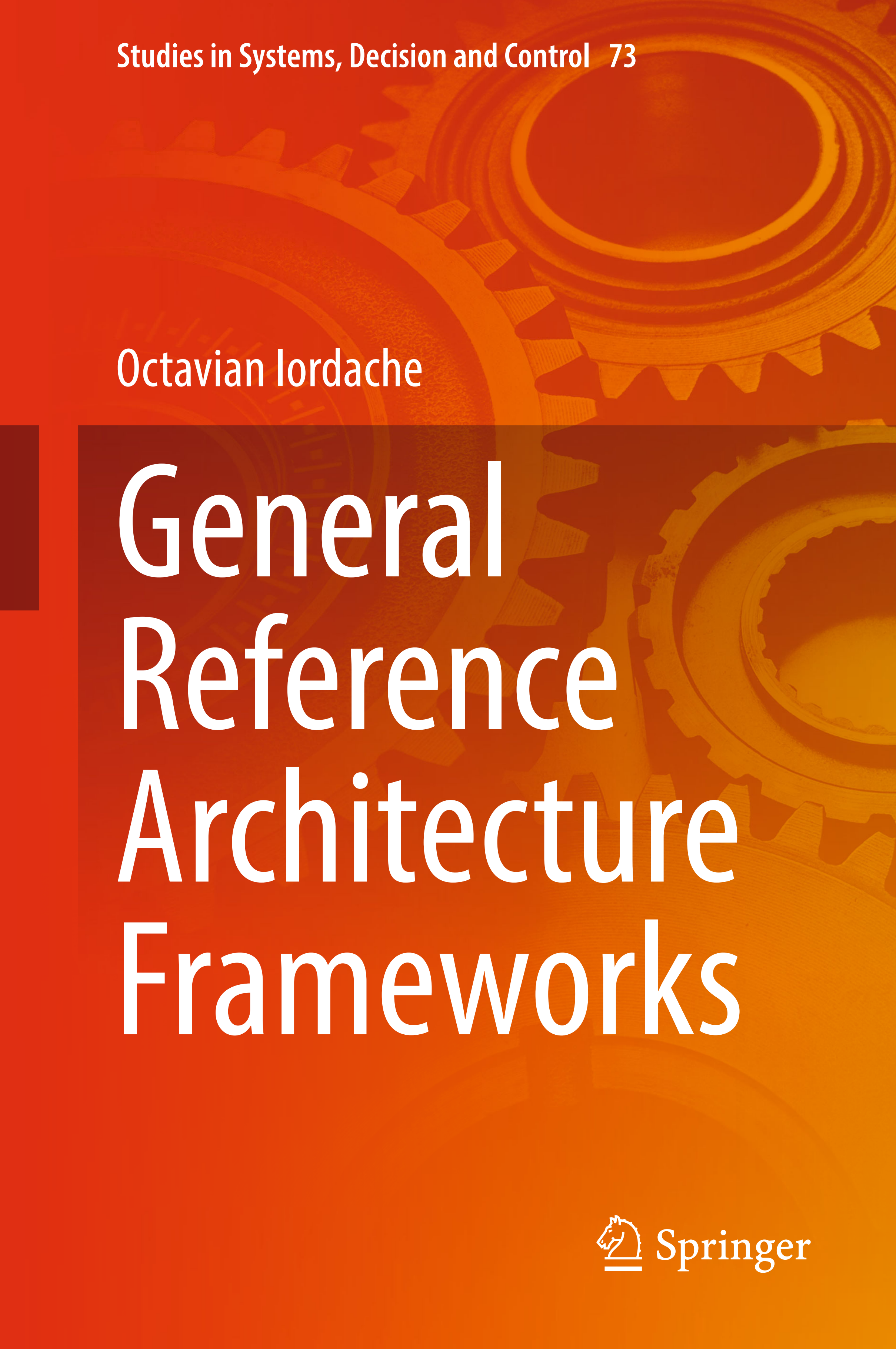
Studies in Systems, Decision and Control 73

Octavian Iordache

General Reference Architecture Frameworks



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For it is the same thing that can be thought
and that can be.
Parmenides

… that there is in the being of things
something which corresponds to the process
of reasoning, that the world lives, and moves,
and has its being, in a logic of events.
C. S. Peirce, 1898

