Simplicity is Complex

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Foundations of Cyber-Physical System Design

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Preface

It is the objective of this book to investigate what are the characteristics of *simple* versus *complex* systems and to find out what are the *design principles* that make a *Cyber-Physical System* understandable, simple to use, and easy to maintain. The adherence to these principles in the design of a *Cyber-Physical System* should lead to a significant reduction of the system complexity.

The targeted audiences of this book are engineers, managers, and advanced students who are involved in the design and evolution of Cyber-Physical Systems and are willing to spend some time outside the silo of their daily work in order to widen their background and learn more about the pervasive problems of *system complexity*.

My interest in the topic of complexity started when I was a manager of a process control department industry more than 40 years ago. This topic kept me hostage up to today. Forty years ago, the design of a process control system (today these systems are called *Cyber-Physical Systems*) was more of an art than an engineering endeavor. The software technology at that time was concerned primarily with *functional correctness* and did not pay much attention to the *temporal dimension* of program execution that is as important as functional correctness when a physical process must be controlled.

In the following years in academia, we tried to develop a *real-time system design methodology* where time was considered a first-order citizen. By taking time from the *problem domain* and putting it into the *solution domain*, many problems in the design of Cyber-Physical Systems can be simplified. We developed the *time-triggered protocols* and the *time-triggered architecture* that are now deployed in industry. But with an increase in the functional requirements and system size, the complexity problems appeared again in a different disguise.

A sound analysis of the *complexity problem* requires some insight in cognition, human problem-solving, and parts of philosophy. After becoming an *emeritus*, I had the time to look into these diverse fascinating fields more seriously.

After the introductory chapter, this book is divided into two parts. The first part (Chaps. 2–5) deals with the foundational issues of complexity, i.e., the conceptual, psychological, and philosophical aspects of complexity and the multi-level hierarchy

of models that are required to orient oneself in a complex world. The distinction between *essential data* (e-data) and *context data* (c-data) in Chap. 3 is of particular importance when a responsive real-time communication system must be designed and helped us in the design of the time-triggered protocol (TTP).

A reader who does not want to start with the rather heavy foundational issues of the first part is advised to initially jump over this part and go directly to Chap. 6. The reader may go back to these foundational issues at a later time when some deeper degree of understanding of the complexity problem is desired.

Chapter 6 points out that Cyber-Physical Systems are fundamentally different from conventional data processing systems. Chaps. 7–10 deal with the simplification and the engineering design of understandable Cyber-Physical Systems and present a framework for the development of a safety-critical CPS.

More than 100 small examples are interwoven throughout the text to demonstrate how the abstract ideas are related to concrete situations.

The present book contains the essence of my thinking about complexity accumulated over the past 40 years. In some sense, this book presents the rationale for the design of the time-triggered architecture (TTA). The TTA provides a sound engineering framework and methodology for the development of Cyber-Physical Systems.

The ideas presented in this book have grown over many years: first in the industry and then out of the numerous discussions at the Institute of Computer Engineering at the Vienna University of Technology, at IFIP WG 10.4 meetings, and in a number of exciting European research projects (particularly the AMADEOS projects on *Cyber-Physical Systems of System*, headed by Andrea Bondavalli). At this point, I would like to thank many friends who have contributed valuable comments on the earlier drafts of this book: Bernhard Froemel, Frank Furrer, Laila Gide, Radu Grosu, Brian Randell, Klaus Schmidt, Lui Sha, Rob Siegel, Wilfried Steiner, Neeraj Suri, and Martin Törngren.

Parts of the material have been derived from some of my previous publications and have been revised in order to bring them into a coherent whole.

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