@tufts.edu or paper letters mailed to CG Search Committee Chair, Department of Mathematics, 503 Boston Ave., Tufts University, Medford, MA 02155.

Review of applications will begin on November 4, 2016, and will continue until the position is filled.

Tufts University is an Affirmative Action/Equal Opportunity Employer and is committed to increasing the diversity of its faculty. Members of underrepresented groups are strongly encouraged to apply.

000054

WILLIAMS COLLEGE
Tenure-Track Assistant
Professor of Mathematics

The Williams College Department of Mathematics and Statistics invites applications for two tenure-track positions in mathematics, beginning fall 2017, at the rank of assistant professor (in an exceptional case, a more advanced appointment may be considered). We are seeking highly qualified candidates who have demonstrated excellence in teaching and research and who are committed to working with an increasingly diverse student body. The teaching load is four 12-week semester courses per year and a pass-fail Winter Study class every other January. Preference will be given to candidates who will have a PhD in mathematics by September 2017. We welcome applications from members of groups traditionally underrepresented in the field.

Applicants can apply electronically at MathJobs.Org. Evaluations of applications will begin on or after November 15 and will continue until the position is filled. All offers of employment are contingent upon completion of a background check dean-faculty.williams.edu/prospective-faculty/background-check-policy.

For more information on the Department of Mathematics and Statistics, visit math.williams.edu/.

Williams College is a coeducational liberal arts institution located in the Berkshire Hills of western Massachusetts. The college has built its reputation on outstanding teaching and scholarship and on the academic excellence of its approximately 2,000 students. Please visit the Williams College website (www.williams.edu).

Beyond meeting fully its legal obligations for nondiscrimination, Williams College is committed to building a diverse and inclusive community where members from all backgrounds can live, learn, and thrive.

000038

NEW JERSEY

INSTITUTE FOR ADVANCED STUDY
School of Math
Princeton, NJ 08540

The School of Mathematics at the Institute for Advanced Study has a limited number of memberships with financial support for research during the 2017–18 academic year. The School frequently sponsors special programs. However, these programs comprise no more than one-third of the memberships so that each year a wide range of mathematics is supported. Candidates must give evidence of ability in research comparable at least with that expected for the PhD degree, but otherwise can be at any career stage. Successful candidates will be free to devote themselves full time to research. About half of our members will be postdoctoral researchers within 5 years of their PhD. We expect to offer some two-year postdoctoral positions. Up to 8 von Neumann Fellowships will be available for each academic year. To be eligible for the von Neumann Fellowships, applications should be at least 5, but no more than 15 years following the receipt of their PhD. The Veblen Research Instructorship is a three-year position in partnership with the department of Mathematics at Princeton University. Three-year instructorships will be offered each year to candidates in pure and applied mathematics who have received their PhD within the last 3 years. Usually the first and third year of the instructorship will be spent at Princeton University and will carry regular teaching responsibilities. The second year is spent at the Institute and dedicated to independent research of the instructor's choice. Candidates interested in a Veblen instructorship position may apply directly at the IAS website https://applications.ias.edu or they may apply through MathJobs.Org. If they apply at MathJobs.Org, they must also complete the application form at https://applications.ias.edu but do not need to submit a second set of reference letters. Questions about the application procedure should be addressed to applications@math.ias.edu. In addition, there are also two-year postdoctoral positions in computer science and discrete mathematics offered jointly with the following institutions: The Department of Computer Science at Princeton University, www.cs.princeton.edu, DIMACS at Rutgers, The State University of New Jersey, www.dimacs.rutgers.edu and the Simons Foundation Collaboration on Algorithms and Geometry, www.simonsfoundation.org/mathematics-and-physical-science/algorithms-and-geometry-collaboration/. School term dates for 2017–18 academic year are: term I, Monday September 25 to Friday December 22, 2017; term II, Monday January 15, 2018, to Friday, April 13, 2018. During the 2017–18 year, the School will have a special program on Locally Symmetric Spaces: Analytical and Topological Aspects. Akshay Venkatesh of Stanford University will be the Distinguished Visiting Professor. The topology of locally symmetric spaces interacts richly with number theory via the theory of automorphic forms (Langlands program). Many new phenomena seem to appear in the non-Hermitian case (e.g., torsion cohomology classes, relations with mixed motives and algebraic K-theory, derived nature of deformation rings). One focus of the program will be to try to better understand some of these phenomena. Much of our understanding of this topology comes through analysis Hodge theory). Indeed harmonic analysis on locally symmetric spaces plays a foundational role in the theory of automorphic forms and is of increasing importance in analytic number theory. A great success of such harmonic analysis is the Arthur-Selberg trace formula; on the other hand, the analytic aspects of the trace formula are not fully developed, and variants such as the relative trace formula are not as well understood. Thus analysis on such spaces, interpreted broadly, will be another focus of the program.

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RUTGERS UNIVERSITY
NEW BRUNSWICK
Mathematics Department

The Mathematics Department of Rutgers University—New Brunswick invites applications for the following positions which may be available September 2017.

TENURE-TRACK ASSISTANT/TENURED ASSOCIATE/TENURED FULL PROFESSORSHIP: Subject to availability of funding, the Department expects at least two openings at the level of Tenure-Track Assistant Professor. In exceptional cases, there may be the possibility of appointment at a higher level. Candidates must have a PhD and have a strong record of research accomplishments in pure or applied mathematics as well as effective teaching. The Department has hiring priorities in Discrete Mathematics, Mathematical Data Analysis, Geometry/Topology, Analysis, and Algebra. However, outstanding candidates in any field of pure or applied mathematics will be considered. The normal teaching load for research-active faculty is 2-1. Review of applications begins November 1, 2016.

HILL AND OTHER ASSISTANT PROFESSORSHIPS: These are three-year nontenure-track, nonrenewable, Post-Doctoral appointments. Subject to availability of funding, the department expects three positions of this nature. These positions carry a reduced teaching load of 2-1 for research; candidates should have received a PhD and show outstanding promise of research ability in pure or applied mathematics as well as a capacity for effective teaching. Review of applications begins December 1, 2016.

Applicants for the above positions should submit a curriculum vitae (including a publication list) and arrange for four letters of reference to be submitted, one of which evaluates teaching. Applicants should first go to the website `https://www.mathjobs.org/jobs` and fill out the AMS Cover Sheet electronically. It is essential to fill out the cover sheet completely, including naming the positions being applied for (TTAP, HILL, PD, respectively). The strongly preferred way to submit the CV, references, and any other application materials is online at: `https://www.mathjobs.org/jobs`. Alternatively, the materials may be filed at the listing at `https://jobs.rutgers.edu`.

Rutgers, the State University of New Jersey, is an Equal Opportunity/Affirmative Action Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity or expression, national origin, disability, protected veteran status or any other classification protected by law.

000043

NORTH CAROLINA

THE UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
Tenured/Tenure-Track Associate Professor of Numerical PDEs

The University of North Carolina at Greensboro (UNCG), Department of Mathematics and Statistics seeks applications for one tenured/tenure-track position in Numerical Partial Differential Equations at the Associate Professor rank beginning August 1, 2017. Candidates must hold a PhD in mathematics or a closely related discipline and have qualifications to be hired at the Associate Professor rank. Tenure may be offered at the associate professor rank depending on the selected candidate's qualifications. Competitive applicants will have research expertise that strengthens our PhD program in Computational Mathematics and be ready to direct PhD students. Successful applicants will be expected to excel in teaching, maintain a vigorous research program, seek external research funding, contribute to the interdisciplinary mission at UNCG, and educate a diverse group of undergraduate and graduate students from various background. Application materials should be submitted electronically to `www.mathjobs.org`. Review of applications will begin on December 15, 2016, and will continue until the position is filled. UNCG is especially proud of the diversity of its student body which is 43 percent ethnic minority (`admissions.uncg.edu/discover-about.php`). UNCG has been designated as a Minority Serving Institution by the US Department of Education. We seek to attract a diverse applicant pool for this position, especially women and members of minority groups, and we are strongly committed to increasing faculty diversity. UNCG is an EOE AA/M/F/D/V employer.

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THE UNIVERSITY OF NORTH CAROLINA AT GREENSBORO
Tenure-Track Assistant Professor of Computational Topology

The University of North Carolina at Greensboro, Department of Mathematics and Statistics seeks applications for one tenure-track position in Computational Topology at the Assistant Professor rank beginning August 1, 2017. Candidates must hold (or anticipate) a PhD in mathematics or closely related area by August 1, 2017. Competitive applicants will have research expertise that strengthens our PhD program in Computational Mathematics. Successful applicants will be expected to excel in teaching, maintain a vigorous research program, seek external research funding, contribute to the interdisciplinary mission at UNCG, and educate a diverse group of undergraduate and graduate students from various backgrounds. Application materials should be submitted electronically to `www.mathjobs.org`. Review of applications will begin on December 15, 2016, and will be continued until filled. UNCG is especially proud of the diversity of its student body which is 43 percent ethnic minority (`admissions.uncg.edu/discover-about.php`). UNCG has been designated as a Minority Serving Institution by the US Department of Education. We seek to attract a diverse applicant pool for this position, especially women and members of minority groups, and we are strongly committed to increasing faculty diversity. UNCG is an EOE AA/M/F/D/V employer.

000048

UTAH

THE UNIVERSITY OF UTAH
Biophysics/Neuroscience/Chemical Biology Cluster

Biophysics/Neuroscience/Chemical Biology Cluster, University of Utah. The proposed cluster comprises multiple tenure-track faculty positions to establish excellence in emerging interdisciplinary fields; departmental appointments may be in Physics, Biology, Chemistry, Mathematics or Biochemistry. A major goal is to strengthen both Cellular and Molecular Neuroscience and Biophysics, as well as to link Neuroscience to the Chemical Biology of Natural Products. All candidates are expected to demonstrate the ability to develop a vigorous, competitive and well-funded research program and will be evaluated on how their research potentially contributes to the long-term goal of excellence in interdisciplinary bridge areas. Applications by investigators, both experimental and theoretical, interested in macromolecular complexes on membranes are particularly encouraged. An undergraduate track in Neuroscience and Biophysics will be established within the College of Science, and faculty hired through this cluster are expected to participate in the development and teaching of innovative courses related to this initiative. We expect to make two or more faculty appointments in the 2016–2017 academic year, with additional appointments in subsequent years. While the openings are at the Assistant Professor level, exceptional senior candidates will be considered.

Assistant Professor applicants should upload an application letter with vita, a description of proposed research, and arrange for three letters of recommendation to be sent on their behalf. Senior applicants should upload an application letter and CV. Applications should be uploaded in PDF format to `utah.peopleadmin.com/postings/55718`. Initial interview selections will begin on October 15, 2016, but applications submitted at a later date will be considered as needed.

The University of Utah values candidates who have experience working with students from diverse backgrounds and possess a strong commitment to improving access to higher education for historically underrepresented groups. The University of Utah is an equal opportunity/affirmative action employer and educator. Minorities, women, veterans and those with disabilities are strongly encouraged to apply. Veterans' Preference is extended to qualified veterans. Reasonable disability accommodations will be provided with adequate notice. For additional information about the University's commitment to equal opportunity and access, see `www.utah.edu/nondiscrimination/`.

000042

UNIVERSITY OF UTAH
Department of Mathematics

The Department of Mathematics at the University of Utah invites applications for the following positions:

- Full-time tenure-track or tenured appointments at the level of Assistant, Associate, or Full Professor in all areas of mathematics.

- Full-time tenure-track or tenured appointments at the level of Assistant, Associate, or Full Professor in all areas of statistics. These positions are part of a University-wide cluster hiring effort in statistics, with particular emphasis in mathematics, computer science, and bioengineering. Successful candidates will have strong interdisciplinary interests.
- Three-year Burgess, Tucker, and Wylie Assistant Professor Lecturer positions.
- Research Training Group (RTG) postdoctoral positions in Algebraic Geometry and Topology.

