

Springer Complexity

Springer Complexity is a publication program, cutting across all traditional disciplines of sciences as well as engineering, economics, medicine, psychology and computer sciences, which is aimed at researchers, students and practitioners working in the field of complex systems. Complex Systems are systems that comprise many interacting parts with the ability to generate a new quality of macroscopic collective behavior through self-organization, e.g. the spontaneous formation of temporal, spatial or functional structures. This recognition, that the collective behavior of the whole system cannot be simply inferred from the understanding of the behavior of the individual components, has led to various new concepts and sophisticated tools of complexity. The main concepts and tools - with sometimes overlapping contents and methodologies are the theories of self-organization, complex systems, synergetics, dynamical systems, turbulence, catastrophes, instabilities, nonlinearity, stochastic processes, chaos, neural networks, cellular automata, adaptive systems, or genetic algorithms.

The topics treated within Springer Complexity are as diverse as lasers or fluids in physics, cutting phenomena of workpieces or electric circuits with feedback in engineering, growth of crystals or pattern formation in chemistry, morphogenesis in biology, brain functions in neurology, behavior of stock exchange rates in economics, or the formation of public opinion in sociology. All these seemingly quite different kinds of structure formation have a number of important features and underlying structures in common. These deep structural similarities can be exploited to transfer analytical methods and understanding from one field to another. Therefore the Springer Complexity program seeks to foster cross-fertilization between the disciplines and a dialogue between theoreticians and experimentalists for a deeper understanding of the general structure and behavior of complex systems.

The program consists of individual books, books series such as "Springer Series in Synergetics", "Institute of Nonlinear Science", "Physics of Neural Networks", and "Understanding Complex Systems", as well as various journals.

Springer-Verlag Berlin Heidelberg GmbH

Springer Series in Synergetics

Series Editor

Hermann Haken

Institut für Theoretische Physik
und Synergetik
der Universität Stuttgart
70550 Stuttgart, Germany
and

Center for Complex Systems
Florida Atlantic University
Boca Raton, FL 33431, USA

Members of the Editorial Board

Åke Andersson, Stockholm, Sweden

Gerhard Ertl, Berlin, Germany

Bernold Fiedler, Berlin, Germany

Yoshiki Kuramoto, Kyoto, Japan

Jürgen Kurths, Potsdam, Germany

Luigi Lugiato, Milan, Italy

Jürgen Parisi, Oldenburg, Germany

Peter Schuster, Wien, Austria

Frank Schweitzer, Zürich, Switzerland

14.1.04 Didier Sornette, Los Angeles, CA, USA, and Nice, France

Manuel G. Velarde, Madrid, Spain

SSSyn – An Interdisciplinary Series on Complex Systems

The success of the Springer Series in Synergetics has been made possible by the contributions of outstanding authors who presented their quite often pioneering results to the science community well beyond the borders of a special discipline. Indeed, interdisciplinarity is one of the main features of this series. But interdisciplinarity is not enough: The main goal is the search for common features of self-organizing systems in a great variety of seemingly quite different systems, or, still more precisely speaking, the search for general principles underlying the spontaneous formation of spatial, temporal or functional structures. The topics treated may be as diverse as lasers and fluids in physics, pattern formation in chemistry, morphogenesis in biology, brain functions in neurology or self-organization in a city. As is witnessed by several volumes, great attention is being paid to the pivotal interplay between deterministic and stochastic processes, as well as to the dialogue between theoreticians and experimentalists. All this has contributed to a remarkable cross-fertilization between disciplines and to a deeper understanding of complex systems. The timeliness and potential of such an approach are also mirrored – among other indicators – by numerous interdisciplinary workshops and conferences all over the world.

Hermann Haken

Synergetic Computers and Cognition

A Top-Down Approach to Neural Nets

Second Enlarged Edition
With 180 Figures



Springer

Professor Dr. Dr. h.c.mult. Hermann Haken
Universität Stuttgart
Institut für Theoretische Physik und Synergetik
Pfaffenwaldring 57/IV
70550 Stuttgart, Germany

The first edition appeared as Vol. 50 in the series.

