This book describes the progress that has been made towards the development of a comprehensive understanding of the formation of complex, disorderly patterns under far-from-equilibrium conditions.

The application of fractal geometry and scaling concepts to the quantitative description and understanding of structure formed under non-equilibrium conditions is described. Self-similar fractals, self-affine fractals, multifractals and scaling methods are discussed, with examples, to facilitate applications in the physical sciences. Computer simulations and experimental studies are emphasised, but the author also includes a discussion of theoretical advances in the subject. Much of the book deals with diffusion-limited growth processes and the evolution of rough surfaces, although a broad range of other applications is also included. The book concludes with an extensive reference list and guide to additional sources of information.

This book will be of interest to graduate students and researchers in physics, chemistry, materials science, engineering and the earth sciences, and especially those interested in applying the ideas of fractals and scaling to their work or those who have an interest in non-equilibrium phenomena.

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Fractals, scaling and growth far from equilibrium

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Fractals, scaling and growth far from equilibrium

Paul Meakin
Department of Physics, University of Oslo

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Plate section between pp. 242 and 243*

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Preface

The development of a full understanding of the universe around us, in terms of the basic properties of fundamental "particles" and their interactions, has long been a dream of the physicist. Mindful of the difficulties encountered when this approach is used to calculate the behavior of very simple systems, such as molecules containing just a few atoms, the problem of understanding the nature of much more complex systems, such as snowflakes, soot aggregates and rough surfaces produced by processes such as vapor deposition or erosion, might seem to be a daunting prospect. However, during the past one or two decades, substantial progress has been made, based on statistical physics concepts such as scaling and the independent development of fractal geometry, based on late 19th century and early 20th century mathematics, by Benoit Mandelbrot. To a large extent, this progress has been made by giving up the idea that an understanding of complex systems can be based on an ever more detailed knowledge of their microscopic components and focusing instead on the "universal" properties that all materials possess in common, irrespective of their atomic and molecular structure, and the manner in which properties on one length scale relate to those on other length scales. The connection between microscopic and macroscopic behavior is still important, and the theoretical justification for much of the work described in this book is based on models that contain microscopic components and interactions, at least on an abstract level. However, one of the objectives of this book is to illustrate that scaling symmetries can be used, in much the same way as other symmetries, to study a wide variety of systems and phenomena, without taking into account the underlying microscopic physics on a detailed level.

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One of the main objectives of this book is to show how a surprisingly wide range of complex, disorderly systems can be quantitatively understood using simple statistical physics concepts and simple mathematical tools. This book contains many equations, but it should be accessible to anyone with a good undergraduate education in the physical sciences. My original idea was to write a single volume on the basics of fractals and scaling and applications in various areas of science and technology. It soon became apparent that I wanted to say more than could reasonably be contained in one book. Consequently this book concentrates on some of the more fundamental aspects of pattern formation, fractals and scaling. I am in the process of writing a second book, focusing on colloidal fractals and aggregation kinetics, and a third monograph on the applications of fractals and scaling in selected areas of science and technology.

My own interest in this area was first stimulated by the work of Thomas Witten and Leonard Sander, more than ten years ago, on diffusion-limited aggregation. The diffusion-limited aggregation model has become one of the most important paradigms for disorderly growth, far from equilibrium, and plays a central role in this book.

Much of the work on this book was carried out during a one year visit to the Center for Advanced Studies at the Norwegian Academy of Science and Letters. The remainder of the work was carried out in the Physics Department at the University of Oslo. I would like to thank Jens Feder and especially Torstein Jøssang for hospitality at the University of Oslo, and Torstein Jøssang for making my stay at the Center for Advanced Studies possible. I have also benefited considerably from stimulating interactions with a quite large number of graduate students and post-doctoral associates at the University of Oslo.

I would like to thank Fereydoon Family, Joachim Krug, Leonard Sander, Lorraine Siperko, Tamás Vicsek and Stephanie Wunder for making valuable comments on a draft of this book and for making suggestions that have led to substantial improvements. I am also grateful to many colleagues and collaborators who have contributed figures; they are acknowledged in the figure captions. Many of the figures have been provided by graduate students in the Cooperative Phenomena Group at the University of Oslo and illustrate various aspects of their own research.

Paul Meakin

Oslo, Norway