Please see our website at www.math.utah.edu/positions for information regarding available positions and application requirements. Applications must be completed through www.mathjobs.org/jobs/Utah. Review of complete applications for tenure-track positions will begin on November 1, 2016, and will continue until the positions are filled. Completed applications for postdoctoral positions received before January 1, 2017, will receive full consideration. The University of Utah is an Equal Opportunity/Affirmative Action employer and educator. Minorities, women, veterans, and those with disabilities are strongly encouraged to apply. Veterans' preference is extended to qualified veterans. Reasonable disability accommodations will be provided with adequate notice. For additional information about the University's commitment to equal opportunity and access see: www.utah.edu/nondiscrimination/.

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WASHINGTON

UNIVERSITY OF WASHINGTON
Department of Mathematics

Applications are invited for one or more non-tenure-track Acting Assistant Professor positions. Each appointment is for a period of up to three years, to begin in September 2017. Applicants are required to have a PhD, or foreign equivalent, by the starting date, and to be highly qualified for undergraduate and graduate teaching and independent research.

Applications should include the American Mathematical Society's Cover Sheet for Academic Employment, a curriculum vitae, statements of research and teaching interests, and three letters of recommendation. We prefer applications and supporting materials to be submitted electronically via www.mathjobs.org. Application materials may also be mailed to: Appointments Committee Chair (AAP position), Department of Mathematics, Box 354350, University of Washington, Seattle, WA 98195-4350. Priority will be given to applicants whose complete applications, including recommendations, are received by December 1, 2016.

The Department of Mathematics at the University of Washington is committed to fostering a diverse and inclusive academic community. See https://www.math.washington.edu/General/diversity.php. We encourage applications from individuals whose backgrounds or interests align with this commitment.

University of Washington is an Affirmative Action and Equal Opportunity Employer. All qualified applicants will receive consideration for employment without regard to race, color, religion, sex, sexual orientation, gender identity, gender expression, national origin, age, protected veteran or disabled status, or genetic information. University of Washington faculty engage in teaching, research, and service.

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CHINA

CENTER FOR APPLIED MATHEMATICS
Tianjin University, China
Tenured/Tenure-Track/
Postdoctoral Positions

Dozens of positions at all levels are available at the recently founded Center for Applied Mathematics, Tianjin University, China. We welcome applicants with backgrounds in pure mathematics, applied mathematics, statistics, computer science, bioinformatics, and other related fields. We also welcome applicants who are interested in practical projects with industries. Despite its name attached with an accent of applied mathematics, we also aim to create a strong presence of pure mathematics. Chinese citizenship is not required. Light or no teaching load, adequate facilities, spacious office environment, and strong research support. We are prepared to make quick and competitive offers to self-motivated hard workers, and to potential stars, rising stars, as well as shining stars. The Center for Applied Mathematics, also known as the Tianjin Center for Applied Mathematics (TCAM), located by a lake in the central campus in a building protected as historical architecture, is jointly sponsored by the Tianjin municipal government and the university. The initiative to establish this center was taken by Professor S. S. Chern. Professor Molin Ge is the Honorary Director, Professor Zhiming Ma is the Director of the Advisory Board, and Professor William Y.C. Chen serves as the Director. TCAM plans to fill in fifty or more permanent faculty positions in the next few years. In addition, there are a number of temporary and visiting positions. We look forward to receiving your application or inquiry at any time. There are no deadlines. For more information, please visit www.cam.tju.edu.cn/ or contact Ms. Debbie Renyuan Zhang at zhangry@tju.edu.cn, telephone: 86-22-2740-5389.

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HONG KONG

THE UNIVERSITY OF HONG KONG
Tenure-Track Professor/
Associate Professor/
Assistant Professor (2 posts)
in the Department of Mathematics
(Ref.: 201600853)

Applications are invited for two tenure-track appointments as Professor/Associate Professor/Assistant Professor in the Department of Mathematics, to commence from September 1, 2017, or as soon as possible thereafter. The appointments will initially be made on a three-year term basis, with the possibility of renewal.

The Department of Mathematics provides a solid general undergraduate education in mathematics, offers supervision in graduate study for students with a strong interest in and a capacity for mathematics, and engages in teaching and research aiming at a high international standing. Information about the Department can be obtained at www.hku.hk/math/.

Candidates in all areas of Applied Mathematics will be considered, with preference given to those working in the areas of Optimization (with applications in Big Data Science) and Scientific Computing (with applications in Financial Mathematics). The appointees will be expected to teach undergraduate and postgraduate courses, supervise research students, and also actively engage in outreach and service.

A globally competitive remuneration package commensurate with the appointee's qualifications and experience will be offered. At current rates, salaries tax does not exceed 15 percent of gross income. The appointments will attract a contract-end gratuity and University contribution to a retirement benefits scheme, totalling up to 15 percent of basic salary, as well as annual leave, and medical benefits. Housing benefits will be provided as applicable.

Applicants should send a completed application form, together with an up-to-date CV containing information on educational and professional experience, a complete list of publications, a survey of past research and teaching experience, a research plan for the next few years, and a statement on teaching philosophy to: scmath@hku.hk. They should also arrange for submission, to the same e-mail address as stated above, three reference letters from senior academics. One of these senior academics should be asked to comment on the applicant's ability in teaching, or the applicant should arrange to have an additional reference letter on his/her teaching sent to the same e-mail address as stated above. Please indicate clearly which level they wish to be considered for and the reference number in the subject of the e-mail. Application forms (341/1111) can be downloaded at www.hku.hk/apptunit/form-ext.doc and further particulars can be obtained at jobs.hku.hk/. Review of applications will start from December 1, 2016, and continue until June 30, 2017. The University thanks applicants for their interest, but advises that only candidates shortlisted for interviews will be notified of the application result.

The University is an Equal Opportunities Employer and is committed to a Non-Smoking Policy.

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THE UNIVERSITY OF HONG KONG
Tenure-Track Professor (1 post)
in the Department of Mathematics
(Ref.: 201600852)

Applications are invited for a tenure-track appointment as Professor in the Department of Mathematics, to commence from September 1, 2017, or as soon as possible thereafter. The appointment will initially be made on a three-year term basis, with the possibility of renewal.

The Department of Mathematics provides a solid general undergraduate education in mathematics, offers supervision in graduate study for students with a strong interest in and a capacity for mathematics, and engages in teaching and research aiming at a high international standing. Information about the Department can be obtained at www.hku.hk/math/.

Candidates in all areas of Pure Mathematics will be considered, with preference given to those working in Algebra, Representation Theory, and related areas. The appointee will be expected to teach undergraduate and postgraduate courses, supervise research students, and also actively engage in outreach and service.

A globally competitive remuneration package commensurate with the appointee's qualifications and experience will be offered. At current rates, salaries tax does not exceed 15 percent of gross income. The appointments will attract a contract-end gratuity and University contribution to a retirement benefits scheme, totalling up to 15 percent of basic salary, as well as annual leave, and medical benefits. Housing benefits will be provided as applicable.

Applicants should send a completed application form, together with an up-to-date CV containing information on educational and professional experience, a complete list of publications, a survey of past research and teaching experience, a research plan for the next few years, and a statement on teaching philosophy to: scmath@hku.hk. They should also arrange for submission, to the same e-mail address as stated above, three reference letters from senior academics. One of these senior academics should be asked to comment on the applicant's ability in teaching, or the applicant should arrange to have an additional reference letter on his/her teaching sent to the same e-mail address as stated above. Please indicate clearly which level they wish to be considered for and the reference number in the subject of the e-mail. Application forms (341/1111) can be downloaded at www.hku.hk/apptunit/form-ext.doc and further particulars can be obtained at jobs.hku.hk/. Review of applications will start from December 1, 2016, and continue until June 30, 2017. The University thanks applicants for their interest, but advises that only candidates shortlisted for interviews will be notified of the application result.

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PUBLICATIONS FOR SALE

BOOKS AND A JOURNAL

Integral Equations, Wavelets, both with Student Solutions Manual, Advances in the Gibbs Phenomenon, and a Journal: Sampling Theory in Signal and Image Processing. (Visit stsip.org, Amazon and ebay). Contact:jerria12@yahoo.com.

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CALL FOR Suggestions

Your suggestions are wanted by:

the Nominating Committee, for the following contested seats in the 2017 AMS elections:
vice president, trustee,
and five members at large of the Council.

Deadline for suggestions: November 1, 2016

the President, for the following contested seats in the 2017 AMS elections:
three members of the Nominating Committee and
two members of the Editorial Boards Committee.

Deadline for suggestions: January 31, 2017

the Editorial Boards Committee, for appointments to various editorial boards of AMS publications.

Deadline for suggestions: Can be submitted any time

Send your suggestions for any of the above to:

Carla D. Savage, Secretary
American Mathematical Society
Department of Computer Science
North Carolina State University
Raleigh, NC 27695-8206 USA
secretary@ams.org
or submit them online at www.ams.org/committee-nominate

AMS
American Mathematical Society
www.ams.org

MATHEMATICS CALENDAR

This section contains new announcements of worldwide meetings and conferences of interest to the mathematical public, including ad hoc, local, or regional meetings, and meetings and symposia devoted to specialized topics, as well as announcements of regularly scheduled meetings of national or international mathematical organizations. New announcements only are published in the print Mathematics Calendar featured in each *Notices* issue.

An announcement will be published in the *Notices* if it contains a call for papers and specifies the place, date, subject (when applicable). A second announcement will be published only if there are changes or necessary additional information. Asterisks (*) mark those announcements containing revised information.

In general, print announcements of meetings and conferences carry only the date, title and location of the event.

The complete listing of the Mathematics Calendar is available at: `www.ams.org/meetings/calendar/mathcal`

All submissions to the Mathematics Calendar should be done online via: `www.ams.org/cgi-bin/mathcal/mathcal-submit.pl`

Any questions or difficulties may be directed to `mathcal@ams.org`.

Disclaimer The publisher reserves the right to reject any posting not in keeping with the Society's standards. Acceptance of a posting shall not be construed as approval of the accuracy or the legality of any information therein.

September 2016

9 – May 19, 2017 **The BD2K Guide to the Fundamentals of Data Science Online Lecture Series, Begins Friday, 9/9, 12noon–1pm ET.**
Location: *Online Webinar www.bigdatau.org/data-science seminars. Open to the Public, No Fee.*
URL: `www.bigdatau.org/data-science-seminars`

16 – 17 **Prairie Analysis Seminar 2016**
Location: *Department of Mathematics, University of Kansas, Lawrence, Kansas.*
URL: `https://www.math.ku.edu/conferences/prairie/prairie16`

October 2016

12 – 13 **2016 Modern Math Workshop at SACNAS**
Location: *Long Beach Convention Center in Long Beach, CA.*
URL: `www.ipam.ucla.edu/mmw2016`

November 2016

3 – 5 **Recent Trend of Research in Mathematics and Applications in Diverse Field**
Location: *Department of Mathematics, T.D.P.G. College, Jaunpur (UP) India.*
URL: `rsmams.org/newsdetails.php?id=18`

3 – 7 **One Week DST-Sponsored National Workshop on "Treasure of Great Indian Mathematician Srinivasa Ramanujan"**
Location: *Deapartment of Mathematics, T.D.P.G. College, Jaunpur-222002 (UP) India.*
URL: `rsmams.org/newsdetails.php?id=17`

4 – 6 **Field of Dreams Conference**
Location: *St. Louis, MO.*
URL: `https://mathalliance.org/2016-field-of-dreams-conference`

5 – 6 **Vaintrobfest: Representations, Combinatorics, Knots and Geometry**
Location: *Department of Mathematics, University of Oregon, Eugene, Oregon, USA.*
URL: `www-math.mit.edu/~etingof/vaintrobfest.html`

10 – 12 **19th Annual Conference of Vijnana Parishad of India and a Symposium on Fixed Point Theory and Application (Dedicated To Professor S.L. Singh)**
Location: *Department of Mathematics, H.N.B. Garhwal University, Campus Pauri, Pauri Garhwal, Uttarakhand, India.*
URL: `hnbgu.ac.inandvijnanaparishadofindia.org`

December 2016

11 – 12 **Conference on Dynamical Systems and Geometric Theories**
Location: *Mahani Mathematical Research Center, Shahid Bahonar University of Kerman, Kerman, Kerman/Iran.*
URL: `mahani.uk.ac.ir`

