2004 Wiener Prize

James A. Sethian

The 2004 AMS-SIAM Norbert Wiener Prize in Applied Mathematics was awarded at the 110th Annual Meeting of the AMS in Phoenix in January 2004.

The Wiener Prize is awarded every three years to recognize outstanding contributions to applied mathematics in the highest and broadest sense (until 2001 the prize was awarded every five years). Established in 1967 in honor of Norbert Wiener (1894–1964), the prize was endowed by the Department of Mathematics of the Massachusetts Institute of Technology. The prize is given jointly by the AMS and the Society for Industrial and Applied Mathematics (SIAM). The recipient must be a member of one of these societies and a resident of the United States, Canada, or Mexico. The prize carries a cash award of $5,000.

The recipient of the Wiener Prize is chosen by a joint AMS-SIAM selection committee. For the 2004 prize the members of the selection committee were: Alexandre J. Chorin (chair), Martin Grötschel, and Philip J. Holmes.

The previous recipients of the Wiener Prize are: Richard E. Bellman (1970), Peter D. Lax (1975), Tosio Kato (1980), Gerald B. Whitham (1980), Clifford S. Gardner (1985), Michael Aizenman (1990), Jerrold E. Marsden (1990), Hermann Flaschka (1995), Ciprian Foias (1995), Alexandre J. Chorin (2000), and Arthur T. Winfree (2000).

The 2004 Wiener Prize was awarded to James Sethian. The text that follows presents the selection committee's citation, a brief biographical sketch, and the awardee's response upon receiving the prize.

Citation

The Norbert Wiener Prize in Applied Mathematics is awarded to James A. Sethian of the University of California at Berkeley for his seminal work on the computer representation of the motion of curves, surfaces, interfaces, and wave fronts, and for his brilliant applications of mathematical and computational ideas to problems in science and engineering.

His earliest work included an analysis of the motion of flame fronts and of the singularities they develop; he found important new links between the motion of fronts and partial differential equations, and in particular found that the correct extension of front motion beyond a singularity follows from an entropy condition as in the theory of nonlinear hyperbolic equations. These connections made possible the development of advanced numerical methods to describe front propagation through the solution of regularized equations on fixed grids.

In a subsequent work (with S. Osher) Sethian extended this work through an implicit formulation. The resulting methodology has come to be known as the "level set method", because it represents a front propagating in n dimensions as a level set of an object in $(n + 1)$ dimensions. Next, Sethian tamed the cost of working in higher dimensions by reducing the problem back down to its original dimensionality. This set of ideas makes possible the solution of practical problems of increasing importance and sophistication and constitutes a major mathematical development as well as an exceptionally useful computational tool with numerous applications.

Among the practical problems solved by Sethian are: the tracking of interfaces and drops in fluid mechanics with applications to inkjet design for high-speed printers; the analysis of crystal growth (with J. Strain); motion under mean curvature, construction of minimal surfaces, and knot recognition in computational geometry; design of optimal structures under loads (with A. Wiegmann); and the analysis of anisotropic front propagation and mixed discrete-continuous control. Each of these applications required extensions and modifications of the basic tools as well as new understanding of the problems under investigation.

Sethian's mathematical description of etching and deposition in the manufacture of computer chips has illuminated processes such as ion-milling, visibility, resputter, and material-dependent etch rates; the resulting algorithms are now an indispensable part of industrial semiconductor fabrication simulations throughout the world. His models of implicit surface motion together with fast Eikonal solvers are standard fare in medical and biomedical shape extraction and in fields such as shape-based image interpolation, shape-from-shading, stereoscopic vision, and texture segmentation; they are used in hospital electron beam scanners to quantify cardiac motion and efficiency. Recently, Sethian (with S. Fomel) developed efficient numerical methods for simulating multiple-arrival wavefront propagation by solving Liouville-type equations; this work has direct applications in seismic imaging and geophysical inverse problems and has already been put to use by the petroleum industry.

A particularly noteworthy aspect of Sethian's work is that he pursues his ideas from a first formulation of a mathematical model all the way to concrete applications in national laboratory and industrial settings; his algorithms are currently distributed in widely available packages. Sethian's work is a shining example of what applied mathematics can accomplish to benefit science as a whole.

Biographical Sketch

James A. Sethian was born on May 10, 1954, in Washington, DC. He received a B.A. in mathematics from Princeton University in 1976 and a Ph.D. in applied mathematics from the University of California, Berkeley, in 1982. After a National Science Foundation Postdoctoral Fellowship at the Courant Institute of Mathematical Sciences, he joined the faculty at UC Berkeley, where he is now professor of mathematics as well as head of the mathematics department at the Lawrence Berkeley National Laboratory. He has been a plenary speaker at the International Congress of Industrial and Applied Mathematicians, has been an invited speaker at the International Congress of Mathematicians, and has received SIAM's I. E. Block Community Lecture Prize.

He is an associate editor of *SIAM Review*, the *Journal of Mathematical Imaging and Vision*, and the *Journal on Interfaces and Free Boundaries.*

Response

In the course of a normal day, a letter from the AMS appears and jolts one out of a busy routine. I am grateful for this unexpected shock: It is a wonderful honor to be the recipient of the Norbert Wiener Prize.

