THE BIOLOGICAL PHYSICIST

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In this Issue

This issue of THE BIOLOGICAL PHYSICIST brings you a feature interview with Boston University's Mal Teich, who has recently published, with co-author Steve Lowen, a new book on *Fractal-Based Point Processes* (Wiley 2005).

We also bring you the announcement of the winner of the Biological Physics Prize, important information about the upcoming March Meeting, including a listing of all Symposia and Focus Sessions, and a tentative schedule of Symposia. (Remember the abstract submission deadline is Wednesday November 30!) Finally, we bring you PRE Highlights, and a plentiful batch of job ads, as the fall academic hiring season gets into full swing. Enjoy!

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FEATURE

A Conversation with Mal Teich

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***Malvin Carl Teich** is a faculty member at Boston University, where he holds joint appointments in the Departments of Electrical and Computer Engineering, Physics, and Biomedical Engineering. He is Co-Director of the Quantum Imaging Laboratory and a Member of the Photonics Center, the Hearing Research Center, the Program in Neuroscience, and the Center for Adaptive Systems. He is also Professor Emeritus of Engineering Science and Applied Physics at Columbia University. His well-known research achievements extend from the development of nonlinear heterodyne detection to the role of point processes in the neurosciences. He spoke recently with* THE BIOLOGICAL PHYSICIST *about his research and his latest book, Fractal-Based Point Processes, co-authored with Steven Bradley Lowen and published in 2005 by Wiley.*

THE BIOLOGICAL PHYSICIST: **What got you interested in point processes? Was your interest initially generated by your work in engineering and photonics?**

Mal Teich: My interest in point processes began with the work I carried out for my doctoral dissertation at Cornell in the mid 1960s. With the advent of the laser a few years earlier, nonlinear optics had become an area of great interest in physics. My PhD thesis centered on observing two-photon photoemission from a metal (sodium) illuminated by laser light. This process occurs when two photons conspire to release an electron from the material, a single photon having insufficient energy to do so. The probability of a pair of photons being localized at a point in the material is determined by the point process representing the photon arrivals of the laser light. In subsequent years, as a faculty member at Columbia working with my own PhD students, I carried out many experimental and theoretical studies in photonics that involved point processes, including the generation of photon-number squeezed light, the transformation of photon statistics imparted by fiber-optic amplifiers, and the analysis of noise in avalanche photodiodes.

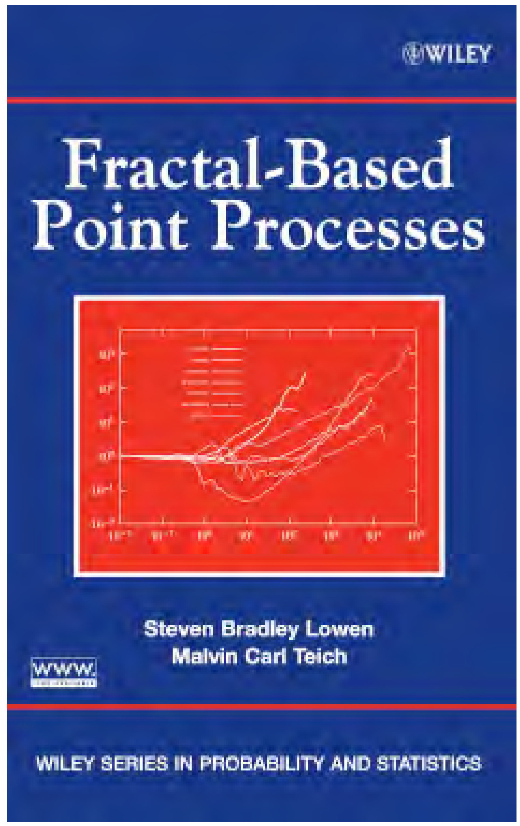
In the "About the Authors" section of the new book, one reads that "Teich's interest in point processes in the neurosciences was fostered by a chance encounter in 1974 with William J. McGill, then Professor of Psychology and President of Columbia University." Describe that "chance encounter". What exactly did you talk about with McGill?