12 – 16 **Marrakesh Workshop On Control, Inverse Problems, and Stabilization of Infinite Dimensional Systems**
Location: *Cadi Ayyad University of Marrakech, Marrakesh/Morocco.*
URL: `cipsmar2016.uca.ma`

22 – 25 **KMITL International Conference on Mathematics: Number Theory, Graph Theory, and Applications**
Location: *Department of Mathematics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand.*
URL: `www.math.sci.kmitl.ac.th/kicm2016/index`

January 2017

24 – 27 **Topical Workshop: Current Developments in Mathematical Fluid Dynamics: Regularity, Instabilities, and Turbulence**
Location: *ICERM/Brown University, Providence, RI, USA.*
URL: `https://icerm.brown.edu/topical_workshops/tw17-2-mfd/`

27 – 29 **International Conference on "Advances in Mathematical Sciences and Applications in Engineering & Technology (AMSAET 2017)"**
Location: *Poornima University, Jaipur, Rajasthan, India.*
URL: `www.poornima.edu.in/international-conference-on-amsaet-2017`

30 – May 5 **ICERM Semester Program: Singularities and Waves in Incompressible Fluids**
Location: *ICERM/Brown University, Providence, RI, USA.*
URL: `https://icerm.brown.edu/programs/sp-s17`

February 2017

11 – 12 **The 24th SCGAS Southern California Geometric Analysis Seminar**
Location: *University of California, San Diego February 11-12, 2017.*
URL: `www.math.ucsd.edu/~scgas`

March 2017

27 – 31 **Hot Topics: Galois Theory of Periods and Applications**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: `www.msri.org/workshops/826`

April 2017

25 – 26 **2017 IEEE International Symposium on Technologies for Homeland Security**
Location: *Westin-Waltham Hotel, Waltham, MA.*
URL: `ieee-hst.org`

26 – 28 **The International Conference on Algebra and its Applications ICAA 2017**
Location: *Sciences and Techniques Faculty, Moulay Ismail University, Errachidia, Morocco.*
URL: `https://icaa2017fste.sciencesconf.org`

May 2017

21 – 25 **SIAM Conference on Applications of Dynamical Systems (DS17)**
Location: *Snowbird Ski and Summer Resort, Snowbird, Utah, USA.*
URL: `www.siam.org/meetings/ds17`

22 – June 2 **Summer Graduate School: Commutative Algebra and Related Topics**
Location: *Mathematical Sciences Research Institute, Berkley, CA.*
URL: `www.msri.org/summer_schools/795`

31 – June 2 **Thera Stochastics - A Mathematics Conference in Honor of Ioannis Karatzas**
Location: *Fira, Santorini (Greece).*
URL: `www.math.columbia.edu/department/thera`

June 2017

10 – July 21 **Summer Graduate School: Positivity Questions in Geometric Combinatorics**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: `www.msri.org/summer_schools/823`

19 – 23 **Preservers Everywhere**
Location: *Bolyai Institute, University of Szeged, Szeged, Hungary.*
URL: `www.math.u-szeged.hu/~gehergy/conference.html`

21 – 26 **AMiTaNS'17**
Location: *Congress Centre, Black-Sea resort of Albena, Bulgaria.*
URL: `2017.eac4amitans.eu`

July 2017

17 – 21 **Women in Data Science and Mathematics Research Collaboration Workshop (WiSDM)**
Location: *ICERM/Brown University, Providence, RI, USA.*
URL: `https://icerm.brown.edu/topical_workshops/tw17-3-wisdm`

August 2017

21 – 25 **Topical Workshop: Pedestrian Dynamics: Modeling, Validation, and Calibration**
Location: *ICERM/Brown University, Providence, RI, USA.*
URL: `https://icerm.brown.edu/topical_workshops/tw17-1-pd`

September 2017

4 – 8 **Number Theory Week 2017**
Location: *Adam Mickiewicz University in Poznań, Poland.*
URL: `ntw.amu.edu.pl/`

5 – 8 **Introductory Workshop: Geometric and Topological Combinatorics**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: `www.msri.org/workshops/813`

6 – December 8 **ICERM Semester Program: Mathematical and Computational Challenges in Radar and Seismic Reconstruction**
Location: *ICERM/Brown University, Providence, RI, USA.*
URL: `https://icerm.brown.edu/programs/sp-f17`

January 2018

7 – 10 **ACM-SIAM Symposium on Discrete Algorithms (SODA18)**
Location: *Astor Crowne Plaza - New Orleans French Quarter, New Orleans, Louisiana, USA.*
URL: `www.siam.org/meetings/da18`

8 – 9 **Analytic Algorithmics and Combinatorics (ANALCO18)**
Location: *Astor Crowne Plaza - New Orleans French Quarter, New Orleans, Louisiana, USA.*
URL: `www.siam.org/meetings/analco18`

February 2018

1 – 2 **Connections for Women: Group Representation Theory and Applications**
Location: *Mathematical Sciences Research Institute, Berkeley CA.*
URL: `www.msri.org/workshops/817`

June 2018

5 – 8 **SIAM Conference on Imaging Science (IS18)**
Location: *University of Bologna, Bologna, Italy.*
URL: `www.siam.org/meetings/is18`

11 – 22 **Summer Graduate School: The δ-Problem in the Twenty-First Century**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: www.msri.org/summer_schools/828

25 – July 6 **Summer Graduate School: Derived Categories**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: www.msri.org/summer_schools/821

July 2018

8 – 20 **Summer Graduate School: Representations of High Dimensional Data**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: www.msri.org/summer_schools/827

23 – August 3 **Summer Graduate School: From Symplectic Geometry to Chaos**
Location: *Mathematical Sciences Research Institute, Berkeley, CA.*
URL: www.msri.org/summer_schools/825

MEETINGS & CONFERENCES OF THE AMS

NOVEMBER TABLE OF CONTENTS

The Meetings and Conferences section of the Notices gives information on all AMS meetings and conferences approved by press time for this issue. Please refer to the page numbers cited on this page for more detailed information on each event.

Invited Speakers and Special Sessions are listed as soon as they are approved by the cognizant program committee; the codes listed are needed for electronic abstract submission. For some meetings the list may be incomplete. Information in this issue may be dated.

The most up-to-date meeting and conference information can be found online at: **www.ams.org/meetings/**.

Important Information About AMS Meetings: Potential organizers, speakers, and hosts should refer to page 88 in the January 2016 issue of the *Notices* for general information regarding participation in AMS meetings and conferences.

Abstracts: Speakers should submit abstracts on the easy-to-use interactive Web form. No knowledge of LaTeX is necessary to submit an electronic form, although those who use LaTeX may submit abstracts with such coding, and all math displays and similarily coded material (such as accent marks in text) must be typeset in LaTeX. Visit **www.ams.org/cgi-bin/abstracts/abstract.pl/**. Questions about abstracts may be sent to `abs-info@ams.org`. Close attention should be paid to specified deadlines in this issue. Unfortunately, late abstracts cannot be accommodated.

MEETINGS IN THIS ISSUE

Conferences in Cooperation with the AMS

Indian Mathematics Consortium

December 14–17, 2016

Banaras Hindu University

Varanasi, India

See **www.ams.org/meetings/** *for the most up-to-date information on these conferences.*

ASSOCIATE SECRETARIES OF THE AMS

Central Section: Georgia Benkart, University of Wisconsin-Madison, Department of Mathematics, 480 Lincoln Drive, Madison, WI 53706-1388; e-mail: benkart@math.wisc.edu; telephone: 608-263-4283.

Eastern Section: Steven H. Weintraub, Department of Mathematics, Lehigh University, Bethlehem, PA 18015-3174; e-mail: steve.weintraub@lehigh.edu; telephone: 610-758-3717.

Southeastern Section: Brian D. Boe, Department of Mathematics, University of Georgia, 220 D W Brooks Drive, Athens, GA 30602-7403, e-mail: brian@math.uga.edu; telephone: 706-542-2547.

Western Section: Michel L. Lapidus, Department of Mathematics, University of California, Surge Bldg., Riverside, CA 92521-0135; e-mail: lapidus@math.ucr.edu; telephone: 951-827-5910.

Meetings & Conferences of the AMS

IMPORTANT INFORMATION REGARDING MEETINGS PROGRAMS: AMS Sectional Meeting programs do not appear in the print version of the *Notices.* However, comprehensive and continually updated meeting and program information with links to the abstract for each talk can be found on the AMS website. See `www.ams.org/meetings/`.

Final programs for Sectional Meetings will be archived on the AMS website accessible from the stated URL .

Minneapolis, Minnesota

University of St. Thomas (Minneapolis campus)

October 28–30, 2016

Friday – Sunday

Meeting #1123

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: August 2016
Program first available on AMS website: To be announced
Issue of *Abstracts*: Volume 37, Issue 4

Deadlines

For organizers: Expired
For abstracts: Expired

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Thomas Nevins, University of Illinois at Urbana-Champaign, *Algebraic symplectic varieties, classical and quantum.*

Charles Rezk, University of Illinois, *On some approximations to homotopy theory.*

Christof Sparber, Department of Mathematics, Statistics & Computer Science, University of Illinois at Chicago, *Semiclassical quantum dynamics via Bohmian trajectories.*

Samuel N. Stechmann, University of Wisconsin-Madison, *Stochastic PDEs for tropical weather and climate.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `www.ams.org/cgi-bin/abstracts/abstract.pl`.

Advances in Algebraic Coding Theory, **Sarah E. Anderson**, University of St. Thomas, and **Katie Haymaker**, Villanova University.

Chip-Firing and Divisors on Graphs and Complexes, **Caroline Klivans**, Brown University, and **Gregg Musiker** and **Victor Reiner**, University of Minnesota.

Combinatorial Matrix Theory, **Adam Berliner**, St. Olaf College, **Brenda Kroschel**, University of St. Thomas, and **Nathan Warnberg**, University Wisconsin-LaCrosse.

Combinatorial Representation Theory, **Michael Chmutov**, University of Minnesota, **Tom Halverson**, Macalester College, and **Travis Scrimshaw**, University of Minnesota.

Discrete Structures: Analysis and Applications (IMA Reunion), **Leslie Hogben** and **Ryan Martin**, Iowa State University, and **Elisabeth Werner**, Case Western Reserve University.

Effective Mathematics in Discrete and Continuous Worlds, **Wesley Calvert**, Southern Illinois University, and **Timothy McNicholl**, Iowa State University.

Enumerative Combinatorics, **Eric Egge**, Carleton College, and **Joel Brewster Lewis**, University of Minnesota.

Extremal and Probabilistic Combinatorics, **Andrew Beveridge**, Macalester College, **Jamie Radcliffe**, University of Nebraska Lincoln, and **Michael Young**, Iowa State University.

Geometric Flows, Integrable Systems and Moving Frames, **Joseph Benson**, St. Olaf College, **Gloria Mari-Beffa**, University of Wisconsin-Madison, **Peter Olver**, University of Minnesota, and **Rob Thompson**, Carleton College.

Integrable Systems and Related Areas, **Sam Evens**, University of Notre Dame, **Luen-Chau Li**, Pennsylvania State University, and **Zhaohu Nie**, Utah State University.

Knotting in Physical Systems, in celebration of Kenneth C. Millett's 75th birthday, **Jorge Alberto Calvo**, Ave Maria University, and **Eric Rawdon**, University of St. Thomas.

Mathematics and Physics of Tornado Modeling, **Pavel Belik**, Augsburg College, and **Douglas P. Dokken**, **Kurt Scholz**, and **Misha Shvartsman**, University of St. Thomas.

Modeling and Predicting the Atmosphere, Oceans, and Climate, **Sam Stechmann**, University of Wisconsin-Madison.

Multi-scale Phenomena in Linear and Nonlinear Partial Differential Equations, **Zaher Hani**, Georgia Tech, and **Christof Sparber**, University of Illinois at Chicago.

New Developments in the Analysis of Nonlocal Operators, **Donatella Danielli** and **Arshak Petrosyan**, Purdue University, and **Camelia Pop**, University of Minnesota.

Noncommutative Algebras and Their Representations, **Miodrag Iovanov** and **Ryan Kinser**, University of Iowa, and **Peter Webb**, University of Minnesota.

