Avner Friedman: Mathematician in Control >>>

Avner Friedman

Interview of Avner Friedman by Y.K. Leong (matlyk@nus.edu.sg)

Avner Friedman has made important contributions, both in theory and applications, to partial differential equations, stochastic differential equations and control theory. His career, especially during the past two decades, epitomizes a personal mission and relentless drive in bringing the tools of modern analysis to bear in the service of industry and science.

His distinguished career began at the Hebrew University, Israel and weaved, in a somewhat colorful way, through Kansas, Indiana, Berkeley, Minnesota, Stanford, Northwestern and Purdue, culminating in the directorship of the Institute for Mathematics and its Applications (IMA) , Minnesota (1987–97), Minnesota Center for Industrial Mathematics (MCIM) (1994–2002) and Mathematical Biosciences Institute (MBI) of the Ohio State University (2001–). He is also the Distinguished Professor of Mathematical and Physical Sciences at Ohio State University, the latest in a chain of numerous distinguished professorships in the universities he has passed through.

His service on many U.S. national boards and advisory committees is an indication of his boundless energy and selfless efforts in promoting the applications of mathematics and advancing the mathematical sciences. Among the honors and awards he received for his wide-ranging contributions are the Stampacchia Prize, NSF Special Creativity Award, and membership of American Academy of Arts and Sciences and of the U.S. National Academy of Sciences, He has served and continues to serve on the editorial boards of numerous leading journals in analysis, applied mathematics and mathematical physics. His prolific research and scholarly output has resulted in more than 400 publications, written singly and jointly, and 20 books. He has always been in demand for invited lectures in and outside the U.S. Even at the biblical age of three score and ten and beyond, he is directing a concerted effort to bring problems of the biosciences within the reach of the mathematical sciences.

As a founding member of the Scientific Advisory Board (SAB) of IMS since 2000, Friedman has contributed to the development and success of the Institute in its first five years. On his annual visit to the Institute, he was interviewed by Y.K. Leong on behalf of *Imprints* on 6 January 2006. In the following edited and vetted account of the interview, one can feel the palpable excitement of applying mathematics to the real world and of being drawn into the personal world of a creative and gregarious personality.

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Imprints: What was the topic of your Ph D thesis? Did it set the general direction of your future research?

Avner Friedman: My thesis was in partial differential equations. It dealt with several different subjects. I have been involved in differential equations my entire career, but have also diversified to other areas.

I: You didn't change fields?

F: I didn't change fields in the sense of going from partial differential equations to algebra. But within partial differential equations, I diversified to a number of areas. Partial differential equations are used in, for example, control theory, applications to industry and, recently, mathematical biology.

I: You went to University of Kansas immediately after your doctorate. Was there any specific reason for this decision?

F: One chapter in my thesis dealt with the so-called problem of unique continuation. Professor Nachman Aronszjan, at the University of Kansas, had done some very important work on unique continuation. I wrote him about my results, and, soon afterward, he invited me to come as a research associate to his department. I was there for one year.

I: From your publications, it seems that initially you were primarily interested in the theoretical aspects (analysis) of partial differential equations but very soon afterwards, you also did and continue to do a lot of work in applied areas

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like control theory and stochastic differential equations. When and how did that happen?

F: I have always worked on partial differential equations, and I have looked for areas where they can be applied. That's why I started to migrate into areas of applications such as control theory. For a while, I went completely into stochastic differential equations because there were interesting problems in game theory, that is, stochastic games: problems of pursuit of objects when only partial information is known. It turned out that this topic was very well connected with partial differential equations, and I came back to doing partial differential equations through stochastic differential equations. By exploring these applications, I enriched my areas of knowledge and research.

I: Did those applied problems contribute new insights or new developments in partial differential equations?

F: Absolutely. They were very exciting problems. I started to be interested in real applications in the late 1980s when I was exposed to problems in industry that some of my colleagues, especially in England, were tackling. Later on, I moved from Northwestern to Purdue and then to Minnesota to be the director of IMA (Institute for Mathematics and its Applications). By that time I was completely immersed in problems from industry, and I found out that a large number of theoretical problems in partial differential equations came out of industrial problems.

