

Springer Complexity

Springer Complexity is an interdisciplinary program publishing the best research and academic-level teaching on both fundamental and applied aspects of complex systems - cutting across all traditional disciplines of the natural and life sciences, engineering, economics, medicine, neuroscience, social and computer science.

Complex Systems are systems that comprise many interacting parts with the ability to generate a new quality of macroscopic collective behavior the manifestations of which are the spontaneous formation of distinctive temporal, spatial or functional structures. Models of such systems can be successfully mapped onto quite diverse "real-life" situations like the climate, the coherent emission of light from lasers, chemical reaction-diffusion systems, biological cellular networks, the dynamics of stock markets and of the internet, earthquake statistics and prediction, freeway traffic, the human brain, or the formation of opinions in social systems, to name just some of the popular applications.

Although their scope and methodologies overlap somewhat, one can distinguish the following main concepts and tools: self-organization, nonlinear dynamics, synergetics, turbulence, dynamical systems, catastrophes, instabilities, stochastic processes, chaos, graphs and networks, cellular automata, adaptive systems, genetic algorithms and computational intelligence.

The two major book publication platforms of the Springer Complexity program are the monograph series "Understanding Complex Systems" focusing on the various applications of complexity, and the "Springer Series in Synergetics", which is devoted to the quantitative theoretical and methodological foundations. In addition to the books in these two core series, the program also incorporates individual titles ranging from textbooks to major reference works.

Editorial and Programme Advisory Board

Dan Braha

New England Complex Systems, Institute and University of Massachusetts, Dartmouth

Péter Érdi

Center for Complex Systems Studies, Kalamazoo College, USA and Hungarian Academy of Sciences, Budapest, Hungary

Karl Friston

Institute of Cognitive Neuroscience, University College London, London, UK

Hermann Haken

Center of Synergetics, University of Stuttgart, Stuttgart, Germany

Viktor Jirsa

Centre National de la Recherche Scientifique (CNRS), Université de la Méditerranée, Marseille, France

Janusz Kacprzyk

System Research, Polish Academy of Sciences, Warsaw, Poland

Scott Kelso

Center for Complex Systems and Brain Sciences, Florida Atlantic University, Boca Raton, USA

Markus Kirkilionis

Mathematics Institute and Centre for Complex Systems, University of Warwick, Coventry, UK

Jürgen Kurths

Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

Linda Reichl

Center for Complex Quantum Systems, University of Texas, Austin, USA

Peter Schuster

Theoretical Chemistry and Structural Biology, University of Vienna, Vienna, Austria

Frank Schweitzer

System Design, ETH Zürich, Zürich, Switzerland

Didier Sornette

Entrepreneurial Risk, ETH Zürich, Zürich, Switzerland

Understanding Complex Systems

Founding Editor: J.A. Scott Kelso

Future scientific and technological developments in many fields will necessarily depend upon coming to grips with complex systems. Such systems are complex in both their composition - typically many different kinds of components interacting simultaneously and nonlinearly with each other and their environments on multiple levels - and in the rich diversity of behavior of which they are capable.

The Springer Series in Understanding Complex Systems series (UCS) promotes new strategies and paradigms for understanding and realizing applications of complex systems research in a wide variety of fields and endeavors. UCS is explicitly transdisciplinary. It has three main goals: First, to elaborate the concepts, methods and tools of complex systems at all levels of description and in all scientific fields, especially newly emerging areas within the life, social, behavioral, economic, neuroand cognitive sciences (and derivatives thereof); second, to encourage novel applications of these ideas in various fields of engineering and computation such as robotics, nano-technology and informatics; third, to provide a single forum within which commonalities and differences in the workings of complex systems may be discerned, hence leading to deeper insight and understanding.

UCS will publish monographs, lecture notes and selected edited contributions aimed at communicating new findings to a large multidisciplinary audience.