Quantum Field Theories and Geometric Representation Theory, **Emily Cliff**, University of Oxford, and **Thomas Nevins**, University of Illinois at Urbana-Champaign.

Representation Theory, Automorphic Forms and Related Topics, **Kwangho Choiy**, Southern Illinois University, **Dihua Jiang**, University of Minnesota, and **Shuichiro Takeda**, University of Missouri.

Symplectic Geometry and Contact Geometry, **Tian-Jun Li** and **Cheuk Yu Mak**, University of Minnesota, and **Ke Zhu**, Minnesota State University.

The Topology of 3- and 4-Manifolds, **Maggy Tomova**, University of Iowa, and **Alexander Zupan**, University of Nebraska-Lincoln.

Topology and Arithmetic, **Tyler Lawson** and **Craig Westerland**, University of Minnesota, Twin Cities.

Topology and Physics, **Ralph Kaufmann**, Purdue University, and **Alexander Voronov**, University of Minnesota, Twin Cities.

Women in Analysis and Partial Differential Equations, **Svitlana Mayboroda**, University of Minnesota.

p-Adic Analysis in Number Theory, **C. Douglas Haessig**, University of Rochester, and **Steven Sperber**, University of Minnesota.

Raleigh, North Carolina

North Carolina State University

November 12–13, 2016

Saturday – Sunday

Meeting #1124

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: September 2016
Program first available on AMS website: September 22, 2016

Issue of *Abstracts*: Volume 37, Issue 4

Deadlines

For organizers: Expired
For abstracts: Expired

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Ricardo Cortez, Tulane University, *Mathematical and Computational Modeling of Microorganism Swimming.*

Gaven J. Martin, Massey University, *Siegel's problem on small volume lattices* (AMS-NZMS Maclaurin Lecture).

Jason L. Metcalfe, University of North Carolina, *Local energy decay for the wave equation.*

Agnes Szanto, North Carolina State University, *Certification of Approximate Roots of Exact Polynomial Systems.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

Advances in Numerical Methods for Partial Differential Equations, **Andreas Aristotelous**, West Chester University, and **Thomas Lewis**, The University of North Carolina at Greensboro.

Algebraic Structures Motivated by and Applied to Knot Theory, **Jozef H. Przytycki**, The George Washington University, and **Radmila Sazdanovic**, North Carolina State University.

Applied Algebraic Geometry, **Seth Sullivant** and **Agnes Szanto**, North Carolina State University.

Commutative Ring Theory (in honor of Jay Shapiro's retirement), **Neil Epstein**, George Mason University, and **Alan Loper**, Ohio State University.

Contemporary Geometric Methods in Mechanics and Control, **Vakhtang Putkaradze**, University of Alberta, and **Dmitry Zenkov**, North Carolina State University.

Control, Optimization, and Differential Games, **Lorena Bociu**, North Carolina State University, and **Tien Khai Nguyen**, Penn State University.

Difference Equations and Applications, **Michael A. Radin**, Rochester Institute of Technology, and **Youssef Raffoul**, University of Dayton.

Geometry and Topology in Image and Shape Analysis, **Irina Kogan**, North Carolina State University, and **Facundo Mémoli**, The Ohio State University.

Graphs, Hypergraphs, and Set Systems, **David Galvin**, University of Notre Dame, and **Clifford Smyth**, University of North Carolina Greensboro.

Harmonic Analysis and Dispersive PDE, **Robert Booth**, **Jason Metcalfe**, and **Katrina Morgan**, University of North Carolina.

Homological Methods in Commutative Algebra, **Alina Iacob** and **Saeed Nasseh**, Georgia Southern University.

Low-dimensional Topology, **Caitlin Leverson**, Georgia Tech, **Tye Lidman**, North Carolina State University, and **Leonard Ng**, Duke University.

Mathematical Modeling of Infectious Disease and Immunity, **Lauren Childs**, Virginia Tech and Harvard Chan School of Public Health, and **Stanca Ciupe**, Virginia Tech.

Mathematical String Theory, **Paul Aspinwall**, Duke University, **Ilarion Melnikov**, James Madison University, and **Eric Sharpe**, Virginia Tech.

Metric and Topological Oriented Fixed Point Theorems, **Clement Boateng Ampadu**, Boston, MA, **Sartaj Ali**, National College of Business Administration and Economics, Lahore, Pakistan, **Xiaorong Liu**, University of Colorado at Boulder, and **Xavier Alexius Udo-Utun**, University of Uyo, Uyo, Nigeria.

Nonlinear Boundary Value Problems, **Maya Chhetri**, UNC Greensboro, and **Stephen Robinson**, Wake Forest University.

Recent Advances in Stochastic Processes and Stochastic Computation, **Jianfeng Lu** and **James Nolen**, Duke University, and **Kostas Spiliopoulous**, Boston University.

Representations of Lie Algebras, Quantum Groups and Related Topics, **Naihuan Jing** and **Kailash C. Misra**, North Carolina State University.

Set Theoretic Topology, **Alan Dow**, UNC-Charlotte, and **Jerry Vaughan**, UNC-Greensboro.

Structural and Computational Graph Theory, **Stephen Harte**, University of Colorado Denver, and **Bernard Lidický**, Iowa State University.

The Analysis of Inverse Problems and their Applications, **Shitao Liu**, Clemson University, and **Loc Nguyen**, University of North Carolina.

Varieties, Their Fibrations and Automorphisms in Mathematical Physics and Arithmetic Geometry, **Jimmy Dillies** and **Enka Lakuriqi**, Georgia Southern University, and **Tony Shaska**, Oakland University.

Atlanta, Georgia

Hyatt Regency Atlanta and Marriott Atlanta Marquis

January 4–7, 2017

Wednesday – Saturday

Meeting #1125

Joint Mathematics Meetings, including the 123rd Annual Meeting of the AMS, 100th Annual Meeting of the Mathematical Association of America, annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic, with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: October 2016
Program first available on AMS website: To be announced

Issue of *Abstracts*: Volume 38, Issue 1

Deadlines

For organizers: Expired
For abstracts: Expired

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/national.html`.

Joint Invited Addresses

Ingrid Daubechies, Duke University, *Mathematics for Art Investigation* (MAA-AMS-SIAM Gerald and Judith Porter Public Lecture).

Lisa Jeffrey, University of Toronto, *Real loci in symplectic manifolds* (AWM-AMS Noether Lecture).

Donald Richards, Penn State University, *Distance Correlation: A New Tool for Detecting Association and Measuring Correlation Between Data Sets* (AMS-MAA Invited Address).

Alice Silverberg, University of California, Irvine, *Through the Cryptographer's Looking-Glass, and what Alice found there* (AMS-MAA Invited Address).

AMS Invited Addresses

Tobias Colding, Massachusetts Institute of Technology, *Title to be announced*.

Carlos E. Kenig, University of Chicago, *Overview: The focusing energy critical wave equation* (AMS Colloquium Lectures: Lecture I).

Carlos E. Kenig, University of Chicago, *The focusing energy critical wave equation: the non-radial case* (AMS Colloquium Lectures: Lecture III).

Carlos E. Kenig, University of Chicago, *The focusing energy critical wave equation: the radial case in 3 space dimensions* (AMS Colloquium Lectures: Lecture II).

John Preskill, California Institute of Technology, *Title to be announced* (AMS Josiah Willard Gibbs Lecture).

Barry Simon, Caltech, *Spectral Theory Sum Rules, Meromorphic Herglotz Functions and Large Deviations*.

Gigliola Staffilani, Massachusetts Institute of Technology, *The many faces of dispersive and wave equations*.

Richard Taylor, Institute for Advanced Study, *Galois groups and locally symmetric spaces*.

Anna Wienhard, Ruprecht-Karls-Universität Heidelberg, *A tale of rigidity and flexibility - discrete subgroups of higher rank Lie groups*.

AMS Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `jointmathematicsmeetings.org/meetings/abstracts/abstract.pl?type=jmm`.

Some sessions are cosponsored with other organizations. These are noted within the parenthesis at the end of each listing, where applicable.

Advanced Mathematical Programming and Applications, **Ram N. Mohapatra**, University of Central Florida, **Ram U. Verma**, University of North Texas, and **Gayatri Pany**, Indian Institute of Technology.

Advances in Mathematics of Ecology, Epidemiology and Immunology of Infectious Diseases, **Abba Gumel**, Arizona State University.

Advances in Numerical Analysis for Partial Differential Equations, **Thomas Lewis**, University of North Carolina at Greensboro, and **Amanda Diegel**, Louisiana State University.

Advances in Operator Algebras, **Michael Hartglass**, University of California, Riverside, **David Penneys**, University of California, Los Angeles, and **Elizabeth Gillaspy**, University of Colorado, Boulder.

Algebraic Statistics (a Mathematics Research Communities Session), **Mateja Raic**, University of Illinois at Chicago, **Nathanial Bushnek**, University of Alaska, Anchorage, and **Daniel Irving Bernstein**, North Carolina State University.

An Amicable Combination of Algebra and Number Theory (Dedicated to Dr. Helen G. Grundman), **Eva Goedhart**, Lebanon Valley College, **Pamela E. Harris**, Williams College, **Daniel P. Wisniewski**, DeSales University, and **Alejandra Alvarado**, Eastern Illinois University.

Analysis of Fractional, Stochastic, and Hybrid Dynamic Systems and their Applications, **Aghalaya S. Vatsala**, University of Louisiana, **Gangaram S. Ladde**, University of South Florida, and **John R. Graef**, University of Tennessee at Chattanooga.

Analytic Number Theory and Arithmetic, **Robert Lemke Oliver**, Tufts University, **Paul Pollack**, University of Georgia, and **Frank Thorne**, University of South Carolina.

Analytical and Computational Studies in Mathematical Biology, **Yanyu Xiao**, University of Cincinnati, and **Xiang-Sheng Wang**, University of Louisiana at Lafayette.

ApREUF: Applied Research Experience for Undergraduate Faculty, **Shenglan Yuan**, LaGuardia Community College, CUNY, **Jason Callahan**, St. Edwards University, **Eva Strawbridge**, James Madison University, and **Ami Radunskaya**, Pomona College.

Applications of Partially Ordered Sets in Algebraic, Topological, and Enumerative Combinatorics, **Rafael S. González D'León**, University of Kentucky, and **Joshua Hallam**, Wake Forest University.

Arithmetic Properties of Sequences from Number Theory and Combinatorics, **Eric Rowland**, Hofstra University, and **Armin Straub**, University of South Alabama.

Automorphic Forms and Arithmetic, **Frank Calegari**, University of Chicago, **Ana Caraiani**, Princeton University, and **Richard Taylor**, Institute for Advanced Study.

Bases in Function Spaces: Sampling, Interpolation, Expansions and Approximations, **Shahaf Nitzan** and **Christopher Heil**, Georgia Institute of Technology, and **Alexander V. Powell**, Vanderbilt University.

Character Varieties (a Mathematics Research Communities Session), **Nathan Druivenga**, University of Kentucky, **Brett Frankel**, Northwestern University, and **Ian Le**, Perimeter Institute for Theoretical Physics.

Coding Theory for Modern Applications, **Christine A. Kelley**, University of Nebraska-Lincoln, **Iwan M. Duursma**, University of Illinois Urbana-Champaign, and **Gretchen L. Matthews**, Clemson University.

Combinatorial and Cohomological Invariants of Flag Manifolds and Related Varieties, **Martha Precup**, Northwestern University, and **Rebecca Goldin**, George Mason University.

Commutative Algebra: Research for Undergraduate and Early Graduate Students, **Nicholas Baeth**, University of Central Missouri, and **Courtney Gibbons**, Hamilton College.

Complex Analysis and Special Functions, **Brock Williams**, Texas Tech University, **Kendall Richards**, Southwestern University, and **Alex Solynin**, Texas Tech University.

Continued Fractions, **James McLaughlin**, West Chester University, **Geremías Polanco**, Hampshire College, and **Nancy J. Wyshinski**, Trinity College.

