Preface

The two notions of Complexity and Synergetics appear equally weighted in the title of this book. The word "complexity" has been used in a quite general way for a long time before it appeared more and more often in a scientific context. The initiator of deciphering the hieroglyphes, Jean-Francois Champillon, wrote already in the year 1824: *The hieroglyphic scripture is a complex system, it is pictorial, symbolic and phonetic at the same time*. In biology, the evolution of insect communities can be described by relatively simple mathematical equations, about which the biologist Robert May stated in 1976 that we are dealing here with *simple mathematical models with very complicated dynamics.* Two seemingly far separated disciplines come to a similar statement about complex behavior, which is, in fact, determining the temporal and spatial evolution of many systems in a very large number of dynamical situations.

An explanation of such system behavior calls for intensive experimentation as well as intelligent modelling, based on physical principles and closely supported by mathematical methods, to solve the nonlinear equations that govern complexity. Thus, the field of nonlinear dynamics comes into play, which comprises a number of mechanistic approaches, among which the concept of "synergetics" has played a major role since its introduction by Hermann Haken in the 1970s. (A description of the history is given in the book "Beiträge zur Geschichte der Synergetik" by H. Haken, P.J. Plath, W. Ebeling, and Y. Romanovsky, Springer Spektrum, Wiesbaden, 2016.)

Going further, we notice that complexity and synergetics are intimately connected with the unfolding of ordered and irregular structures and their temporal evolution, which is an omnipresent phenomenon in our natural world. One may think of the shape of galaxies, various cloud formations, vortices that form in mountain creeks, or the wonderful patterns on snail shells and tropical fish. In addition to spatio-temporal self-organization acting here on the basis of system immanent mechanisms, there are other aspects to be considered: For instance, the far reaching coordination of a multitude of small individuals (subsystems) within a much larger entity, typically found in the surprisingly coherent motion of large swarms of birds or fish. Equally impressive is the interaction among individuals that form large systems and can accomplish global synchronization, as manifested in the periodic blinking of many hundreds of fireflies. If we consider the most complex biological system, the human brain, we can state that from measurements of electroencephalograms (EEG) quite different dynamical states can be deduced. One of the most pronounced transitions between such states is observed when an epileptic seizure occurs: distinct periodicities with large amplitude develop in the normally quite irregular EEG, an indication for a large scale coordinated activity of many thousands of neurons. Moreover, another “dynamical disease”, migraine, is frequently connected with the appearance of a visual aura, which moves in a scintillating and patterned way through the visual field and hints at a strong reduction of excitability of the affected brain tissue.

In view of such a diversity of natural phenomena, for which an “invisible” ordering hand must be involved, the scientist will ask the question, whether a basic principle stands behind all these patterning phenomena to form a common basis for this diversity. Among other approaches, the introduction of the slaving principle by Hermann Haken, originating from laser physics, has achieved this goal to a large extent. For a laser to function, an appropriate optical material has to be “pumped” with light. Then, above a certain threshold of light intensity, i.e., in a state far from thermal equilibrium, a sharp change (a non-equilibrium phase transition) occurs, beyond which intensive and phase coherent light is emitted from the optically active material. A bifurcation has taken place from irregular fluctuations with incoherent phase relations to a highly organized state characterized by coherent light radiating with a well-defined phase. The numerous fluctuating modes of light emission have disappeared (the suppressed slaves) and a master dominates the event, namely a light beam generated by stimulated emission. If the initial pump intensity is restored, the laser light disappears and the system returns to an equilibrium state with no phase coherence.

This picture of enslaving of modes by a dominant master mode (the coherently emitted laser light) has shaped the idea of synergetics since its “inauguration” by Hermann Haken.

There are many other well-known examples of spontaneous structure formation that can be explained by this approach, e.g., the pioneering experiments performed by Henri Bérnard around 1900, shortly later analyzed theoretically by Lord Rayleigh (1916). A liquid layer is heated from below. While for a small temperature difference between the layer’s bottom and surface heat conduction determines the upward energy flux, there is a sharp threshold (a bifurcation) at a critical value of the temperature gradient. Beyond this point the heat transfer in the liquid is mostly facilitated by convection and characteristic convective rolls or hexagonal cells are formed—in a spontaneous process the formation of patterns with a well-defined spatial wavelength has emerged. As in the laser, a dominant spatial mode gains the upper hand and enslaves all the others.

A great variety of theoretical treatments based on the synergistic concept and other approaches of complex systems theory can be found in the literature and will not be discussed here. Generally, the book focusses on the complex behavior of macroscopic and mesoscopic systems, composed of numerous interacting subsystems existing under non-equilibrium conditions. One goal is to find low-dimensional systems of differential equation with appropriate initial and boundary conditions to describe the dynamical properties satisfactorily. This is a challenging and difficult endeavor of many research groups all over the world. By virtue of the interdisciplinary character of their common goals, fruitful contacts between various study groups have been established and are constantly growing.

To strengthen international and interdisciplinary connections, a Symposium with the title of this book was held in Summer 2015 in Hannover-Herrenhausen under the roof of the Volkswagen Stiftung, organized by S.C. Müller, P.J. Plath and G. Radons. The scientific program of the Symposium forms the basis of this volume, and a few more contributions have been added.