Octavian Iordache

Modeling Multi-Level Systems

 Springer

Author

Dr. Octavian Iordache
Polystochastic
Pitfield blvd. St. Laurent 3205
H4S 1H3 Montreal
Canada
E-mail: polystochastic@bellnet.ca

ISBN 978-3-642-17945-7

e-ISBN 978-3-642-17946-4

DOI 10.1007/978-3-642-17946-4

Understanding Complex Systems

ISSN 1860-0832

Library of Congress Control Number: 2011921006

© 2011 Springer-Verlag Berlin Heidelberg

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. Violations are liable to prosecution under the German Copyright Law.

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.

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

...his way was to carry his mind into his laboratory, and literally to make of his alembics and cucurbits instruments of thought...

C. S. Peirce

The Fixation of Belief, 1877

Preface

Modeling multi-level complex systems is the object of this book.

Complex systems are assemblies of several subsystems and are characterized by emergent behavior resulting by nonlinear interactions among subsystems for multiple levels of organization.

The complexity of numerous systems is rooted in the existence of many levels of self-organization corresponding to different time and space scales.

There is a need to provide general frameworks able to combine several scales and reality levels of the complex systems in one coherent and transdisciplinary discourse. A challenge for complex systems science and technology is to develop mathematical formalisms and modeling methods able to capture complete systems dynamics by integration of contribution at several hierarchically organized levels. Existing models involve a large number of nonlinear equations, difficult to handle analytically or numerically, and to correlate with real systems behavior. Among the open questions, we mention the definition of relevant parameters and variables to be measured at each scale or level, the study of coupling between different levels, the insufficiency of the algorithmic schema for evolvable or autonomous systems modeling.

The proposed modeling tools for multi-scale and multi-level systems are the polystochastic models, PSM. These characterize systems coming out when several stochastic processes, running at different conditioning levels, are capable to interact with each other, resulting in qualitatively new processes and systems.

Polystochastic models aim to discover and describe new structures and behaviors, which cannot be detected by one level approaches and cannot be reduced to the summation of several levels contributions.

The book is divided in 12 chapters. The chapters 1 to 4 delineate the problems and the methods. The role of multiple levels of reality for different concepts and theories of complexity is highlighted in the first chapter of the book. The relation between levels of reality and categories is emphasized.

Several mathematical methods that have been used in PSM development are briefly presented in chapter 2. This refers to “random systems”, “non-Archimedean analysis”, and “category theory”. Specific concepts as categorification and integrative closure are introduced. Categorical formulation of integrative closure offers the general PSM framework which serves as a flexible guideline for the large variety of research and multi-level modeling problems presented in the book.

Chapter 3 introduces the conventional real-field frame for PSM and some illustrative examples. Chapter 4 leads into the new PSM methodologies. The model categorification method is illustrated. The need of appropriate notions of time and probabilities and of new theoretical concepts is emphasized.

The chapters 5 to 8 are dedicated to case studies relevant to the sciences of nature.

For this part the levels are usually associated to time scales. Chapters 5 and 6 elaborate PSM for mixing and transport in single or multi-compartmental systems while chapter 7 contains a multi-scale study of dispersion and turbulence. Major applications for these chapters range from chemical engineering to pharmacology and environment.

Chapter 8 highlights entropy and entropy production roles for integrative closure conceptual framework. Application concerns entropy production for multi-scale biosystems. Based on different types of causation, new informational entropy criteria are proposed.

The next four chapters, 9 to 12, outline the potential of the proposed multi-level modeling methods for the domain of system sciences. For this part the levels are conceptual knowledge levels or reality levels associated to categories. Chapter 9 establishes the contact of PSM with formal concept analysis. Applications include enumeration of separation flow-sheets, pharmacology, security management for information technology, and failure analysis. Diagrammatic reasoning using existential graphs is presented in chapter 10. The correlations with pragmatism and studies of continuity are emphasized.

Chapter 11 applied evolvable designs of experiments to pharmaceutical pipeline for drug discovery and development, to reliability management systems and failure analysis for printed circuits.

The connection of the presented PSM methodology with some forward-looking research directions for autonomous systems has been outlined by Chapter 12. Delineated case studies refer to autonomous experimentation, case based reasoning, beliefs desires intentions agents, organic and autonomic computing, autonomous animats, viable systems modeling, and multi-level modeling for informational systems.