Control and Long Time Behavior of Evolutionary PDEs, **Louis Tebou**, Florida International University, and **Luz de Teresa**, Instituto de Matemáticas, UNAM.

Discrete Geometry and Convexity (Dedicated to András Bezdek on the occasion of his 60th birthday), **Krystyna Kuperberg**, Auburn University, **Gergely Ambrus**, Renyi Institute of Mathematics, **Braxton Carrigan**, Southern Connecticut State University, and **Ferenc Fodor**, University of Szeged.

Discrete Structures in Number Theory, **Anna Haensch**, Duquesne University, and **Adriana Salerno**, Bates College.

Dynamical Systems, **Jim Wiseman**, Agnes Scott College, and **Aimee Johnson**, Swarthmore College.

Dynamics of Fluids and Nonlinear Waves, **Zhiwu Lin**, **Jiayin Jin**, and **Chongchun Zeng**, Georgia Institute of Technology.

Ergodic Theory and Dynamical Systems, **Mrinal Kanti Roychowdhury**, University of Texas Rio Grande Valley, and **Tamara Kucherenko**, City College of New York.

Fusion Categories and Quantum Symmetries, **Julia Plavnik**, Texas A&M University, **Paul Bruillard**, Pacific Northwest National Laboratory, and **Eric Rowell**, Texas A&M University.

Gaussian Graphical Models and Combinatorial Algebraic Geometry, **Rainer Sinn**, Georgia Institute of Technology, **Seth Sullivant**, North Carolina State University, and **Josephine Yu**, Georgia Institute of Technology.

Graphs and Matrices, **Sudipta Mallik**, Northern Arizona University, **Keivan Hassani Monfared**, University of Calgary, and **Bryan Shader**, University of Wyoming.

Group Actions and Geometric Structures, **Anna Wienhard**, Universität Heidelberg, and **Jeffrey Danciger**, University of Texas at Austin.

Group Representations and Cohomology, **Hung Nguyen**, The University of Akron, **Nham Ngo**, The University of Arizona, **Andrei Pavelescu**, University of South Alabama, and **Paul Sobaje**, University of Georgia.

Harmonic Analysis (In Honor of Gestur Olafsson's 65th Birthday), **Jens Christensen**, Colgate University, and **Susanna Dann**, Technische Universität Wien-Vienna, Austria.

History of Mathematics, **Adrian Rice**, Randolph-Macon College, **Sloan Despeaux**, Western Carolina University, and **Daniel Otero**, Xavier University (AMS-MAA-ICHM).

Hopf Algebras and their Actions, **Henry Tucker**, University of California, San Diego, **Susan Montgomery**, University of Southern California - Los Angeles, and **Siu-Hung Ng**, Louisiana State University.

Inverse Problems and Applications, **Vu Kim Tuan** and **Amin Boumenir**, University of West Georgia.

Inverse Problems and Multivariate Signal Analysis, **M. Zuhair Nashed**, University of Central Florida, **Willi Freeden**, University of Kaiserslautern, and **Otmar Scherzer**, University of Vienna.

Lie Group Representations, Discretization, and Gelfand Pairs (a Mathematics Research Communities Session), **Matthew Dawson**, CIMAT, **Holley Friedlander**, Dickenson College, **John Hutchens**, Winston-Salem State University, and **Wayne Johnson**, Truman State University.

Mapping Class Groups and their Subgroups, **James W. Anderson**, University of Southampton, UK, and **Aaron Wootton**, University of Portland.

Mathematics and Music, **Mariana Montiel**, Georgia State University, and **Robert Peck**, Louisiana State University.

Mathematics in Physiology and Medicine (a Mathematics Research Communities Session), **Kamila Larripa**, Humboldt State University, **Charles Puelz**, Rice University, **Laura Strube**, University of Utah, and **Longhua Zhao**, Case Western Reserve University.

Mathematics of Cryptography, **Nathan Kaplan** and **Alice Silverberg**, University of California, Irvine (AMS-MAA).

Mathematics of Signal Processing and Information, **Rayan Saab**, University of California, San Diego, and **Mark Iwen**, Michigan State University.

Measure and Measurable Dynamics (In Memory of Dorothy Maharam, 1917-2014), **Cesar Silva**, Williams College.

Minimal Integral Models of Algebraic Curves, **Tony Shaska**, Oakland University.

NSFD Discretizations: Recent Advances, Applications, and Unresolved Issues, **Talitha M. Washington**, Howard University, and **Ronald E. Mickens**, Clark Atlanta University.

New Developments in Noncommutative Algebra & Representation Theory, **Ellen Kirkman**, Wake Forest University, and **Chelsea Walton**, Temple University.

Nonlinear Systems and Applications, **Wenrui Hao**, Ohio State University.

Open & Accessible Problems for Undergraduate Research, **Allison Henrich**, Seattle University, **Michael Dorff**, Brigham Young University, and **Nicholas Scoville**, Ursinus College.

Operator Theory, Function Theory, and Models, **William Ross**, University of Richmond, and **Alberto Condori**, Florida Golf Coast University.

Orthogonal Polynomials, **Doron Lubinsky** and **Jeff Geronimo**, Georgia Institute of Technology.

PDE Analysis on Fluid Flows, **Xiang Xu**, Old Dominion University, and **Geng Chen** and **Ronghua Pan**, Georgia Institute of Technology.

PDEs for Fluid flow: Analysis and Computation, **Thinh Kieu**, University of North Georgia, **Emine Celik**, University of Nevada, Reno, and **Hashim Saber**, University of North Georgia.

Partition Theory and Related Topics, **Amita Malik**, University of Illinois at Urbana-Champaign, **Dennis Eichhorn**, University of California, Irvine, and **Tim Huber**, University of Texas-Rio Grande Valley.

Problems in Partial Differential Equations, **Alex Himonas**, University of Notre Dame, and **Dionyssios Mantzavinos**, State University of New York at Buffalo.

Public School Districts and Higher Education Mathematics Partnerships, **Virgil U. Pierce** and **Aaron Wilson**, University of Texas Rio Grande Valley.

Pure and Applied Talks by Women Math Warriors Presented by EDGE (Enhancing Diversity in Graduate Education), **Candice Price**, University of San Diego, and **Amy Buchman**, Tulane University.

Quantum Groups, **Shuzhou Wang** and **Angshuman Bhattacharya**, University of Georgia.

Quaternions, **Johannes Familton**, Borough of Manhattan Community College, **Terrence Blackman**, Medgar Evers College, and **Chris McCarthy**, Borough of Manhattan Community College.

RE(UF)search on Graphs and Matrices, **Cheryl Grood**, Swarthmore College, **Daniela Ferrero**, Texas State University, and **Mary Flagg**, University of St. Thomas.

Random Matrices, Random Percolation and Random Sequence Alignments, **Ruoting Gong**, Illinois Institute of Technology, and **Michael Damron**, Georgia Institute of Technology.

Real Discrete Dynamical Systems with Applications, **M. R. S. Kulenovic**, University of Rhode Island, and **Abdul-Aziz Yakubu**, Howard University.

Recent Advances in Mathematical Biology, **Zhisheng Shuai**, University of Central Florida, **Guihong Fan**, Columbus State University, **Andrew Nevai**, University of Central Florida, and **Eric Numfor**, Augusta University.

Recent Progress on Nonlinear Dispersive and Wave Equations, **Dana Mendelson**, **Carlos Kenig**, and **Hao Jia**, University of Chicago, **Andrew Lawrie**, University of California, Berkeley, **Gigliola Staffilani**, Massachusetts Institute of Technology, and **Magdalena Czubak**, University of Colorado Boulder.

Representations and Related Geometry in Lie Theory, **Laura Rider**, Massachusetts Institute of Technology, and **Amber Russell**, Butler University.

Research in Mathematics by Undergraduates and Students in Post-Baccalaureate Programs, **Darren A. Narayan**, Rochester Institute of Technology, **Tamas Forgacs**, California State University, Fresno, and **Ugur Abdulla**, Florida Institute of Technology (AMS-MAA-SIAM).

Sheaves in Topological Data Analysis, **Mikael Vejdemo-Johansson**, CUNY College of Staten Island, **Elizabeth Munch**, University at Albany, SUNY, and **Martina Scolamiero**, École polytechnique fédérale de Lausanne.

Spectral Calculus and Quasilinear Partial Differential Equations, **Shijun Zheng**, Georgia Southern University, **Marius Beceanu**, State University of New York - Albany, and **Tuoc Van Phan**, University of Tennessee, Knoxville.

Spin Glasses and Disordered Media, **Antonio Auffinger**, Northwestern University, **Aukosh Jagannath**, New York University, and **Dmitry Panchenko**, University of Toronto.

Statistical Methods in Computational Topology and Applications, **Yu-Min Chung** and **Sarah Day**, College of William & Mary.

Stochastic Matrices and Their Applications, **Selcuk Koyuncu**, University of North Georgia, and **Lei Cao**, Georgian Court University.

Stochastic Processes and Modelling, **Erkan Nane**, Auburn University, and **Jebessa B. Mijena**, Georgia College and State University.

Symmetries, Integrability, and Beyond, **Maria Clara Nucci**, Università di Perugia, ITALY, and **Sarah Post**, University of Hawaií at Manoa.

Symplectic Geometry, Moment Maps and Morse Theory, **Lisa Jeffrey**, University of Toronto, and **Tara Holm**, Cornell University (AMS-AWM).

Teaching Assistant Development Programs: Why and How?, **Solomon Friedberg**, Boston College, **Jessica Deshler**, West Virginia University, **Jeffrey Remmel**, University of California, San Diego, and **Lisa Townsley**, University Of Georgia.

The Mathematics of the Atlanta University Center, **Talitha M. Washington**, Howard University, **Monica Jackson**, American University, and **Colm Mulcahy**, Spelman College (AMS-NAM).

The Modeling First Approach to Teaching Differential Equations, **Chris McCarthy**, City University of New York, and **Brian Winkel**, US Military Academy, West Point.

Theory and Applications of Numerical Algebraic Geometry, **Daniel Brake**, University of Notre Dame, **Robert Krone**, Queen's University, and **Jose Israel Rodriguez**, University of Chicago.

Topics in Graph Theory, **Songling Shan**, Vanderbilt University, and **Xiaofeng Gu**, University of West Georgia.

Topology, Representation Theory, and Operator Algebras (A Tribute to Paul Baum), **Efton Park** and **Jose Carrion**, Texas Christian University.

Women in Analysis (In Honor of Cora Sadosky), **Alexander Reznikov**, Vanderbilt University, **Oleksandra**

Beznosova and **Hyun-Kyoung Kwon**, University of Alabama, and **Katharine Ott**, Bates College.

Women in Topology, **Jocelyn Bell**, Hobart and William Smith Colleges, **Eleanor Ollhoff**, University of Tennessee, **Candice Price**, University of San Diego, and **Arunima Ray**, Brandeis University.

Charleston, South Carolina

College of Charleston

March 10–12, 2017

Friday – Sunday

Meeting #1126

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines

For organizers: Expired
For abstracts: January 17, 2017

The scientific information listed below may be dated. For the latest information, see `www.ams.org/amsmtgs/sectional.html`.

Invited Addresses

Pramod N. Achar, Louisiana State University, *Title to be announced*.

Hubert Bray, Duke University, *Title to be announced*.

Alina Chertock, North Carolina State University, *Title to be announced*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `www.ams.org/cgi-bin/abstracts/abstract.pl`.

Active Learning in Undergraduate Mathematics (Code: SS 21A), **Draga Vidakovic**, Georgia State University, **Harrison Stalvey**, University of Colorado, Boulder, and **Darryl Chamberlain,Jr.**, **Aubrey Kemp**, and **Leslie Meadows**, Georgia State University.

Advances in Long-term Behavior of Nonlinear Dispersive Equations (Code: SS 27A), **Brian Pigott**, Wofford College, and **Sarah Raynor**, Wake Forest University.

Advances in Nonlinear Waves: Theory and Applications (Code: SS 23A), **Constance M. Schober**, University of Central Florida, and **Andrei Ludu**, Embry Riddle University.

Algebras, Lattices, Varieties (Code: SS 19A), **George F. McNulty**, University of South Carolina, and **Kate S. Owens**, College of Charleston.

