Preface

The rapid evolution of computing, communication, control, and sensor technologies has brought about the proliferation of new man-made dynamic systems, mostly technological and often highly complex. Examples around us are air traffic control systems; automated manufacturing systems; computer and communication networks; embedded and networked systems; and software systems. The activity in these systems is governed by operational rules designed by humans and their dynamics is often driven by asynchronous occurrences of discrete events. This class of dynamic systems is therefore called discrete-event (dynamic) systems.

Based on finite-state automata and formal languages, the seminal work by Ramadge and Wonham in the early 1980s aims at providing a comprehensive and structural treatment of the modeling and control of discrete-event systems (DESs). The results in this area are gradually shaped and lead to supervisory control theory (SCT). SCT considers a DES as a generator of a formal language. Its behavior can be controlled by a supervisor that prevents event occurrences in order to satisfy a given specification.

Due to its generality, SCT is a paradigm that bridges the two worlds of control theory and computer science. In the latter, there exists a well-established Petri net community. As a natural and alternative modeling formalism, Petri nets are widely used for DES modeling and control. Their structural properties have been successfully exploited for the design of supervisors for supervisory control problems. Significant progress in this direction was made over the last two decades. The results obtained so far deal mainly with the safety of a plant, i.e., avoidance of dangerous or forbidden conditions given in a control specification. Liveness in Petri nets is an important behavioral property that leads to the safety of the supervised plant. It implies the freedom of deadlock–a highly undesired situation that an automated system must completely avoid. This property is equivalent to the non-blockingness in SCT. SCT is independent of the specific representation. That is to say, it is independent of a specific implementation technology.

A variety of theoretical results and computational algorithms have been developed in the literature to assess the liveness of certain classes of Petri nets. Most of these results are based on the fact that the liveness of a Petri net is closely related

to the satisfiability of certain predicates on siphons. As a set of place elements, a siphon is a structural object in Petri nets. This relation between liveness and siphons becomes strong and apparent when we investigate the practical DES including a variety of resource allocation systems in a contemporary technological domain. Consequently, the siphon-based characterization of liveness and liveness-enforcing supervision for DESs modeled with Petri nets is usually considered to be one of the most interesting developments in the last decade from both theoretical and practical points of view.

However, the power of siphon-based liveness-enforcing approaches is degraded and deteriorated as the number of siphons grows quickly beyond practical limits and in the worst case grows exponentially fast with respect to the Petri net size. They suffer from the computational complexity problem since it is known that in general the complete siphon enumeration in a Petri net is NP-complete. Furthermore, they usually lead to a much more structurally complex liveness-enforcing Petri net supervisor than the plant net model that is originally built. This book tries to show how an elementary siphon-based methodology tackles these problems.

The book is intended for researchers, graduate students, and engineers who are interested in the control problems arising from manufacturing, transportation, workflow systems, communication, computer networks, complex software, and chemical industry. It is also appropriate for the students in automatic control, computer science, and applied mathematics and can be used as a supplementary textbook in the courses on Petri net theory and applications as well as the supervisory control of DESs.

Nevertheless, we try to maintain as a goal the presentation of a detailed discussion of the fundamental aspects of the related theory used throughout this book and hope to give readers a sufficiently solid foundation for their own advanced work and further study of the literature on this subject, it is highly desired that readers are familiar with the basics of linear algebra, set theory, and (integer) linear programming. In this sense, this book is self-contained. However, it is not intended to be an introductory textbook on Petri net theory. Being already familiar with net theory is hardly necessary to open this book but surely helpful if readers know its preliminaries.

Following the introduction in Chap. 1, the basics of Petri nets are presented in Chap. 2, which is used throughout this book. Explanatory examples are given to illustrate the concepts so that readers can understand the book without the prior knowledge of general Petri net theory. The concept of elementary and dependent siphons in a net is proposed in Chap. 3. As a natural extension to the concept of elementary siphons, Chap. 4 presents a novel monitor implementation to enforce generalized mutual exclusion constraints (GMECs). Chap. 5 presents a number of deadlock prevention policies that are developed on the basis of elementary siphons. The role of elementary siphons is fully shown in Chap. 6 by investigating the existence of a maximally permissive (optimal) liveness-enforcing monitor-based Petri net supervisor for a flexible manufacturing system. A survey and comparison of a variety of deadlock prevention policies in the literature are presented in Chap. 7. The comparison is conducted from the following points of view: computational complexity,

structural complexity, and behavior permissiveness. The last chapter concludes this book by summarizing the results in the literature and presenting some interesting and open problems as well as some guidelines to tackle them.

Attached to the end of every chapter is a reference bibliography, and a glossary and a complete index in the final part, which should facilitate readers in using this book.

Readers of this book can learn the basics of Petri nets, siphon-based characterization of liveness, the theory of elementary siphons, and deadlock resolution methods and strategies for automated manufacturing systems. They can also learn a number of deadlock prevention policies developed on the basis of elementary siphons. They can finally master the concept of elementary siphons and related methods in designing structurally simple liveness-enforcing monitor-based Petri net supervisors.

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August 2008