I: From your large number of publications, it seems that not only are you prolific in writing papers on your own but you also enjoy collaborating with a lot of people. How much of this is due to your own personal temperament and how much to a research philosophy that is consciously pursued?

F: I think that if you look at the trend in mathematics, you will see that increasing numbers of papers are co-authored by two, sometimes three people. More and more, mathematicians and mathematical scientists are talking among themselves. It is extremely stimulating to do so, especially in applied areas. Many of my first papers were done alone, but most of my work now is joint. I often collaborate with others, particularly my former students.

I: Unlike the term "applied mathematics," the term "industrial mathematics" is a relatively new one. Could you tell us briefly what exactly is "industrial mathematics"?

F: In applied mathematics, you pick up problems from the sciences, engineering and other academic disciplines; you may look at the literature to find out where the problems are and try to solve them using mathematical tools. You may discover new mathematics. In industrial mathematics, by contrast, you go to industry to find the problems. The problems are not usually published, and you have to talk to people. You have to find out what those in industry are interested in *today*, because tomorrow they may be interested in something else — or they may be out of job. Find out what they are doing now, what is interesting to them and what the time horizon is for solving the problems. Then you may talk to them, or to your colleagues, or simply think by yourself to come up with suggestions for a solution. You don't necessarily need to find complete solutions. If you publish a paper in mathematics, you must present complete proofs. In industrial mathematics, you may get a 90 percent instead of 100 percent solution, but you must get it in a timely fashion.

I: Is work in industrial mathematics usually acceptable to journals in mathematics for publication?

F: Oh, yes. In the IMA, we had a seminar for industrial mathematics, and we had about 25 speakers every year coming from industry. Each one came with a different set of problems. I wrote up, and sometimes rewrote, the problems. There are 10 volumes of these, each containing about 25 sets of problems in a particular subject. About 50 publications were based directly on these problems. There are another 50 papers that might be called second-generation. For example, there was a lot of work done in optics, in scattering, that came from my contacts with Honeywell and some other companies. This has been pursued by some of the people at the IMA, some of my students and postdocs, and they are still working on them with Maxwell's equations. There is a stream of papers that has come out of industry.

I: You mentioned that you published a series of volumes on industrial mathematics. They are not papers but actually books.

F: Yes, in each chapter, there is an introduction to the industrial problem, and then I formulate open problems for mathematicians.

I: It's quite encyclopedic in scope, isn't it? This must have required tremendous energy.

F: Yes, but energy is a function of enthusiasm.

I: Has any of your applied research been used in industry?

F: Absolutely. Work that we have done in optics, called "diffractive grading," was used by Honeywell in order to get grants from the defense department. Also in collaboration with postdocs, I did some work that led to patents at Ford Motor Company. Work that I did myself involving semiconductors and modeling was used by Motorola in chip

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design for instrumental control to control the acceleration of a car.

I: You are also working on problems in biology?

F: Well, that's what we do at the MBI. I am personally fascinated by the mathematics of cancer, which happens once again to involve partial differential equations.

I: What is your most satisfying piece of applied research work?

F: Well, I think the most satisfying piece of research is whatever I'm working on now. Whenever you work on a problem, it is the most exciting thing in your life for the time you are working on it. If you work in a field that is rapidly developing, it's not just one paper but a sequence of papers. Right now, we have a very interesting line of research that is motivated by cancer, but is nonetheless pure partial differential equations. This is the question of bifurcation problems in free boundary problems. The solid tumor is a moving region, and you don't know how it's going to move and grow. It develops fingering and so on. We try to prove theorems for moving boundaries with fingers, developing fingers as bifurcations. This is really an open area of problems.

I: Do you have to talk to other people like biologists?

F: I would say that I *get* to talk to biologists, specifically to experimentalists who work as oncologists. Of course, I also talk to other mathematicians working in partial differential equations.