Analysis and Control of Fluid-Structure Interactions and Fluid-Solid Mixtures (Code: SS 6A), **Justin T. Webster**, College of Charleston, and **Daniel Toundykov**, University of Nebraska-Lincoln.

Analysis, Control and Stabilization of PDE's (Code: SS 13A), **George Avalos**, University of Nebraska-Lincoln, and **Scott Hansen**, Iowa State University.

Bicycle Track Mathematics (Code: SS 25A), **Ron Perline**, Drexel University.

Coding Theory, Cryptography, and Number Theory (Code: SS 17A), **Jim Brown**, **Shuhong Gao**, **Kevin James**, **Felice Manganiello**, and **Gretchen Matthews**, Clemson University.

Commutative Algebra (Code: SS 1A), **Bethany Kubik**, University of Minnesota Duluth, **Saeed Nasseh**, Georgia Southern University, and **Sean Sather-Wagstaff**, Clemson University.

Computability in Algebra and Number Theory (Code: SS 8A), **Valentina Harizanov**, The George Washington University, **Russell Miller**, Queens College and Graduate Center - City University of New York, and **Alexandra Shlapentokh**, East Carolina University.

Data Analytics and Applications (Code: SS 2A), **Scott C. Batson**, **Lucas A. Overbuy**, and **Bryan Williams**, Space and Naval Warfare Systems Center Atlantic.

Factorization and Multiplicative Ideal Theory (Code: SS 16A), **Jim Coykendall**, Clemson University, and **Evan Houston** and **Thomas G. Lucas**, University of North Carolina, Charlotte.

Fluid-Boundary Interactions (Code: SS 26A), **M. Nick Moore**, Florida State University.

Frame Theory (Code: SS 22A), **Dustin Mixon**, Air Force Institute of Technology, **John Jasper**, University of Cincinnati, and **James Solazzo**, Coastal Carolina University.

Free-boundary Fluid Models and Related Problems (Code: SS 7A), **Marcelo Disconzi**, Vanderbilt University, and **Lorena Bociu**, North Carolina State University.

Geometric Analysis and General Relativity (Code: SS 20A), **Hubert L. Bray**, Duke University, **Otis Chodosh**, Princeton University, and **Greg Galloway** and **Pengzi Miao**, University of Miami.

Geometric Methods in Representation Theory (Code: SS 15A), **Pramod N. Achar**, Louisiana State University, and **Amber Russell**, Butler University.

Geometry and Symmetry in Integrable Systems (Code: SS 10A), **Annalisa Calini**, **Alex Kasman**, and **Thomas Ivey**, College of Charleston.

Graph Theory (Code: SS 5A), **Colton Magnant**, Georgia Southern University, and **Zixia Song**, University of Central Florida.

Knot Theory and its Applications (Code: SS 3A), **Elizabeth Denne**, Washington & Lee University, and **Jason Parsley**, Wake Forest University.

Nonlinear Waves: Analysis and Numerics (Code: SS 18A), **Anna Ghazaryan**, Miami University, **St é phane Lafortune**, College of Charleston, and **Vahagn Manukian**, Miami University.

Numerical Methods for Coupled Problems in Computational Fluid Dynamics (Code: SS 11A), **Vincent J. Ervin** and **Hyesuk Lee**, Clemson University.

Oscillator Chain and Lattice Models in Optics, the Power Grid, Biology, and Polymer Science (Code: SS 14A), **Alejandro Aceves**, Southern Methodist University, and **Brenton LeMesurier**, College of Charleston.

Recent Trends in Finite Element Methods (Code: SS 9A), **Michael Neilan**, University of Pittsburgh, and **Leo Rebholz**, Clemson University.

Representation Theory and Algebraic Mathematical Physics (Code: SS 12A), **Iana I. Anguelova**, **Ben Cox**, and **Elizabeth Jurisich**, College of Charleston.

Riemann-Hilbert Problem Approach to Asymptotic Problems in Integrable Systems, Orthogonal Polynomials and Other Areas (Code: SS 24A), **Alexander Tovbis**, University of Central Florida, and **Robert Jenkins**, University of Arizona.

Rigidity Theory and Inversive Distance Circle Packings (Code: SS 4A), **John C. Bowers**, James Madison University, and **Philip L. Bowers**, The Florida State University.

Bloomington, Indiana

Indiana University

April 1–2, 2017

Saturday – Sunday

Meeting #1127

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: February 2017
Program first available on AMS website: February 23, 2017

Issue of *Abstracts*: Volume 38, Issue 2

Deadlines

For organizers: Expired
For abstracts: February 7, 2017

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Ciprian Demeter, Indiana University, *Title to be announced.*

Sarah Koch, University of Michigan, *Title to be announced.*

Richard Evan Schwartz, Brown University, *Title to be announced* (Einstein Public Lecture in Mathematics).

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

AMS Invited Address (Code: KOCH), .

Algebraic and Enumerative Combinatorics with Applications (Code: SS 6A), **Saúl A. Blanco**, Indiana University, and **Kyle Peterson**, DePaul University.

Analysis and Numerical Computations of PDEs in Fluid Mechanics (Code: SS 20A), **Gung-Min Gie**, University of Louisville, and **Makram Hamouda** and **Roger Temam**, Indiana University.

Analysis of Variational Problems and Nonlinear Partial Di fferential Equations (Code: SS 11A), **Nam Q. Le** and **Peter Sternberg**, Indiana University.

Automorphic Forms and Algebraic Number Theory (Code: SS 2A), **Patrick B. Allen**, University of Illinois at Urbana-Champaign, and **Matthias Strauch**, Indiana University Bloomington.

Commutative Algebra (Code: SS 19A), **Ela Celikbas** and **Olgur Celikbas**, West Virginia University.

Computability and Inductive Definability over Structures (Code: SS 3A), **Siddharth Bhaskar**, **Lawrence Valby**, and **Alex Kruckman**, Indiana University.

Dependence in Probability and Statistics (Code: SS 7A), **Richard C. Bradley** and **Lanh T. Tran**, Indiana University.

Differential Equations and Their Applications to Biology (Code: SS 27A), **Changbing Hu**, **Bingtuan Li**, and **Jiaxu Li**, University of Louisville.

Discrete Structures in Conformal Dynamics and Geometry (Code: SS 5A), **Sarah Koch**, University of Michigan, and **Kevin Pilgrim** and **Dylan Thurston**, Indiana University.

Extremal Problems in Graphs, Hypergraphs and Other Combinatorial Structures (Code: SS 25A), **Amin Bahmanian**, Illinois State University, and **Theodore Molla**, University of Illinois Urbana-Champaign.

Financial Mathematics and Statistics (Code: SS 24A), **Ryan Gill**, University of Louisville, **Rasitha Jayasekera**, Butler University, and **Kiseop Lee**, Purdue University.

Fusion Categories and Applications (Code: SS 26A), **Paul Bruillard**, Pacific Northwest National Laboratory, and **Julia Plavnik** and **Eric Rowell**, Texas A&M University.

Harmonic Analysis and Partial Differential Equations (Code: SS 9A), **Lucas Chaffee**, Western Washington University, **William Green**, Rose-Hulman Institute of Technology, and **Jarod Hart**, University of Kansas.

Homotopy Theory (Code: SS 12A), **David Gepner**, Purdue University, **Ayelet Lindenstrauss** and **Michael Mandell**, Indiana University, and **Daniel Ramras**, Indiana University-Purdue University Indianapolis.

Model Theory (Code: SS 14A), **Gabriel Conant**, University of Notre Dame, and **Philipp Hieronymi**, University of Illinois Urbana Champaign.

Multivariate Operator Theory and Function Theory (Code: SS 21A), **Hari Bercovici**, Indiana University, **Kelly Bickel**, Bucknell University, **Constanze Liaw**, Baylor University, and **Alan Sola**, Stockholm University.

Network Theory (Code: SS 8A), **Jeremy Alm** and **Keenan M.L. Mack**, Illinois College.

Nonlinear Elliptic and Parabolic Partial Differential Equations and Their Various Applications (Code: SS 13A), **Changyou Wang**, Purdue University, and **Yifeng Yu**, University of California, Irvine.

Probabilistic Methods in Combinatorics (Code: SS 22A), **Patrick Bennett** and **Andrzej Dudek**, Western Michigan University.

Probability and Applications (Code: SS 16A), **Russell Lyons** and **Nick Travers**, Indiana University.

Randomness in Complex Geometry (Code: SS 1A), **Turgay Bayraktar**, Syracuse University, and **Norman Levenberg**, Indiana University.

Representation Stability and its Applications (Code: SS 23A), **Patricia Hersh**, North Carolina State University,

Jeremy Miller, Purdue University, and **Andrew Putman**, University of Notre Dame.

Representation Theory and Integrable Systems (Code: SS 18A), **Eugene Mukhin**, Indiana University,Purdue University Indianapolis, and **Vitaly Tarasov**, Indiana University, Purdue University Indianapolis.

Self-similarity and Long-range Dependence in Stochastic Processes (Code: SS 10A), **Takashi Owada**, Purdue University, **Yi Shen**, University of Waterloo, and **Yizao Wang**, University of Cincinnati.

Spectrum of the Laplacian on Domains and Manifolds (Code: SS 4A), **Chris Judge** and **Sugata Mondal**, Indiana University.

Topics in Extremal, Probabilistic and Structural Graph Theory (Code: SS 15A), **John Engbers**, Marquette University, and **David Galvin**, University of Notre Dame.

Topological Mathematical Physics (Code: SS 17A), **E. Birgit Kaufmann** and **Ralph M. Kaufmann**, Purdue University, and **Emil Prodan**, Yeshiva University.

Pullman, Washington

Washington State University

April 22–23, 2017

Saturday – Sunday

Meeting #1128

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: February 2017
Program first available on AMS website: March 9, 2017

Issue of *Abstracts*: Volume 38, Issue 2

Deadlines

For organizers: October 20, 2016
For abstracts: February 28, 2017

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Michael Hitrik, University of California, Los Angeles, *Title to be announced*.

Andrew S. Raich, University of Arkansas, *Title to be announced*.

Daniel Rogalski, University of California, San Diego, *Title to be announced*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

Analysis on the Navier-Stokes equations and related PDEs (Code: SS 9A), **Kazuo Yamazaki**, University of Rochester, and **Litzheng Tao**, University of California, Riverside.

Combinatorial and Algebraic Structures in Knot Theory (Code: SS 5A), **Sam Nelson**, McKenna College, and **Allison Henrich**, Seattle University.

Commutative Algebra (Code: SS 3A), **Jason Lutz** and **Katharine Shultis**, Gonzaga University.

Fixed Point Methods in Differential and Integral Equations (Code: SS 1A), **Theodore A. Burton**, Southern Illinois University in Carbondale.

Inverse Problems (Code: SS 2A), **Hanna Makaruk**, Los Alamos National Laboratory (LANL), and **Robert Owczarek**, University of New Mexico, Albuquerque & Los Alamos.

Mathematical & Computational Neuroscience (Code: SS 12A), **Alexander Dimitrov**, Washington State University Vancouver, **Andrew Oster**, Eastern Washington University, and **Predrag Tosic**, Washington State University.

Mathematical Modeling of Forest and Landscape Change (Code: SS 11A), **Nikolay Strigul** and **Jean Lienard**, Washington State University Vancouver.

Partial Differential Equations and Applications (Code: SS 8A), **V. S. Manoranjan**, **C. Moore**, **Lynn Schreyer**, and **Hong-Ming Yin**, Washington State University.

Recent Advances on Mathematical Biology and Their Applications (Code: SS 7A), **Robert Dillon** and **Xueying Wang**, Washington State University.

Several Complex Variables and PDEs (Code: SS 10A), **Andrew Raich** and **Phillip Harrington**, University of Arkansas.

Special Session on Analytic Number Theory and Automorphic Forms (Code: SS 6A), **Steven J. Miller**, Williams College, and **Sheng-Chi Liu**, Washington State University.

Theory and Applications of Linear Algebra (Code: SS 4A), **Judi McDonald** and **Michael Tsatsomeros**, Washington State University.

