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Editor

# Fluctuations and Order

## The New Synthesis

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Mark Millonas
The James Franck Institute
University of Chicago
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# Preface

The volume that you have before you is the result of a growing realization that fluctuations in nonequilibrium systems play a much more important role than was first believed.[1] It has become clear that in nonequilibrium systems noise plays an active, one might even say a creative, role in processes involving self-organization, pattern formation, and coherence, as well as in biological information processing, energy transduction, and functionality. Now is not the time for a comprehensive summary of these new ideas, and I am certainly not the person to attempt such a thing. Rather, this short introductory essay (and the book as a whole) is an attempt to describe where we are at present and how the viewpoint that has evolved in the last decade or so differs from those of past decades.

Fluctuations arise either because of the coupling of a particular system to an external unknown or "unknowable" system or because the particular description we are using is only a coarse-grained description which on some level is an approximation. We describe the unpredictable and random deviations from our deterministic equations of motion as noise or fluctuations. A nonequilibrium system is one in which there is a net flow of energy.

There are, as I see it, four basic levels of sophistication, or paradigms, concerning fluctuations in nature. At the lowest level of sophistication, there is an implicit assumption that noise is negligible: the *deterministic paradigm*. This is the assumption that is always made whenever one studies deterministic models of natural processes.

A great deal of progress has been made in the study of deterministic dynamics systems, and in our own time the study of nonlinear dynamics and chaos has radically transformed the way we look at such systems. Twenty years ago, scientists found it hard to believe that deterministic systems could exhibit low-dimensional chaotic behavior that was indistinguishable from random motion. Today it seems that these ideas often so dominate the intellectual climate that many scientists have a hard time believing there is any other type of randomness. It is currently quite popular when one is faced with a system that exhibits unpredictable behavior to apply tools appropriate to the analysis of chaotic deterministic systems, even when these systems are often demonstrably random at a fundamental level. Such an approach is even less valid now that it is beginning to be understood that the addition of even small amounts of noise to a nonlinear dynamical system can alter its statistical behavior in a fundamental way—a change that has nothing to do with the "sensitive dependence on initial conditions" in chaotic systems.

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[1]The title of this book is a homage to E.O. Wilson's integrative work, *Sociobiology: The New Synthesis*.

The use of deterministic systems as models of nature depends on the implicit assumption that nonlinear, nonequilibrium systems can be separated into a deterministic part that contains the essence, and a random part that can be thrown away. Often this viewpoint is very successful. However, just as it is not possible to separate nonlinear dynamical systems into simple parts that can be understood separately, it is not always possible to separate the deterministic element from the stochastic element in systems subject to fluctuations. Since randomness enters into the fundamental processes that make up many systems in nature, it is probably impossible to understand the vast majority of these processes, even qualitatively, without explicitly incorporating this randomness into our models.

On the next higher level, noise is often regarded as a source of pure disorder: the *equilibrium paradigm*. This is the sometimes misleading lesson of equilibrium statistical mechanics. In this picture, noise is included, but still a deterministic dynamics controls everything. The noise merely provides for fluctuation about the deterministic, stable limit sets, disrupting orderly or coherent behaviors as it is increased. Many researchers organize their understanding of a particular complex system around such pictures without any clear understanding of their validity (and sometimes even without conscious awareness).

On a still more sophisticated level is the concept of "order through fluctuations," put forward by Prigogine and others, according to which the amplification of fluctuations near an instability leads to a more ordered macroscopic state. At the risk of oversimplification, I will call this idea the *passive noise paradigm*, in that only the transitions to certain ordered macroscopic states and not the states themselves are influenced by the fluctuations. In using this paradigm, one often assumes that the probability that a system will be found in one of a number of possible ordered states after the transition can be determined from macroscopic criteria, without reference to the detailed kinetics.

While the passive noise paradigm often applies to systems composed of a great number of parts, the accompanying assumption is in general not valid (see chapter 1). In systems where the internal fluctuations are large, or where there are external fluctuations, neither the paradigm nor the assumption applies; however, this is the category into which many important nonequilibrium systems in nature fall.

Finally, there is the center around which much of this book is focused, which I will call the *active noise paradigm*. In general, even when the fluctuations are small, the probability of a macroscopic state depends on the explicit details of the global kinetics and cannot be determined from the macroscopic state alone. In addition, if the fluctuations are macroscopically large, as is the case in many complex systems, the qualitative structure of the macroscopic states, as well as their relative probabilities, will also depend on the global kinetics. In simple terms, this means that a knowledge of the global kinetics is necessary to understand nonequilibrium systems, even near the stable points.

In such cases, one cannot eliminate the fluctuations from consideration because they also contain important qualitative information about the behavior of the system. Such systems cannot be described by deterministic or passive noise because there are no macroscopic thermodynamic variables capable of describing the system. Put another way, important nonequilibrium effects are inextricably mixed in both the macroscopic net forces and the fluctuating forces.