I: Do the biologists seek you out to solve their problems?

F: At first, I go to them. When they are convinced that we are actually useful to them, then they also come to us. That has been my experience.

I: But it's not very easy to convince a pure mathematician to go and solve those problems.

F: It's not easy at first, because you have to do a lot of work before you can be useful to the biologists. You have to learn a lot. But I started the MBI because I was certain that mathematicians could make key contributions in the biosciences. Now, it's my personal research interest and my administrative role combined. And we have 14 postdocs involved in different fields of the biosciences. Some of them work on cancer and others on neuroscience, physiology, ecology, genomics, etc.

I: Can you tell us something about the IMA and MBI?

F: The IMA was started in 1982. There was a national competition for mathematical institutes. The NSF decided to have two — one in Berkeley in core mathematics, and the other in Minnesota in more applied work. Hans Weinberger was the director of the Minnesota institute for its first five years. I succeeded him as director. At that time I started to emphasize interaction with industry in addition to general applied mathematics. My point of view was that applied mathematics could only gain wide acceptance, say, in industry, if those doing mathematical research in industry knew you actually could connect with and care about the problems with which they were dealing. In addition, I thought you would find very interesting problems in industry, so I started to visit companies. Typically, I would spend two days in one company and talk to about 20 people. Out of these, I would identify one or two people whose problems might benefit from mathematical input. I would then invite them to talk in my seminar.

After 10 years, I stepped down from IMA, and started the Center for Industrial Mathematics in University of Minnesota. It is a degree program. Graduate students who want degrees in applied and industrial mathematics spend a summer internship in a company and come back to author a masters thesis. Some of them continue to write PhD theses supported by industry.

When NSF called for new proposals, I was already interested in the opportunities biology was bringing to mathematics. I was in Minnesota at that time, and you can't expect NSF to support two institutes in one department, so I worked together with people at Ohio State University to write a proposal in mathematical biosciences. It was a good time for OSU: the medical school was hiring many new people in biological sciences, and people in statistics were very active in biology. Our proposal was successful, and I became the first director of the MBI.

I: What is generally understood as "applied mathematics" in the United States?

F: Keith Moffat and I have talked about the fact the "English applied mathematics" has a different flavor from "US applied mathematics." To give you a flavor of US applied mathematics, materials science is an important area of applied math in the United States. You can use mathematics in the modeling of it. For example, car companies want to increase mileage per gallon — it's a government requirement. To do so, they want to replace steel with lighter material, say aluminum. But aluminum is not strong enough, so they add carbon particles to make it stronger, and it turns out that partial differential equations can be used to predict how this new material will behave. Ford Motor Company actually came up with a problem and we did some work on it at the IMA.

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I: Are these predictions successful mathematically?

F: Yes, it turns out that the predictions have been very useful to the engineers. As a result, the field has completely changed since our first materials science program in 1985. The mathematical community of people working in materials science has increased tremendously. Other examples of US applied mathematics come from applications in control theory, computational science, applied linear algebra, fluid dynamics, scattering theory, nonlinear waves in oceans and materials, polymeric materials and polymers.

I: What about operations research?

F: Operations research applications have ranged from manufacturing to finance, and there is so much more. Imaging has developed rapidly in many aspects: imaging distant targets is a different problem than imaging at the molecular level. Speech recognition — we have a volume at the IMA in speech recognition — involves Markov processes. Applications even come in from traditionally pure mathematics. The field of U.S. applied mathematics is vast and diverse. We had programs in applied number theory, in coding, communications, graph theory, scientific computation as well as fluid dynamics.

In England, by contrast, fluid dynamics used to be the crowning theme, because England is surrounded by water. Traditionally, England is very strong in computational fluid dynamics, and they are looking at all kinds of phenomena in waves and fluids. Many of the mathematicians working on these problems inspired me to get involved in applied mathematics in the first place and ultimately to bring industry to the table to expand the kinds of problems mathematicians are involved in solving.