Necessary elements of non-Archimedean functional analysis and category theory are presented in appendices.

The case studies analyzed in the book, represent a source of inspiration for emerging technologies in their current transition from adaptive toward evolvable and autonomous systems. They joint also recent trends advocating the convergence of disciplines and the need for transdisciplinary research for complexity. The multi-level modeling is in place at the intersection of sciences of matter as chemistry, life sciences, cognitive sciences, engineering and mathematics.

The PSM methodology presented and developed in this book is successfully confronted with an exciting field of major practical interest and a key area for future investigations, the multi-level complexity.

Contents

1	Introduction	1
1.1	Multi-level Systems	1
1.1.1	Levels and Complexity	1
1.1.2	Related Concepts and Theories	3
1.2	Levels of Reality and Categories	6
	References	9
2	Methodological Resources.....	11
2.1	Random Systems	11
2.2	Non-Archimedean Analysis.....	13
2.3	Categorical Frames	14
2.3.1	Introducing Category Theory	14
2.3.2	Higher Dimensional Categories	16
2.3.3	Models Categorification.....	18
2.3.4	Synthetic Differential Geometry	19
2.4	Closure.....	21
2.4.1	Semantic Closure	21
2.4.2	Two Levels Modeling	22
2.4.3	Integrative Closure.....	24
	References	31
3	Conventional PSM Frames	35
3.1	One Conditioning Level Frame	35
3.2	Multiple Conditioning Levels	38
3.3	Illustrative Case Studies	41
3.3.1	Mixing in Turbulent Flow	41
3.3.2	Diffusion on a Hierarchical Space.....	44
3.3.3	Different Views for the Same Phenomenon.....	48
	References	51
4	New PSM Frames	53
4.1	General Frameworks for PSM.....	53
4.1.1	Basic Categorical Frameworks.....	53
4.1.2	Multiple Levels	55
4.2	Time Frames	61
4.2.1	The Problem of Time Frame	61
4.2.2	Frame of Infinitesimals	62
4.3	Probabilities and Possibilities	63

4.3.1	Frame of Infinitesimals for Probabilities and Possibilities.....	63
4.3.2	Non Well Founded Sets and Probabilities.....	65
4.4	Models Categorification Methodology.....	66
4.4.1	Frame of Infinitesimals for PSM.....	66
4.4.2	NA Difference Equation.....	68
	References.....	69
5	Mixing in Chemical Reactors.....	71
5.1	Discrete Model of Imperfect Mixing.....	71
5.1.1	Residence Time Distribution, RTD.....	71
5.1.2	Discrete Model for Residence Time Distributions.....	75
5.1.3	Local Anesthetic Effects.....	80
5.1.4	Stochastic Features. Real Field Probabilities.....	81
5.1.5	PSM Frame for Discrete Model.....	83
5.1.6	Comparison with Theory.....	84
5.2	Continuous Model of Imperfect Mixing.....	85
5.2.1	The Continuous Model.....	85
5.2.2	PSM Frame for Continuous Model.....	89
5.2.3	Comparison with Theory.....	90
5.2.4	SDG Solution for Imperfect Mixing.....	93
	References.....	94
6	Compartmental Systems.....	95
6.1	Compartmental Models.....	95
6.2	Discrete Models for a Series of Imperfectly Mixed Vessels.....	97
6.3	Continuous Time Model.....	99
6.3.1	Residence Time Distributions.....	99
6.3.2	Interaction of Chemical Compound with Membranes.....	103
	References.....	105
7	Turbulent Mixing.....	107
7.1	Dispersion.....	107
7.1.1	The Dispersion Equation.....	107
7.1.2	The Frame of Infinitesimals.....	109
7.1.3	Hydrological Experiments.....	113
7.1.4	SDG Solution for Dispersion.....	115
7.1.5	Convection Model.....	117
7.2	Intermittency by Vortex Line Stretching.....	118
7.2.1	Conventional Frame.....	118
7.2.2	Multi-level Frame.....	120
	References.....	123
8	Entropy.....	125
8.1	Background.....	125
8.2	Informational Entropy.....	127
8.3	Entropy Production for Biosystems.....	129