The 'scientific part' of chemical engineering
consists in breaking down real complex
systems into subsystems, which are then
described using our understanding of
fundamental chemical and physical
processes. The 'engineering part' of chemical
engineering consists in using this new-found
knowledge in the design and construction of
a working plant which is capable of
producing the desired product, even if our
understanding of the single subsystems is
today incomplete.
K. Wintermantel, 1999

Preface

Studying high complexity in engineering and science, in reality and virtuality is the object of this book. Complex systems are assemblies of several systems characterized by emergent behavior resulting from nonlinear interactions. The main source of complexity is the multiplicity of processes, scales, fields, dimensions, disciplines, and logic rules for the considered systems. Multiple interactions and emergences are the core of higher complexity and of associated models and methods for projects implementations.

The starting point of our approach is the observed similarity or isomorphism of roadmaps towards higher complexity and of reference architectures for different domains.

Logical reference architecture of our virtual conceptual schemes corresponds to the structural reference architecture of reality. Systems ranging from inorganic to biological, cognitive, intelligent, to design and modeling mathematical models share similar roadmaps and similar reference architecture frameworks.

The objective is to propose General Polytopic Roadmaps (GPTR) and General Reference Architecture Frameworks (GRAF) and to use these for 8D Program implementation.

The GPTR shows the stages: 0D, 1D, 2D, 4D, and 8D. They correspond, respectively, to:

Descriptive, Adaptive, Evolvable, Self-Evolvable (SE), and SE of SE systems.

For example, correlating the real physical with virtual cyber in cyber-physical systems, allows developing Industry 4.0 or in other words, 4D, live-like or SE systems. This is the A-Life or Industry 4.0 evolution stage. Then, by grafting 4D for any component of the existing 4D live-like systems, the 8D intelligent-like, or SE of SE systems will result.

This is the A-Intelligence or Industry 8.0 evolution stage. The 4D stage is devoted to replace physical activities, while the 8D stage tries to replace mental activities of humans.

The GPTR and the GRAF are committed to explore the high complexity in different domains. High-dimensional reference architectures should be envisaged in industry giving that the conventional operations, equipments, methodologies, or organizations exploring the ever-growing complexification reached their limits and need both 4D, live-like, as 8D, intelligent-like capabilities. The exploration of ever growing complexities needs the high dimensional polytopic projects implementation. Polytopic projects impose connecting science and engineering, virtuality and reality.

The book is divided into eight chapters. Chapter 1 introduces the GRAF. This is presented as a 4D hypercube of 4D hypercubes that is as an 8D polytope. Conservative and innovative strategies of evolution, from 4D to 8D, are presented.

Chapter 2 emphasizes the role for the dialogue of processes in duality, of the logic of contradiction, of iteration, and of included middle to explore high complexity. The role of a general method and of included middle or Systems 3, between System 1 and System 2 frames of dual process theory, is revealed. Chapter 3 refers to operations and equipments of chemical engineering interest as permutations, mixings, and separations. Chapter 4 refers to modeling. Here the road to complexity in modeling, to digital twin, and to digital twin of digital twin is illustrated. Model-Based Engineering case studies are analyzed. Chapter 5 concerns creative design models. Dual process design, processes integration, divergence, and convergence design models are presented. Industry 4.0, future developments to Industry 8.0, and chemical engineering paradigms are examined in Chap. 6.

Chapter 7 focuses on complex systems study. Production systems as systems of systems architecture frameworks, decision models, operations process, and cyber-physical social systems have been presented in the new general frame.

Chapter 8 analyzes implementation of high-complexity projects for different levels of reality. The unifying and diversifying strategy for reality and virtuality, and the 8D Program Manifesto closes the Chap. 8.

Despite the fact that the majority of case studies are related to chemical engineering the presented methodologies aim to be universal and equally applicable to other fields of engineering or science. The book will be useful to engineers, researchers, entrepreneurs, and students in different branches of production, science, and engineering of complexity.