Undergraduate Research Experiences in the Classroom (Code: SS 13A), **Heather Moon**, Lewis-Clark State College.

New York, New York

Hunter College, City University of New York

May 6–7, 2017

Saturday – Sunday

Meeting #1129

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: March 2017
Program first available on AMS website: March 22, 2017

Issue of *Abstracts*: Volume 38, Issue 2

Deadlines

For organizers: Expired
For abstracts: March 14, 2017
The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Jeremy Kahn, City University of New York, *Title to be announced*.

Fernando Coda Marques, Princeton University, *Title to be announced.*

James Maynard, Magdalen College, University of Oxford, *Title to be announced* (Erdős Memorial Lecture).

Kavita Ramanan, Brown University, *Title to be announced.*

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at `www.ams.org/cgi-bin/abstracts/abstract.pl`.

Analysis and numerics on liquid crystals and soft matter (Code: SS 16A), **Xiang Xu**, Old Dominion University, and **Wujun Zhang**, Rutgers University.

Applications of network analysis, in honor of Charlie Suffel's 75th birthday (Code: SS 18A), **Michael Yatauro**, Pennsylvania State University-Brandywine.

Banach Space Theory and Metric Embeddings (Code: SS 10A), **Mikhail Ostrovskii**, St John's University, and **Beata Randrianantoanina**, Miami University of Ohio.

Cluster Algebras in Representation Theory and Combinatorics (Code: SS 6A), **Alexander Garver**, Université du Quebéc à Montréal and Sherbrooke, and **Khrystyna Serhiyenko**, University of California at Berkeley.

Cohomologies and Combinatorics (Code: SS 15A), **Rebecca Patrias**, Université du Québec à Montréal, and **Oliver Pechenik**, Rutgers University.

Common Threads to Nonlinear Elliptic Equations and Systems (Code: SS 14A), **Florin Catrina**, St. John's University, and **Wenxiong Chen**, Yeshiva University.

Commutative Algebra (Code: SS 1A), **Laura Ghezzi**, New York City College of Technology-CUNY, and **Jooyoun Hong**, Southern Connecticut State University.

Computability Theory: Pushing the Boundaries (Code: SS 9A), **Johanna Franklin**, Hofstra University, and **Russell Miller**, Queens College and Graduate Center, City University of New York.

Computational and Algorithmic Group Theory (Code: SS 7A), **Denis Serbin** and **Alexander Ushakov**, Stevens Institute of Technology.

Cryptography (Code: SS 3A), **Xiaowen Zhang**, College of Staten Island and Graduate Center-CUNY.

Current Trends in Function Spaces and Nonlinear Analysis (Code: SS 2A), **David Cruz-Uribe**, University of Alabama, **Jan Lang**, The Ohio State University, and **Osvaldo Mendez**, University of Texas at El Paso.

Differential and Difference Algebra: Recent Developments, Applications, and Interactions (Code: SS 12A), **Omár León-Sanchez**, McMaster University, and **Alexander Levin**, The Catholic University of America.

Geometric Function Theory and Related Topics (Code: SS 19A), **Sudeb Mitra**, Queens College and Graduate Center-CUNY, and **Zhe Wang**, Bronx Community College-CUNY.

Geometry and Topology of Ball Quotients and Related Topics (Code: SS 5A), **Luca F. Di Cerbo**, Max Planck Institute, Bonn, and **Matthew Stover**, Temple University.

Hydrodynamic and Wave Turbulence (Code: SS 11A), **Tristan Buckmaster**, Courant Institute of Mathematical Sciences, New York University, and **Vlad Vicol**, Princeton University.

Infinite Permutation Groups, Totally Disconnected Locally Compact Groups, and Geometric Group Theory (Code: SS 4A), **Delaram Kahrobaei**, New York City College of Technology and Graduate Center-CUNY, and **Simon Smith**, New York City College of Technology-CUNY.

Nonlinear and Stochastic Partial Differential Equations: Theory and Applications in Turbulence and Geophysical Flows (Code: SS 8A), **Nathan Glatt-Holtz**, Tulane University, **Geordie Richards**, Utah State University, and **Xiaoming Wang**, Florida State University.

Operator algebras and ergodic theory (Code: SS 17A), **Genady Grabarnik** and **Alexander Katz**, St John's University.

Representation Spaces and Toric Topology (Code: SS 13A), **Anthony Bahri**, Rider University, and **Daniel Ramras** and **Mentor Stafa**, Indiana University-Purdue University Indianapolis.

Montréal, Quebec Canada

McGill University

July 24–28, 2017

Monday – Friday

Meeting #1130

The second Mathematical Congress of the Americas (MCA 2017) is being hosted by the Canadian Mathematical Society (CMS) in collaboration with the Pacific Institute for the Mathematical Sciences (PIMS), the Fields Institute (FIELDS), Le Centre de Recherches Mathématiques (CRM), and the Atlantic Association for Research in the Mathematical Sciences (AARMS).

Associate secretary: Brian D. Boe
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines

For organizers: Expired
For abstracts: To be announced

Denton, Texas

University of North Texas

September 9–10, 2017

Saturday – Sunday

Meeting #1131

Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: June 2017
Program first available on AMS website: July 27, 2017

Issue of *Abstracts*: Volume 38, Issue 3

Deadlines

For organizers: February 2, 2017
For abstracts: July 18, 2017
The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Mirela Çiperiani, University of Texas at Austin, *Title to be announced*.

Adrianna Gillman, Rice University, *Title to be announced*.

Kevin Pilgrim, Indiana University, *Title to be announced*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

Dynamics, Geometry and Number Theory (Code: SS 1A), **Lior Fishman** and **Mariusz Urbanski**, University of North Texas.

Lie algebras, Superalgebras, and Applications (Code: SS 3A), **Charles H. Conley**, University of North Texas, and **Dimitar Grantcharov**, University of Texas at Arlington.

Noncommutative and Homological Algebra (Code: SS 4A), **Anne Shepler**, University of North Texas, and **Sarah Witherspoon**, Texas A&M University.

Real-Analytic Automorphic Forms (Code: SS 2A), **Olav K Richter**, University of North Texas, and **Martin Westerholt-Raum**, Chalmers University of Technology.

Buffalo, New York

State University of New York at Buffalo

September 16–17, 2017

Saturday – Sunday

Meeting #1132

Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: June 2017
Program first available on AMS website: August 3, 2017

Issue of *Abstracts*: Volume 38, Issue 3

Deadlines

For organizers: February 16, 2017
For abstracts: July 25, 2017
The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Inwon Kim, University of California at Los Angeles, *Title to be announced*.

Govind Menon, Brown University, *Title to be announced*.

Bruce Sagan, Michigan State University, *Title to be announced*.

Orlando, Florida

University of Central Florida, Orlando

September 23–24, 2017

Saturday – Sunday

Meeting #1133

Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: June 2017
Program first available on AMS website: August 10, 2017

Issue of *Abstracts*: Volume 38, Issue 4

Deadlines

For organizers: February 23, 2017
For abstracts: August 1, 2017

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Invited Addresses

Christine Heitsch, Georgia Institute of Technology, *Title to be announced*.

Jonathan Kujawa, University of Oklahoma, *Title to be announced*.

Christopher D Sogge, Johns Hopkins University, *Title to be announced*.

Special Sessions

If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

Algebraic Curves and their Applications (Code: SS 3A), **Lubjana Beshaj**, The University of Texas at Austin.

Commutative Algebra: Interactions with Algebraic Geometry and Algebraic Topology (Code: SS 1A), **Joseph Brennan**, University of Central Florida, and **Alina Iacob** and **Saeed Nasseh**, Georgia Southern University.

Structural Graph Theory (Code: SS 2A), **Zixia Song**, University of Central Florida.

Riverside, California

University of California, Riverside

November 4–5, 2017

Saturday – Sunday

Meeting #1134

Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: September 2017
Program first available on AMS website: September 21, 2017

Issue of *Abstracts*: Volume 38, Issue 4

Deadlines
For organizers: April 14, 2017
For abstracts: September 12, 2017

San Diego, California

San Diego Convention Center and San Diego Marriott Hotel and Marina

January 10–13, 2018
Wednesday – Saturday

Meeting #1135
Joint Mathematics Meetings, including the 124th Annual Meeting of the AMS, 101st Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: October 2017
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines
For organizers: April 1, 2017
For abstracts: To be announced

Columbus, Ohio

Ohio State University

March 24–25, 2018
Saturday – Sunday
Central Section
Associate secretary: Georgia Benkart
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines
For organizers: To be announced
For abstracts: To be announced

Portland, Oregon

Portland State University

April 14–15, 2018
Saturday – Sunday
Western Section
Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines
For organizers: To be announced
For abstracts: To be announced

The scientific information listed below may be dated. For the latest information, see www.ams.org/amsmtgs/sectional.html.

Special Sessions
If you are volunteering to speak in a Special Session, you should send your abstract as early as possible via the abstract submission form found at www.ams.org/cgi-bin/abstracts/abstract.pl.

Inverse Problems (Code: SS 2A), **Hanna Makaruk**, Los Alamos National Laboratory (LANL), and **Robert Owczarek**, University of New Mexico, Albuquerque & Los Alamos.

Pattern Formation in Crowds, Flocks, and Traffic (Code: SS 1A), **J. J. P. Veerman**, Portland State University, **Alethea Barbaro**, Case Western Reserve University, and **Bassam Bamieh**, UC Santa Barbara.

Nashville, Tennessee

Vanderbilt University

April 14–15, 2018
Saturday – Sunday
Southeastern Section
Associate secretary: Brian D. Boe
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines
For organizers: To be announced
For abstracts: To be announced

Boston, Massachusetts

Northeastern University

April 21–22, 2018
Saturday – Sunday
Eastern Section
Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines
For organizers: September 21, 2017
For abstracts: March 6, 2018

People's Republic of China

Fudan University

June 11–14, 2018

Monday – Thursday

Associate secretary: Carla D. Savage
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For abstracts: To be announced

Baltimore, Maryland

Baltimore Convention Center, Hilton Baltimore, and Baltimore Marriott Inner Harbor Hotel

January 16–19, 2019

Wednesday – Saturday

Joint Mathematics Meetings, including the 125th Annual Meeting of the AMS, 102nd Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM)and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Steven H. Weintraub
Announcement issue of *Notices*: October 2018
Program first available on AMS website: To be announced
Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 2, 2018
For abstracts: To be announced

Honolulu, Hawaii

University of Hawaii at Manoa

March 29–31, 2019

Friday – Sunday

Central Section
Associate secretaries: Georgia Benkart and Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: To be announced

Issue of *Abstracts*: To be announced

Deadlines

For organizers: To be announced
For abstracts: To be announced

Denver, Colorado

Colorado Convention Center

January 15–18, 2020

Wednesday – Saturday

Joint Mathematics Meetings, including the 126th Annual Meeting of the AMS, 103rd Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM)

Associate secretary: Michel L. Lapidus
Announcement issue of *Notices*: To be announced
Program first available on AMS website: November 1, 2019

Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 1, 2019
For abstracts: To be announced

Washington, District of Columbia

Walter E. Washington Convention Center

January 6–9, 2021

Wednesday – Saturday

Joint Mathematics Meetings, including the 127th Annual Meeting of the AMS, 104th Annual Meeting of the Mathematical Association of America (MAA), annual meetings of the Association for Women in Mathematics (AWM) and the National Association of Mathematicians (NAM), and the winter meeting of the Association of Symbolic Logic (ASL), with sessions contributed by the Society for Industrial and Applied Mathematics (SIAM).