ISSN 0172-7389

ISBN 978-3-642-07573-5 ISBN 978-3-662-10182-7 (eBook)
DOI 10.1007/978-3-662-10182-7

Library of Congress Control Number: 2004103361

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag Berlin Heidelberg GmbH. Violations are liable for prosecution under the German Copyright Law.

springeronline.com

© Springer-Verlag Berlin Heidelberg 1991, 2004

Originally published by Springer-Verlag Berlin Heidelberg New York in 2004

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Typesetting: by the author

Cover design: *design & production*, Heidelberg

Printed on acid-free paper 55/3141/XO - 5 4 3 2 1 0

Preface to the Second Edition

The first edition of this book has found great interest among scientists and engineers dealing with pattern recognition and among psychologists working on psychophysics or Gestalt psychology. This book also proved highly useful for graduate students of informatics.

The concept of the synergetic computer offers an important alternative to the by now more traditional neural nets. I just mention a few advantages: There are no ghost states so that time-consuming methods such as simulated annealing can be avoided; the synaptic strengths are explicitly determined by the prototype patterns to be stored, but they can equally well be learned, and the learning procedure allows a classification. Also a precise meaning and function can be attributed to “hidden variables”. The synergetic computer has found a number of important practical applications in industry.

I use the opportunity of this second edition to include a new section on transformation properties of the equations of the synergetic computer and on the invariance properties of its order parameter equations.

A new section is devoted to the problem of stereopsis that is dealt with by the basic concept of the synergetic computer. Finally, attention is paid to a recent development, namely to the use of pulse-coupled neural nets for pattern recognition. This will allow us to make contact with the functioning of “real” neurons in the brain. Here, I indicate a number of tasks to be solved in future research. It goes without saying that I have made a number of minor additions. I hope that this book will find the same positive response as its first edition.

I wish to thank my secretary Ms. Irmgard Möller for her great help in preparing the additions. She typed the text and composed the formulas in her traditionally fast and perfect manner. My thanks go also to Prof. Wolf Beiglböck and his team for their excellent cooperation.

Stuttgart, March 2004

Hermann Haken

Preface

This book will be of interest to graduate students, researchers and teachers in the computer sciences, in the cognitive sciences and in physics. It provides the reader with a novel approach to the design and study of neural nets. The applicability of this approach is shown explicitly by means of realistic examples. In addition, detailed models of the cognitive abilities of humans are included and compared with the performance of the synergetic computer presented in this book.

The work presented here would not have been possible without the important help of my coworkers. Dr. Arne Wunderlin has helped me in many respects over many years and has made essential contributions, in particular to the slaving principle of synergetics. Drs. Michael Bestehorn, Rudolf Friedrich and Wolfgang Weimer have applied the methods of synergetics to spontaneous pattern formation in fluids and have further developed these methods. Armin Fuchs has not only implemented my algorithm on a VAX computer, but has also made his own important contributions, in particular to pattern recognition that is invariant with respect to translation, rotation, and scaling. Thomas Ditzinger, Richard Haas, and Robert Hönlinger have contributed within the work on their diploma theses to the application of our approach to a number of problems that are shared by humans and computers in the field of pattern recognition. I wish to thank all of them. Chapter 14 is the result of a most fruitful cooperation with my colleague and friend Scott Kelso to whom I am most grateful, also for highly stimulating discussions on a variety of problems in sensory-motor control, and for his constant encouragement. I extend my thanks to Ms. Irmgard Möller, who has not only prepared various versions of the manuscript with great diligence, but also helped very efficiently in a variety of ways to bring the manuscript into its final form. I am indebted to Karin Hahn and Maria Haken-Krell who assisted me in many respects. Last but not least I owe thanks to the staff of Springer-Verlag for their excellent cooperation, in particular to Dr. Angela Lahee, who made numerous highly valuable suggestions for the improvement of my manuscript.

Stuttgart and Boca Raton, FL
November 1990

H. Haken

Contents

1. Goal	1
1.1 Why a New Computer Concept?	1
1.2 What is Synergetics About? Pattern Recognition as Pattern Formation	3
1.3 Cognitive Processes and Synergetic Computers	4