8.4	Entropy and Integrative Closure	135
8.5	Cooperative Model for Nerve Excitation.....	138
	References	141
9	Formal Concept Analysis.....	143
9.1	Galois Lattices	143
9.2	Separation Lattice	144
9.3	Drugs Mixture.....	148
9.4	Failure Analysis	149
9.5	Triadic Context Analysis	151
9.6	Rough Set Approximations.....	153
9.7	Hierarchical Class Analysis	156
9.8	Tetradic Context Analysis	158
9.9	Security Management Architectures.....	160
	References	162
10	Existential Graphs	165
10.1	Systems of Existential Graphs	165
10.2	Continuum and Existential Graphs	170
10.3	Separation Flow Sheets.....	173
	References	176
11	Evolvable Designs of Experiments	179
11.1	Pharmaceutical Pipeline.....	179
11.2	Designs of Experiments for Drug Discovery	182
11.3	Drugs Development	184
11.3.1	General PSM Framework for Discovery and Development....	184
11.3.2	Informational Tools.....	185
11.3.3	Anesthetics Mixtures.....	187
11.3.4	Acylthiocarbamates Library Design.....	190
11.4	Reliability Management System	193
	References	196
12	Autonomous Systems Perspective	199
12.1	Autonomous Experimentation	199
12.2	Case Based Reasoning Systems.....	200
12.3	Belief Desire Intention Agents	203
12.4	Autonomic and Organic Computing	205
12.5	Autonomous Animats	207
12.6	Viable Systems Models	208
12.7	Meta-modeling Architectures	209
	References	211
	Appendices	213
	Appendix 1: Non-Archimedean Analysis.....	213
A1.1	Valued Fields.....	213
A1.2	Normed Linear Spaces and Orthogonality.....	214
	References.....	217

Appendix 2 Category Theory218
A2.1 Category Theory218
A2.2 The n-Categories.....219
A2.3 Periodic Table.....220
A2.4 Categorification and Coherence.....222
A2.5 Toposes Modeling SDG.....225
References226

Index229

List of Figures

2.1	Multiple scales networks and n-graphs.....	17
2.2	Semantic closure.....	22
2.3	Two-level models.....	23
2.4	Integrative closure network.....	24
2.5	Integrative closure network with sub-levels.....	25
2.6	Integrative closure for categories.....	26
2.7	Integrative closure for categories and sub-categories.....	26
2.8	Integrative closure for centered categories.....	29
2.9	Cybersemiotic star and integrative closure.....	30
2.10	Tetradic sign.....	30
3.1	RSCC model.....	36
3.2	Continuous time RSCC model.....	38
3.3	Example of PSM frame.....	41
3.4	Mixing process.....	42
3.5	One level of states.....	44
3.6	Energy barriers.....	45
3.7	PSM frame for one level of states.....	46
3.8	Multi-levels of states.....	46
3.9	PSM frame for multiple levels of states.....	47
3.10	States at different levels.....	48
3.11	RSCC associated to one level conditional stochastic chain.....	49
3.12	PSM frame associated to multiple levels conditional stochastic chain.....	50
4.1	Two levels framework.....	54
4.2	Three levels hierarchical framework.....	55
4.3	Three realms network.....	56
4.4	Four levels hierarchical framework.....	57
4.5	Four realms network.....	57
4.6	Fully integrated four realms network.....	59
4.7	Centered four realms network.....	60
4.8	Cycle of cognition.....	60
5.1	Imperfect mixing.....	75
5.2	Discrete time scales and integrative closure for one cell.....	79
5.3	Continuous time scales and integrative closure for one cell.....	91