Symposium “Complexity and Synergetics” Schloß Herrenhausen, Hannover, July 2015

Totally 30 articles have been assembled in eight chapters representing modern research in various fields around the keywords “complexity” and “synergetics”. Contributions by international experts are complemented by articles from young investigators who appreciated the opportunity to contribute to a book of this kind. The authors made efforts to write a generally comprehensible introduction and to present their actual findings in an understandable way. Therefore, we believe that this volume offers stimulating and appropriate readings for a rather general scientific audience, including students and the interested community.

This book starts with an introductory article by Werner Ebeling and Rainer Feistel on information, the evolution of life and its relation to synergetics. There follows a wonderful overview written by Hermann Haken showing how the synergetic approach can be successfully applied to a multitude of phenomena, covering systems “From Laser Light to Cognition”.

Many of the following chapters can be assigned to specific disciplines, where for each case an effort is made to build interdisciplinary bridges. There are chapters on physics, chemistry, biology, economy, brain science, coordination dynamics, and more. This enumeration underlines the wide range of disciplines dealing with topics that are related to the theme of this book. As an example we take a closer look at the field of chemistry.

Chemistry and Physical Chemistry have their own prototypes of self-organization. The famous “Liesegang rings”, already discovered in 1896, with patterned precipitation of insoluble salts, have been investigated until today, especially with a view to various comparable processes in geology. Another pattern forming prototype in chemistry is the generation of rotating spirals. At the basis of these phenomena are the purely temporal dynamics of some chemical reactions which, due to the interplay between activation (often by autocatalysis) and inhibition, exhibit sustained oscillations, as long as they remain in a state far from thermodynamic equilibrium. Such pattern formation does not only occur in “liquid” chemistry, but also in electrochemical systems. Whereas in liquid systems the coupling of reaction and diffusion (a local activation mechanism) plays a major role to generate propagating chemical waves, in heterogeneous systems, as in catalysis or in electrochemistry, a global coupling mechanism acting through the gas phase or through electrical effects has to be taken into account which leads to a significant increase in the variability of the observed patterns. Especially renowned in this field is the “Belousov-Zhabotinsky reaction” (known since the 1950s), because it is excellently suited for experiments with a large significance beyond pure chemistry, for instance to biology.

On the heart muscle rotating activity may lead to life-threatening fibrillations; by controlling spiral dynamics using external forcing (electric fields or light), important knowledge for cardiology can be obtained. Revealing the excitability concept is of similar importance for a treatment of dynamical diseases such as migraine, epilepsy and an understanding of cerebral cortical dynamics.

Complex system theories and synergetics provide comprehensive approaches for many other domains of science, some of which have found their place in chapters of this volume. An important application lies in various studies about the finance sector. The article on “Financial Market Models” is an attractive introduction to this field, explaining perhaps, why it is so difficult to interpret stock prices. An appropriate counterpart is found in the article on structural changes in dynamic econometric models.

Finally, we venture a big jump to brain research. Chapter “Brain and Coordination Dynamics” shows in several articles how important the concepts discussed above are for the most complex organ known to man. We see the description of specifics about brain diseases and collect the experience of researchers on coordination dynamics (with the example of a ballet dancer). We learn how movement coordination can be used to probe the brain of individual subjects and how coordination modes are reflected in brain signals. Furthermore, how humans with their brains and bodies probe for neural, behavioral and social scales, is investigated using human-human and human-machine interactions.

A short chapter is added to present additional topics. Here we find thoughts on the interplay between art and science; the usefulness of ultra high-speed cameras for observations of fast phenomena (e.g., crack dynamics, microbubbles) is demonstrated.

The last chapter is devoted to a special contribution by Otto Rössler. We read here about a most interesting approach between deterministic thermodynamics and cryodynamics, which is promoted as new fundamental discipline based on long-range attraction. We think that this article will lead to many exciting discussions.

In summary, this book aims to reflect some of the progress made in today's research in the fields of complexity and synergetics, as well as to initiate discussions on the current state and future directions of this research domain.

Acknowledgements

The editors thank all authors for their constructive efforts in preparing the manuscripts and contributing to the rich variety of topics included in this volume. Special thanks are due to Thomas Ditzinger and Holger Schaepe from Springer-Verlag, Heidelberg, for their continuous commitment, efficient support, and skillful technical assistance. We also thank Ulrike Bischler and Margot Jädick-Jäckel from the VW Foundation for their support in organizing the Symposium in Hannover-Herrenhausen in summer 2015 that laid the basis for the layout and chapters of this book. Furthermore, the assistance of Kinko Tsuji and Patricia Dähmlow in preparing this volume, as well as the efficient secretarial and technical support by Katja Guttmann and Dorothea Erndt are gratefully acknowledged.

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May 2017

Springer

http://www.springer.com/978-3-319-64333-5

Complexity and Synergetics
Müller, S.C.; Plath, P.J.; Radons, G.; Fuchs, A. (Eds.)
2018, XIX, 421 p. 215 illus., 125 illus. in color.,
Hardcover
ISBN: 978-3-319-64333-5