Montreal, Canada
June 2024

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Contents

Abbreviations

CPS	Cyber-Physical Systems
DoE	Design of Experiments
DPT	Dual Process Theory
DT	Digital Twin
GPTR	General Polytopic Roadmaps
GRAF	General Reference Architecture Frameworks
IM	Included Middle
MBE	Model-Based Engineering
MBIC	Material-Biologic-Intelligent-Cognitive
OODA	Observe Orient Decide Act
PTP	Polytopic Project
PTR	Polytopic Roadmap
RAMI	Reference Architecture Model for Industry
SE	Self-Evolvable
SO	Self-Organized
SoS	System of Systems

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Chapter 1
Complexity

Abstract A way to explore complexity and emergence is presented here. Reference architectures are introduced as a set of schemes that identifies structures and allows integration of assets, operations, equipments, methods, products, tests and applications in different projects. The proposed main stages for high complexity roadmap are: Descriptive, Adaptive, Evolvable, Self-Evolvable (SE) and SE of SE. They correspond to 0D, 1D, 2D, 4D, and 8D reference architectures. The SE stage is associated to 4D and live-like systems. The SE of SE stage is associated to 8D and to intelligent-like capabilities. General roadmaps and frameworks for 4D and 8D reference architectures are introduced.

1.1 Complexity and Emergence

What is a complex system, and what does it means for a system to show high complexity and emergence?

The study of complex systems or more generally the science of complexity has been a hot research topic for the last decades.

A complex system is described as a structure or process involving non-linear interactions among many parts and levels, which displays emergent properties. In other words this means that the aggregate system activity is not derivable from the linear summations of the activity of individual components and that novel structures, patterns or properties arise, from interactions among parts.

Complex systems are ones in which patterns can be seen and understood, but interplay of individual parts cannot be reduced to the study of individual parts considered in isolation from one another. A survey of the literature indicates that there is no standard agreed upon definition of a complex or emergent system. Some of the existing definitions may even seem contradictory but they may make sense when applied to specific types of systems and from which perspective one choices to observe (Adami 2002; Kauffman 1995). This suggests considering several domains of complexity and a hierarchy of levels for complexity. The complexity for inorganic systems differs from the complexity for biological, cognitive or intelligent systems.

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An example of physical complex system is the global climate, including all components of the atmosphere and oceans and taking into account the effects of extraterrestrial processes as solar radiation and meteorites. An illustration of complex biological system is the human brain composed of millions of nerve cells. Their collective interaction allows recognizing visual, acoustic or olfactory patterns, speaking and performing different mental activities.

An example of complex social system is the human society with its participants, natural resources and capital goods, financial and political systems. For the logical and mathematical realm, examples of high complex calculus systems may consists of large scale distributed software systems or hierarchies of layered computing subsystems self-organized and running together to achieve particular objectives.

What is remarkable is that systems that have apparently little in common-material systems as an array of polymers in a test tube, biological systems as a group of receptors on a cell's surface, knowledge or cognitive systems as a group of ants in a swarm or human agents in a company-often share remarkably similar structures and means of organization. This explains and justifies the need for a science of complexity.

Features such as non-linearity, hierarchy of levels, time-scales, connectivity, non-equilibrium, unpredictability, interconnectivity, collective behavior, self-evolvability, self-organization, self-production, self-reference, and multiple agencies are associated with complexity studies. Complexity is correlated to non-linearity, which is a necessary but not sufficient condition of complexity, as well as to interconnectivity, self-organization, self-evolvability, self-similarity and collective behavior (Mainzer 1996).

The understanding of complexity changes with the domains of application. Surveys consider that complexity has not an absolute meaning, and it is only a relative notion depending on the level of observation or abstraction. It is commonly stated and accepted that some objects and processes are more complex than others.

We must to take into account this facet of complexity as a relative concept which depends both on the task at hand and on the tools available to achieve this task.

For industrial systems, despite the fact that numerous physical, chemical or biological processes are identified as complex, some of the conventional ones may be operated in regimes were complexity properties are neglected. For several centuries, physical and chemical sciences made great steps by experimenting and constructing simplified models of complex phenomena, deriving properties from the models, and verifying those properties by new experiments. This approach worked because the complexities ignored in that models were not the critical properties of the phenomena. It does not work when the complexity becomes the essential characteristic. In a continuously increasing number of cases the complexity is not transient or atypical, but it is an intrinsic, basic property of that systems. Given this situation the challenge for engineers, scientists and entrepreneurs is not only to identify complexity domains but also to show how to overtake the successive complexity barriers. The next defy in science, technology and economy is to explore the complexity, finding the ways from high complexity towards a new simplicity. The 21st century problems