6.1	Cellular model	97
6.2	Cellular models with imperfect mixing	98
6.3	Time scales and integrative closure for multiple cells	103
7.1	Scales and integrative closure.....	115
7.2	Intermittency by vortex line stretching.....	120
7.3	Two time scales intermittency	121
8.1	Entropy production for multi-scale systems	134
8.2	Integrative closure for multi-scale entropy production.....	136
8.3	Integrative closure and entropy principles.....	137
9.1	Galois lattice for separation-four properties	147
9.2	Galois lattice for separation-reduced labeling	147
9.3	Procaine	148
9.4	Galois lattice for composed drugs	149
9.5	Galois lattice for failure analysis	151
9.6	Trillattice for triadic power set context.....	153
9.7	Galois lattice for separation-five properties.....	154
9.8	Oriented formal contexts	155
9.9	Hierarchical structure of classes for dyadic context	157
9.10	Triadic classes hierarchy study	158
9.11	Tetralattice for tetradic power set context.....	159
9.12	Integrative closure for tetradic lattice	160
9.13	Four realms network for security of information systems	161
9.14	Four realms network for failure diagnosis	161
9.15	Four realms network for security management.....	162
10.1	Sep: A is false or separated.....	166
10.2	Subgraphs	166
10.3	Double seps.....	167
10.4	Nested levels of subgraphs	167
10.5	Double seps rule of equivalence	168
10.6	Insertion and erasure.....	168
10.7	Iteration/Deiteration.....	169
10.8	Broken seps.....	170
10.9	Integrative closure for existential graphs.....	172
10.10	Monoidal flow-sheets	174
10.11	Monoidal flow-sheets: tree like form.....	174
10.12	Braided flow-sheets	175
10.13	Parity cube flow-sheets.....	176
11.1	Pharmaceutical pipeline.....	180
11.2	Pharmaceutical pipecycles.....	181
11.3	EDOE basic framework.....	183
11.4	Framework for drug discovery and development	185

11.5	Acylthiocarbamates structure	191
11.6	Framework for reliability management system	194
11.7	Integrative closure for EDOE	196
12.1	Architecture for autonomous experimentation	200
12.2	CBR basic framework.....	201
12.3	Centered frameworks for evolvable CBR.....	203
12.4	Structure of BDI agents	204
12.5	Centered frameworks for evolvable BDI architecture	205
12.6	Automatic computing architecture.....	206
12.7	Organic computing architecture.....	207
12.8	Architecture for autonomous animats	208
12.9	Architecture for viable systems	209
12.10	Centered meta-meta-modeling frameworks.....	210
A2.1	Pentagon relations.....	223
A2.2	Hexagon relations	224
A2.3	Parity cube relations.....	224

List of Tables

5.1	Action potential amplitude for the anesthetic effect	80
5.2	Objective function for single compartment model	80
5.3	RTD functions predicted by different models.....	92
6.1	Compartmental models.....	96
6.2	Relative height of the compound action potential	104
6.3	Objective function for multi-compartments model.....	104
9.1	Input information-isomers properties	145
9.2	Formal context: components and properties	145
9.3	Formal context for separations-four properties.....	146
9.4	Properties of drugs.....	148
9.5	Plating voids type for different processing steps	150
9.6	Triadic power set context.....	152
9.7	Formal context for separations-five properties	154
9.8	Dyadic formal context	156
9.9	Triadic context.....	157
9.10	Tetradic power set context (partial data)	159
11.1	Greco-Latin square design	184
11.2	Topical anesthetics.....	188
11.3	Informational entropies for mixtures	189
11.4	Reference set for acylthiocarbamates-radicals.....	191
11.5	Reference set for acylthiocarbamates-matrix.....	191
11.6	Informational entropies for Acylthiocarbamates	192
11.7	Latin square design	194
11.8	Resistance patterns. Classification table	195
A2.1	Periodic table of categories.....	221
A2.2	Correspondence between sets and categories	222

Abbreviations

CT-category theory

EDOE-evolvable design of experiment

EG-existential graphs

FCA-formal concept analysis

GL-Galois lattice

NA-non-Archimedean

NBIC-nano-bio-info-cogno

PSM-polystochastic model

RS-random systems

RSCC-random systems with complete connections

RTD-residence time distribution

SDG-synthetic differential geometry

SKUP-states, conditions, operators, possibilities