My interest in front propagation began with the suggestions of Alexandre Chorin at Berkeley. Starting with his cell fraction-based Huyghens propagation algorithm, he artfully led me toward unanswered questions about interface evolution, the Landau instability, and ill-posedness. The appeal of alternative approaches stemmed from the sheer frustration of attempting to elevate existing numerical front propagation schemes beyond simple two-dimensional problems. I have a fond memory of buying building blocks in 1978 from a local toy store in an optimistic attempt to visualize the various cases involved in a three-dimensional version of the Volume-of-Fluid algorithm. The visual aids were not enough, and my thesis instead focused on developing and analyzing a mathematical model of flame and front propagation.

A Danforth Fellowship at Berkeley, followed by a National Science Foundation [NSF] Postdoctoral Fellowship at the Courant Institute, and then a Sloan Foundation Fellowship back at Berkeley, coupled to support from the U.S. Department of Energy [DOE], generously allowed me time for subsequent work on entropy conditions for front propagation, as well as links between the regularizing effects of curvature on Hamilton-Jacobi equations for front propagation and viscosity in conservation laws, and opened up the strategy of applying shock schemes to interface problems.

Indeed, this work on casting front propagation in the language of differential geometry and partial differential equations benefitted from a collection of disparate ideas and tools that were bubbling together in the late 1970s and early 1980s. The work of M. Crandall and P.-L. Lions, and then L. C. Evans, on viscosity solutions for Hamilton-Jacobi equations, G. Barles' analysis of that Berkeley flame model, the maturation of numerical schemes for hyperbolic conservation laws, and fresh ideas about curve evolution by M. Gage and M. Grayson all formed part of the landscape in those early years.

These ideas have led to several algorithms based on a partial differential equations view of evolving fronts. The first such algorithm, which relied on embedding the front as a particular level set of a higher-dimensional function and employed high-order schemes for the underlying Hamilton-Jacobi equation, became known as the "Level Set Method". The work is joint with Stanley Osher at UCLA, whose enthusiasm is a force unto itself, and I have warm memories of that collaboration.

As first laid out, that version of the Level Set Method was mathematically appealing, numerically robust, and unnecessarily slow. I was fortunate to have D. Chopp, now at Northwestern, as my first Ph.D. student, with whom the ideas of reinitialization and adaptivity were developed, pointing the way towards making these methods practical and efficient. The resulting Narrow Band Level Set Methods were honed with an equally talented Ph.D. student, D. Adalsteinsson, now at the University of North Carolina, Chapel Hill, who helped put these methods on a competitive footing with other methods of the day.

In this short space I cannot do justice to the large amount of work done on level set methods and the surprising areas to which they have been applied. Many efforts, including large-scale projects at the DOE National Laboratories, in particular at the Lawrence Berkeley National Laboratory, semester-long programs at IPAM [Institute for Mathematics and its Applications] at UCLA, and focused teams such as those in the semiconductor industry, have all contributed to pushing these techniques forward.

I would like to make mention of a few of my most recent collaborators. R. Malladi developed groundbreaking work while at the University of Florida, applying these algorithmic ideas to image segmentation, and I was fortunate that he chose to take his NSF Computational Sciences Postdoctoral Fellowship at Berkeley. He continues to be a leader in applying PDE-based techniques for medical and biomedical applications, and I am grateful for the ongoing collaboration. A. Vladimirsky, a former student now at Cornell, was instrumental in extending PDE-based front propagation techniques to produce extraordinarily fast methods for optimal control and anisotropic front propagation. S. Fomel, a former postdoc now at Texas, was pivotal in devising PDE front schemes for multiple "nonviscosity" arrivals with the same computational efficiency. And J. Wilkening, a former student now at Courant, tackled the difficult problem of front propagation and void motion in the context of electromigration. It is a joy to work with such able talents.

Two other endeavors deserve mention, in part because of the extensive work done long after I left the scene. The work with A. Majda on zero Mach number combustion has been honed and melded into complex combustion calculations by J. Bell and P. Colella. And the work on mathematical botany, anisogamy, and chemotaxis continues to be pioneered by P. Cox, director of the National Tropical Botanical Garden.

I have been lucky to have had pivotal teachers who stood as "transformers" along the way, investing their own energy to raise the voltage and then graciously passing it on. At a public junior high school in Virginia, W. Taylor was the first to tell me to study mathematics. A high school teacher offered similar encouragement, adding that I was almost as good as the kid sitting next to me. I don't feel too bad, since that kid, Eric Schmidt, is now CEO of Google. W. K Allard, then at Princeton, brought me to PDEs. O. Hald at Berkeley introduced me to numerics. A. Chorin is a wise and skilled thesis advisor; I am fortunate to be in the large community of his former students.

Finally, I am grateful to the Department of Energy for its long-term support of these efforts, the National Science Foundation, and the ongoing opportunity to interact at Berkeley and the Lawrence Berkeley National Laboratory with people of singular talent, warmth, and support, including G. I. Barenblatt, A. Grunbaum, O. Hald, and R. Malladi.