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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.

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Modeling Multi-Level Systems

Springer

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…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 informationl 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.

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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