Part I Synergetic Computers

2. What Are Patterns?	9
3. Associative Memory	18
4. Synergetics – An Outline	20
4.1 Some Typical Examples	20
4.2 Reminder of the Basic Concepts and Mathematical Tools of Synergetics	23
5. The Standard Model of Synergetics for Pattern Recognition	36
5.1 Prototype Pattern Vectors and Test Pattern Vectors	36
5.2 Construction of the Dynamics	39
5.3 Important Properties of $V(\xi_k)$	43
5.3.1 Summary of the Results	43
5.3.2 Where Are the Deepest Minima of V ?	43
5.3.3 Where Are the Stationary and Stable Points of V ?	45
5.3.4 How Are Stable Fixed Points and Saddle Points Reached?	49
6. Examples: Recognition of Faces and of City Maps	51
7. Possible Realizations by Networks	56
8. Simultaneous Invariance with Respect to Translation, Rotation and Scaling	60
8.1 An Approach Based on Fourier Transforms and Logarithmic Maps	60
8.2 Numerical Calculations	65

8.3	A Second Approach to the Invariance Problem	68
8.4	General Transformations of Patterns	74
8.5	Invariance of Order Parameter Equations	80
9.	Recognition of Complex Scenes. Scene-Selective Attention	85
10.	Learning Algorithms	88
10.1	Survey; Several Lines of Approach	88
10.2	Learning of the Synaptic Strengths	88
10.2.1	An Iterative Procedure for Determining the Adjoint Vectors v_k^+	88
10.2.2	A Special Case	92
10.2.3	Implementation in a Three-Layer (Two-Layer) Network	93
10.3	Information and Information Gain	96
10.4	The Basic Construction Principle of a Synergetic Computer Revisited	100
10.5	Learning by Means of the Information Gain	103
10.6	A Learning Algorithm Based on a Gradient Dynamics	110
10.6.1	Construction of the Lyapunov Function	111
10.6.2	Projection onto the q_j -Space	113
10.7	Summary	123
11.	Learning of Processes and Associative Action	125
11.1	Derivation of the Fokker-Planck Equation	125
11.2	Derivation of the $\hat{\text{I}}\text{to}$ -Langevin Equation	130
11.3	Taking Care of a Reduced Information	132

Part II Cognition and Synergetic Computers

12.	Comparisons Between Human Perception and Machine "Perception"	137
12.1	Introductory Remarks	137
12.2	Rotational Invariance. Adaption and Assimilation. Gestalt. Decomposition of Scenes	139
12.2.1	Rotational Invariance	139
12.2.2	Adaption and Assimilation. Gestalt	140
12.2.3	Decomposition of Scenes	140
12.3	Recognition of Low- and High-Pass Filtered Faces	142
12.4	Stereopsis	152
13.	Oscillations in the Perception of Ambiguous Patterns	163
13.1	Introduction	163
13.2	Properties of Ambivalent Patterns	166
13.3	Perception of Ambivalent Patterns Without Bias	168
13.4	Oscillations in Perception in the Presence of a Bias	170

13.5 Ambiguous Patterns with More Than Two Alternatives	174
13.6 Hysteresis	177
13.7 The Role of Fluctuations of Attention Parameters	179
13.7.1 The Model	181
13.7.2 Results	181
13.7.3 Discussion	184
14. Dynamic Pattern Recognition of Coordinated Biological Motion	185
14.1 Introduction. Perception of Structure in Biological Motion	185
14.2 The Pattern Generation and Pattern Recognition Experiments	186
14.3 The Behavioral Pattern Recognition Algorithm	188
14.4 Application and Results	190
14.5 Recognition of Patterns of Movement Characterized only by Specific Light Spots	192
14.6 Recognition of Movement Patterns in a Plane Other than that Perpendicular to the Observer	195
<hr/>	
Part III Logical Operations and Outlook	
<hr/>	
15. Realization of the Logical Operation XOR by a Synergetic Computer	205
15.1 Introduction	205
15.2 Solution of the XOR Problem	205
15.3 Comparison with Fluid Instabilities	207
15.4 Learning	208
16. Towards the Neural Level	209
16.1 Neurons Fire and May Mode-Lock	209
16.2 Summary of the Main Results	210
16.3 Oscillator Model of a Neuron: Rotating Wave Approximation and Slowly Varying Amplitude Approximation	211
16.4 A Network of Oscillators for Associative Memory	212
16.5 Frequency Locking of Two Oscillators	220
16.6 Frequency Locking of Several Oscillators	223
16.7 Phase Oscillators	224
16.8 Pulse-Coupled Neural Network for Pattern Recognition	225
17. Concluding Remarks and Outlook	231
17.1 Pattern Recognition Is Pattern Formation	231
17.2 Attractor States and Beyond	232
17.3 Some Problems Left for the Future	233
Bibliography and Comments	235
Subject Index	243