One spring day in 1974, out of curiosity I ambled over to the Columbia Faculty House to hear what the President of the University, a mathematical psychologist named William J. McGill, had to say in a lecture entitled *Signal Detection Theory*. He was presenting a talk at the *University Seminar on Mathematical Methods in the Social Sciences*. I had never met McGill but the title of his talk intrigued me and, after all, he *was* the President of the

University. In his talk, he suggested that Poisson-based stochastic point processes were suitable for modeling information flow in the human auditory and visual systems. I was astonished by his talk because the neural-event probability distributions and generation functions that he presented were identical to those that I had used to describe laser-light photodetection. I mentioned this to him in the open discussion following the talk, and he suggested that I come over to his office to chat. We talked for the remainder of the afternoon, and that was the beginning of a lifelong collaboration on the use of stochastic point processes in sensory-system modeling. We ultimately constructed an information-transmission model in which the brain's neural network amplifies an incoming sensory stimulus. Without intending to do so, we arrived at a model for characterizing the flow of neural events that was identical to the model I had used earlier to describe the transformation of the statistical properties of photons imparted by a fiber-optic amplifier. Here were two distinct phenomena, one in physics and one in biology, described by an identical underlying point-process model.

How did you become interested in biological physics? At what point did you begin to think about point processes in biophysical systems?

My work with McGill was directed principally toward developing systems models for sensory detection. I was also anxious to see if it might be productive to apply a point-process approach to a living neural system at the cellular level. Fortunately, not too long after I met McGill, I encountered Shyam M. Khanna, Director of the *Fowler Memorial Laboratory for Auditory Biophysics* and Professor in the Department of Otolaryngology at the Columbia College of Physicians & Surgeons. In a collaboration that stretched over two decades, we recorded sequences of action potentials from afferent nerve fibers in the mammalian peripheral auditory system, using a broad range of different auditory stimuli. Point-process theory offered an excellent platform for studying these spike trains. After analyzing an enormous number of data sets, over quite a number of years, we reached the unexpected, but unmistakable, conclusion that,



The cover of Mal Teich and Steve Lowen's new book, Fractal-Based Point Processes, published by Wiley. For more information about the book, visit: http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471383767.html. *or* http://cordelia.mclean.org/~lowen/fbpp.html.

without exception, action-potential sequences in the auditory system exhibited power-law correlations and other features characteristic of fractal behavior. Together with my PhD students, including Steve Lowen, the co-author of *Fractal-Based Point Processes*, I developed a fractal-based point-process model that captured the characteristics of these data, and revealed a new feature of neural coding.

What led you to write "Fractal-Based Point Processes"? Describe the genesis of the book and the process of writing it. What is the intended audience and what do you hope the audience will take away from it?

Having observed that all primary auditory-nerve spike trains exhibited fractal behavior, Lowen and I began to wonder whether other neural and neurobiological systems would behave similarly. So, in collaboration with colleagues at a number of institutions, we proceeded to examine action-potential sequences recorded from the retina, thalamus, and visual cortex; neurotransmitter exocytosis at the synapse; and human heartbeat sequences. Making use of point-process theory, we discovered the presence of fractal behavior in all of these systems as well.

Fractal behavior turned out to be so widespread in the systems we examined that we decided to develop a comprehensive theory of fractal-based point processes. This included establishing many new results, elucidating the relative merits of different metrics and estimation procedures, and considering a collection of models that lead to such behavior. We then applied the theory to many data sets in the biological and physical sciences, from the spontaneous release of neurotransmitter vesicles at a developing *Xenopus* neuromuscular junction to consecutive Ethernet-packet arrivals in a computer communication network. We felt that it would be worthwhile gathering the results together in a unified way, and the result is *Fractal-Based Point Processes*. Fortunately, we had a solid point of departure for the project: Lowen's 1992 Columbia PhD thesis entitled *Fractal Point Processes*. We decided to write the book in 1998, signed a contract with the publisher in 1999, and promised a camera-ready manuscript in 2001. We managed to deliver a preliminary manuscript in 2001, but it was not until 2005 that we completed the final camera-ready manuscript that made it into print.