The cases to which active noise applies are to be contrasted strongly with those described by passive noise. In fact, such cases represent an ever growing, and at this point definitive, body of evidence against the general applicability of the ideas of the Prigogine school. Complex is complex, and there are no magic prescriptions, as Rolf Landauer points out in the first chapter. If it is true that many of our present intuitive notions are not entirely valid ways of understanding nature, we may need to radically reappraise the role that noise plays in the behavior of such systems. This book is an attempt to begin such a reappraisal.

A word needs to be said about the topics represented in this book. It goes without saying that they represent my own unique and perhaps warped view, along with the views of the editors of this series. I have chosen to diminish the representation of important subjects (from the pool of submitted papers) such as self-organized criticality and stochastic resonance because entire conferences are now devoted to these subjects.

It is my main goal in this book to illustrate clearly the wide intellectual scope of the subject rather than attempt to subsume all under one or another all-encompassing rubric. I also wanted to show that a great variety of researchers, from theoretical cosmologists to experimental biologists, are contributing to the subject. If some of the chapters in this book are a bit speculative, or a bit outside the strict epicenter of our subject, so be it. The generation of new ideas is vital for the health of any subject, for without them we slip into the stagnant waters.

Many people have contributed to the publication of this volume. It has been a long road but, judging by the final result, I think it has been worth it. Thanks are due to the powers that be at CNLS and the Theoretical Division at the Los Alamos National Laboratory for providing funds and experience for the original workshop at Los Alamos in 1993. In particular, I thank Alan Bishop, Don Cohen, Gary Doolen, Mac Hyman, and Alan Lapedes. The Santa Fe Institute provided some additional financial support for the meeting. Without the able organizational skills and experience of Barbara Rhodes, chaos would have reigned at the conference. Katja Lindenberg made it possible for this volume to be published as part of the INLS series. I would particularly like to thank Tracy Lopez and Elizabeth Henry for helping me with the manuscript in their spare time. Without them, I would still be hunting and pecking my way through the papers—which reminds me to thank those authors who turned in their contributions in the requested form and didn't make us retype the whole thing. Lastly, I acknowledge the patience and professionalism of the people at Springer-Verlag.

James Franck Institute
August 1995

Mark Millonas

# Contributors

*Zvia Agur*, Department of Cell Research and Immunology, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel

*Philip A. Alpatov*, Ilya Prigogine Center for Studies in Statistical Mechanics and Complex Systems, University of Texas, Austin, TX 78712 USA

*Panos Argyrakis*, Department of Physics, 313-1, University of Thessaloniki, GR-54006 Thessaloniki, Greece

*Roland Bartussek*, Institut für Physik, Universität Augsburg, D-86135 Augsburg, Germany

*Raphael Blumenfeld*, Los Alamos National Laboratory, Theoretical Division and Center for Nonlinear Studies, MS B-262, Los Alamos, NM 87545 USA

*Adi R. Bulsara*, NCCOSC, RDT&E Division, Code 573, San Diego, CA 92152-5000 USA

*Louis J. DeFelice*, Department of Pharmacology, Vanderbilt University, Nashville, TN 37232-6600 USA

*Mark I. Dykman*, Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824 USA

*Stephen J.B. Einchcomb*, University of Manchester, Manchester M13 9PL, United Kingdom

*Michael Frey*, Department of Mathematics, Bucknell University, Lewisburg, PA 17837 USA

*William N. Goolsby*, Department of Anatomy and Cell Biology, Emory University, Atlanta, GA 30322 USA

*Karin Hinzer*, Department of Physics, University of Ottawa, 150 Louis Pasteur, Ottawa, Ontario K1N 6N5, Canada

*P.C.W. Holdsworth*, Laboratoire de Physique Theorique ENSLAPP, URA 14-36 du CNRS, École Normale Superieure de Lyon, 69634 Lyon, France

*B.L. Hu*, Department of Physics, University of Maryland, College Park, MD 20742 USA

*Alfred Hübler*, Center for Complex Systems Research, Department of Physics, Beckman Institute, University of Illinois, Urbana, IL 61801-3080 USA

*Peter Jung*, Beckman Institute, University of Illinois, 405 N. Mathews Avenue, Urbana, IL 61801 USA

*Raoul Kopelman*, Chemistry Department, University of Michigan, Ann Arbor, MI 48109 USA

*Lui Lam*, Department of Physics, San Jose State University, One Washington Square, San Jose, CA 95192 USA

*Rolf Landauer*, IBM Thomas J. Watson Research Center, P.O. Box 218, Yorktown Heights, NY 10598 USA