Associate secretary: Brian D. Boe
Announcement issue of *Notices*: October 2020
Program first available on AMS website: November 1, 2020

Issue of *Abstracts*: To be announced

Deadlines

For organizers: April 1, 2020
For abstracts: To be announced

2017 Joint Mathematics Meetings Advance Registration/Housing Form

JOINT MATHEMATICS MEETINGS
ATLANTA JAN 4-7, 2017
AMERICAN MATHEMATICAL SOCIETY
MATHEMATICAL ASSOCIATION OF AMERICA

Name ______________________________
(please write name as you would like it to appear on your badge)

Mailing Address ______________________________

____

Telephone ______________________ Fax: ______________________

In case of emergency (for you) at the meeting, call: Day #__________ Evening #:__________

Email Address ______________________ Additional email address for receipt ______________

Acknowledgment of this registration and any hotel reservations will be sent to the email address(es) given here. **Check this box to receive a copy in U.S. Mail:** ☐

Affiliation for badge ______________________ (company/university) Nonmathematician guest badge name: ______________ (Note fee of US$20

☐ **I DO NOT want my program and badge to be mailed to me on 12/9/16. (Materials will be mailed to the address listed above unless you check this box.)**

Registration Fees

Membership please ✓ all that apply. First row is eligible to register as a member. For undergraduate students, membership in PME and KME also applies.

☐ AMS ☐ MAA ☐ ASL ☐ CMS ☐ SIAM

Undergraduate Students Only: ☐ PME ☐ KME

Other Societies: ☐ AWM ☐ NAM ☐ YMN ☐ AMATYC

Joint Meetings	**by Dec 20**	**at mtg**	**Subtotal**
☐ Member AMS, MAA, ASL, CMS, or SIAM	US$ 316	US$ 416	
☐ Nonmember	US$ 502	US$ 640	
☐ Graduate Student Member (AMS, MAA ASL, CMS, or SIAM)	US$ 71	US$ 83	
☐ Graduate Student (Nonmember)	US$113	US$ 125	
☐ Undergraduate Student (Member AMS, ASL, CMS, MAA, PME, KME, or SIAM)	US$ 71	US$ 83	
☐ Undergraduate Student (Nonmember)	US$113	US$ 125	
☐ High School Student	US$ 7	US$ 13	
☐ Unemployed	US$ 71	US$ 83	
☐ Temporarily Employed	US$ 258	US$ 295	
☐ Developing Countries Special Rate	US$ 71	US$ 83	
☐ Emeritus Member of AMS or MAA	US$ 71	US$ 83	
☐ High School Teacher	US$ 71	US$ 83	
☐ Librarian	US$ 71	US$ 83	
☐ Press	US$ 0	US$ 0	
☐ Exhibitor (Commercial)	US$ 0	US$ 0	
☐ Artist Exhibitor (work in JMM Art Exhibit)	US$ 0	US$ 0	
☐ Nonmathematician Guest of registered mathematician	US$ 20	US$ 20	
			$________

AMS Short Course: *Random Growth Models (1/2-1/3)*

☐ Member of AMS	US$ 112	US$146	
☐ Nonmember	US$ 170	US$200	
☐ Student, Unemployed, Emeritus	US$ 60	US$ 81	
			$________

MAA Minicourses (see listing in text)

I would like to attend: ☐ One Minicourse ☐ Two Minicourses

Please enroll me in MAA Minicourse(s) #______ and #______

Price: US$ 100 for each minicourse.

(For more than 2 minicourses, call or email the MMSB.) $________

Graduate School Fair

☐ Graduate Program Table US$ 80 US$ 80
(includes table, posterboard & electricity) $________

Receptions & Banquets

☐ Graduate Student/First-Time Attendee Reception (1/4) (no charge)

☐ NAM Banquet (1/6)

#____Chicken #____Braised Short Ribs #____Veg US$ 65

#____Kosher (*Additional fees apply for Kosher Meals.*) US$ 104

Total for NAM Banquet $________

☐ AMS Dinner (1/7) Regular Price #____US$ 69

Student Price #____US$ 30

Total for AMS Dinner $________

Total for Registrations and Events $________

Registration for the Joint Meetings is not required for the short course but it is required for the minicourses and the Employment Center. To register for the Employment Center, go to http://www.ams.org/profession/employment-services/employment-center. For questions, email: emp-info@ams.org.

Payment

Registration & Event Total (total from column on left) $ ____________

Hotel Deposit (only if paying by check) $ ____________

If you send a hotel deposit check, the deadline for this form is December 1.

Total Amount To Be Paid **$** ____________

Method of Payment

☐ **Check**. Make checks payable to the AMS. For all check payments, please keep a copy of this form for your records.

☐ **Credit Card**. All major credit cards accepted. For your security, we do not accept credit card numbers by postal mail, email or fax. If the MMSB receives your registration form by fax or postal mail, it will contact you at the phone number provided on this form. For questions, contact the MMSB at mmsb@ams.org.

Signature: ______________________

☐ **Purchase Order #** ______________ (please enclose copy)

Other Information

Mathematical Reviews field of interest #__________

☐ I am willing to serve as a judge for the MAA Undergraduate Student Poster Session

☐ For planning purposes for the MAA Two-year College Reception, please check if you are a faculty member at a two-year college.

☐ I am a mathematics department chair.

☐ Please do not include my name and postal address on any promotional mailing lists. (The JMM does not share email addresses.)

☐ Please do not include my name on any list of JMM participants other than the scientific program if I am, in fact, making a presentation that is part of the meeting.

☐ Please ✓ this box if you have a disability requiring special services.

Deadlines

To receive badges/programs in the mail:	**Nov. 22, 2016**
Hotel reservations with check deposit:	**Dec. 1, 2016**
Hotel reservations, changes/cancellations through the JMM website:	**Dec. 6, 2016**
Advance registration for the Joint Meetings, short course, minicourses, and tickets:	**Dec. 20, 2016**
50% refund on advance registration, banquets, minicourses, and short course, cancel by	**Dec. 29, 2016***

***no refunds issued after this date.**

Mailing Address/Contact:

Mathematics Meetings Service Bureau (MMSB)
P. O. Box 6887
Providence, RI 02940-6887 **Fax**: 401-455-4004; **Email:** mmsb@ams.org
Telephone: 401-455-4144 or 1-800-321-4267 x4144 or x4137

2017 Joint Mathematics Meetings Hotel Reservations – Atlanta, GA

Please see the hotel information in the announcement or on the web for detailed information on each hotel.) To ensure accurate assignments, please rank hotels in order of preference by writing 1, 2, 3, etc. in the column on the left and by circling the requested bed confirguration. If your requested hotel and room type is no longer available, you will be assigned a room at the next available comparable rate. Please call the MMSB for details on suite configurations, sizes, availability, etc. All reservations, including suite reservations, must be made through the MMSB to receive the JMM rates. Reservations made directly with the hotels before **December 14, 2016** may be changed to a higher rate. All rates are subject to applicable local and state taxes in effect at the time of check-in; currently 16% state tax, (8% State Sales Tax plus 8% Hotel Occupancy Tax), plus an additional State of Georgia Hotel/Motel fee of US$5 per day. **Guarantee requirements: First night deposit by check (add to payment on reverse of form) or a credit card guarantee. Please note that reservations with check deposits must be received by the MMSB by December 1, 2016.**

☐ **Deposit enclosed (see front of form)**

☐ **Hold with my credit card. For your security, we do not accept credit card numbers by postal mail, email or fax.** If the MMSB receives your registration form by postal mail or fax, we will contact you at the phone number provided on the reverse of this form.

Date and Time of Arrival ______ **Date and Time of Departure** ______ **Number of adult guests in room** ______ **Number of children** ______

Name of Other Adult Room Occupant (s) ______ **Arrival Date** ______ **Departure Date** ______

Housing Requests: (example: rollaway cot, crib, nonsmoking room, low floor) ______

☐ I have disabilities as defined by the ADA that require a sleeping room that is accessible to the physically challenged. My needs are: ______

☐ I am a member of a hotel frequent-travel club and would like to receive appropriate credit. The hotel chain and card number are: ______

☐ I am not reserving a room. I am sharing with ______, who is making the reservation.

Order of choice	Hotel	Single	Double 1 bed-2 people	Double 2 beds- 2 people	Triple 3 adults-2 beds	Quad 4 adults-2 beds	Rollaway Cot Fee (add to special requests if reserving online)
	Hyatt Regency Atlanta (co-hqtrs)	US$ 175	US$ 175	US$ 175	US$ 195	US$ 215	Rollaways available (at no charge) only in king-bedded rooms.
	Student Rate	US$ 140	US$ 140	US$ 140	US$ 160	UD$ 180	
	Marriott Marquis Atlanta (co-hqtrs)	US$ 175	US$ 175	US$ 175	US$ 175	US$ 175	Rollaways available (at no charge) only in king-bedded rooms.
	Student Rate	US$ 140	US$ 140	US$ 140	US$ 140	US$ 140	
	Hilton Atlanta - First Tier (Rooms will be available at this price until they run out. When they run out, rooms will be priced at second tier	US$ 139	US$ 139	US$ 139	US$ 159	US$ 179	Rollaways available (at no charge) only in king-bedded rooms.
	Hilton Atlanta - Second Tier	US$ 149	US$ 149	US$ 149	US$ 169	US$ 189	

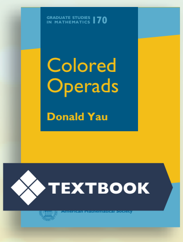
People interested in suites should contact the MMSB directly by email at mmsb@ams.org or by calling 800-321-4267, ext. 4137 or 4144; (401-455-4137 or 401-455-4144).

American Mathematical Society
Distribution Center

35 Monticello Place,
Pawtucket, RI 02861 USA

AMERICAN MATHEMATICAL SOCIETY

Recent Releases in the *Graduate Studies in Mathematics* Series

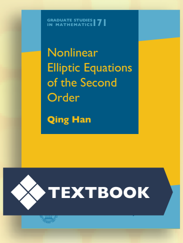


Colored Operads

Donald Yau, *The Ohio State University at Newark, OH*

This book discusses the theory of operads and colored operads, sometimes called symmetric multicategories.

Graduate Studies in Mathematics, Volume 170; 2016; 428 pages; Hardcover; ISBN: 978-1-4704-2723-8; List US$89; AMS members US$71.20; Order code GSM/170

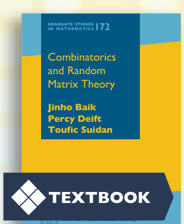


Nonlinear Elliptic Equations of the Second Order

Qing Han, *University of Notre Dame, IN*

A user-friendly introduction to the theory of nonlinear elliptic equations, with special attention given to basic results and the most important techniques.

Graduate Studies in Mathematics, Volume 171; 2016; 368 pages; Hardcover; ISBN: 978-1-4704-2607-1; List US$89; AMS members US$71.20; Order code GSM/171

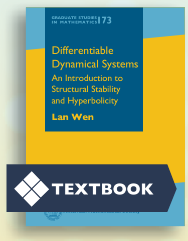


Combinatorics and Random Matrix Theory

Jinho Baik, *University of Michigan, Ann Arbor, MI*, **Percy Deift,** *Courant Institute, New York University, NY*, - **Toufic Suidan**

The goal of this book is to analyze in detail two key examples of this phenomenon, viz., Ulam's problem for increasing subsequences of random permutations and domino tilings of the Aztec diamond.

Graduate Studies in Mathematics, Volume 172; 2016; 461 pages; Hardcover; ISBN: 978-0-8218-4841-8; List US$89; AMS members US$71.20; Order code GSM/172



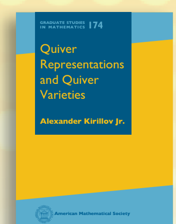
Differentiable Dynamical Systems

An Introduction to Structural Stability and Hyperbolicity

Lan Wen, *Peking University, Beijing, China*

Starting with the basic concepts of dynamical systems, analyzing the historic systems of the Smale horseshoe, Anosov toral automorphisms, and the solenoid attractor, this book develops the hyperbolic theory first for hyperbolic fixed points and then for general hyperbolic sets.

Graduate Studies in Mathematics, Volume 173; 2016; 192 pages; Hardcover; ISBN: 978-1-4704-2799-3; List US$79; AMS members US$63.20; Order code GSM/173



Quiver Representations and Quiver Varieties

Alexander Kirillov Jr., *Stony Brook University, NY*

This book is an introduction to the theory of quiver representations and quiver varieties, starting with basic definitions and ending with Nakajima's work on quiver varieties and the geometric realization of Kac–Moody algebras.

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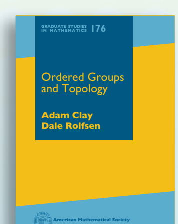

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