The book is addressed principally to students and researchers in the physical, biological, mathematical, and medical sciences who seek to understand, explain, and make use of the ever-growing roster of phenomena that are found to exhibit fractal and point-process characteristics. An extensive set of solved problems accompanies each chapter. The website for the book contains the data sets analyzed as well the source code for all C programs used to analyze, simulate, and modify the data sets.

Is there a fundamental difference between point processes which do and which do not possess fractal characteristics?

Fractal-based point processes are a particular class of point processes, comprising two subclasses: fractal point processes and fractal-rate point processes. By virtue of their power-law features, such point processes are trickier to deal with than are nonfractal point processes and therefore require special treatment.

Describe your early work on heterodyne detection, and the applications of this to neural systems.

My first research project as a new Staff Member at MIT Lincoln Laboratory in the mid-1960s, after receiving the PhD but before joining Columbia, was to investigate heterodyne detection in the middle-infrared region of the electromagnetic spectrum using the then-new CO_2 laser in conjunction with a special semiconductor photon detector that had been developed at the Labs. I demonstrated that optimal heterodyne detection could indeed be achieved. Heterodyning offers a powerful technique for observing the velocity of a moving object. So it was natural for me to become involved in optical heterodyne measurements of the nonlinear-dynamical motions of individual sensory cells in the cochlea, in collaboration with Shyam Khanna and researchers at the Karolinska Institute in Stockholm. We discovered, among other things, that these cells vibrate spontaneously, even in the absence of a stimulus.

Mal Teich (left), and co-author Steven Lowen.

What are your current research projects? Where do you see your work going over the next few years?

Together with Steve Lowen, I am currently examining transformations of the statistical properties of spike trains as they travel up the waysations of the visual system. I am continuing my work on sensory information transmission and expect to complete a book, tentatively entitled *Sensory Transmission and Detection*, that I began with Bill McGill many years ago. My most immediate goal, however, is to finish up the Second Edition of *Fundamentals of Photonics*, a textbook that I co-authored in 1991 with Bahaa Saleh, another long-standing collaborator. I am also continuing my joint work with Saleh in quantum optics, which is directed toward advancing the development of optical imaging systems that make use of entangled photon pairs generated via optical spontaneous parametric down-conversion.

What is your assessment of the current state of interdisciplinary science? Are we truly in the midst of a renaissance, or is that simply propaganda?

Interdisciplinary science has, I believe, become increasingly important and of increasing interest. This can be seen in the ever-growing array of interdisciplinary papers in each week's edition of *Physical Review Letters*. One of the principal impediments to the growth of interdisciplinary science, in my view, has been the hesitation of biological scientists to engage in serious mathematical analysis and modeling, and to appreciate the extent of its value. But I perceive that this state of affairs is changing for the better.

Do you have any advice for scientists in interdisciplinary fields, or for graduate students contemplating an interdisciplinary career?

I would advise those interested in interdisciplinary science to be proactive in exploring opportunities that interest them. I would also advise them to seek collaborators who complement their own talents and abilities, and who have been successful in their own right. I would consider, as especially promising, potential collaborators who are excited by the interdisciplinary aspects of a problem and who welcome a quantitative approach to analysis and modeling, even if they themselves do not have the requisite tools.

WEBSITES FOR MORE INFORMATION:

http://people.bu.edu/teich/
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http://cordelia.mclean.org/~lowen/fbpp.html
http://www.wiley.com/WileyCDA/WileyTitle/productCd-0471383767.html