*James R. Leith*, Department of Mechanical Engineering, University of New Mexico, Albuquerque, NM 87121 USA

*Katja Lindenberg*, Department of Chemistry and Biochemistry, University of California-San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0340 USA

*Vivian Lombillo*, Department of Molecular, Cellular, and Developmental Biology, University of Colorado, Campus Box 347, Boulder, CO 80309-0347 USA

*André Longtin*, Department of Physics, University of Ottawa, 150 Louis Pasteur, Ottawa, Ontario K1N 6N5, Canada

*D.G. Luchinsky*, Russian Research Institute for Metrological Service, Andreevskaya nab. 2, Moscow 117965, Russia

*C.N. Luse*, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332 USA

*Marcelo O. Magnasco*, NEC Research Institute, Rockefeller University, 1230 York Avenue, New York, NY 10021-6399 USA

*Robert S. Maier*, Department of Mathematics, University of Arizona, Tucson, AZ 85721 USA

*Riccardo Mannella*, Dipartimento di Fisica, Università di Pisa, Piazza Torricelli 2, 56100 Pisa, Italy

*Andrew Matacz*, School of Mathematics and Statistics, University of Sydney, Sydney NSW 2006, Australia

*Peter V.E. McClintock*, School of Physics and Chemistry, Lancaster University, Lancaster LA1 4YB, United Kingdom

*Alan J. McKane*, Department of Theoretical Physics, The Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom

*Ramit Mehr*, Theoretical Biology and Biophysics, Los Alamos National Laboratory, MS K710, Drop Point 3/483/01U, Los Alamos, NM 87545 USA

*Ronald E. Meyers*, US Army Research Laboratory, WSMR, NM 88002 USA

*Mark Millonas*, The James Franck Institute, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637 USA

*Mark B. Mineev-Weinstein*, Center for Nonlinear Studies, Los Alamos National Laboratory, MS B-258, Los Alamos, NM 87545 USA

*George Oster*, University of California, 201 Wellman Hall, Berkeley, CA 94720-3112 USA

*Charles S. Peskin*, Department of Mathematical Sciences, Courant Institute, New York University, 251 Mercer Street, New York, NY 10012-1110 USA

*R.D. Pochy*, Department of Physics, San Jose State University, One Washington Square, San Jose, CA 95192 USA

*D.A. Ratoff*, Department of Physics, San Jose State University, One Washington Square, San Jose, CA 95192 USA

*Christian Ratsch*, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany

*Linda E. Reichl*, Ilya Prigogine Center for Studies in Statistical Mechanics and Complex Systems, Department of Physics, University of Texas, Robert Lee Moore Hall 7.220, Austin, TX 78712 USA

*Lutz Schimansky-Geier*, Department of Physics, Humboldt University, Unter den Linden 6, 10099 Berlin, Germany

*Frank Schweitzer*, Department of Physics, Humboldt University, Unter den Linden 6, 10099 Berlin, Germany

*Eugene F. Shender*, Department of Physics, University of California, Berkeley, CA 94720 USA

*H.E. Short*, Department of Theoretical Physics, Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom

*Emil Simiu*, National Institute of Standards and Technology, Building and Fire Research Laboratory, Building 226, Gaithersburg, MD 20899 USA

*Vadim N. Smelyanskiy*, Laboratory of Physics, University of Michigan, Harrison M. Randall Hall, Ann Arbor, MI 48109-1120 USA

*P. Šmilauer*, Höchstleistungsrechenzentrum, Kernforschungsanlage, Jülich D-52425, Germany

*Daniel L. Stein*, Department of Physics, University of Arizona, Tucson, AZ 85721 USA

*N.D. Stein*, School of Physics and Chemistry, Lancaster University, Lancaster LA1 4YB, United Kingdom

*N.G. Stocks*, Department of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

*M.C. Veinott*, Department of Physics, San Jose State University, One Washington Square, San Jose, CA 95192 USA

*Dimitri D. Vvedensky*, The Blackett Laboratory, Imperial College, London SW7 2BZ, United Kingdom

*Charles L. Webber, Jr.*, Department of Physiology, Stritch School of Medicine, Loyola University of Chicago, Maywood, IL 60153 USA

*M.R. Wilby*, Department of Electrical and Electronic Engineering, University College London, Torrington Place, London WC1E 7JE, United Kingdom

*Alexander P. Zak*, Jet Propulsion Laboratory, California Institute of Technology, MS 601-237, 4800 Oak Grove Drive, Pasadena, CA 91109 USA

*Michail Zak*, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109 USA

*Andrew Zangwill*, School of Physics, Georgia Institute of Technology, Atlanta, GA 30332 USA

*Joseph P. Zbilut*, Department of Molecular Biophysics and Physiology, Rush University, 1653 W. Congress, Chicago, IL 60612 USA

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