Review of the book

Synthesis and Control of Discrete Event Systems,

by B. Caillaud, Ph. Darondeau, L. Lavagno and X. Xie (Eds.),

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This book is a collection of fourteen research and survey papers selected from two different meetings: four of them were presented at the *Workshop on Synthesis of Concurrent Systems*[1], and the remaining ten were presented at the *Symposium on Supervisory Control of Discrete Event Systems*[2]. It aims at providing a unifying view of the current trends in the research on synthesis and control of logical Discrete Event Systems merging two different perspectives: the control theory approach and the computer science approach.

The field of Discrete Event Systems (DES) is a relatively new research area that combines different formalisms, methodologies and tools from control theory, computer science and operations research. The research activity in this field is driven by the needs of many different applications domains: manufacturing, process control, supervisory control and data acquisition systems, failure diagnosis, software engineering, transportation, and so on.

The field of DES can be partitioned into two domains.

Logical models and theories are used to describe qualitative properties and aim to control the sequences of events generated by a DES. To achieve this goal, the timing of event occurrence can be ignored and it is only required to keep track of the order among events. Typical problems that are considered within this framework are: avoiding forbidden sequences of events or forbidden states, deadlock avoidance, liveness enforcing, and so on.

Performance models and theories are used to describe quantitative properties and aim to control the timed behavior of a DES. In this case it is necessary to keep

[1] Held in Newcastle upon Tyne, UK, in June 2001 as a satellite event of the joint *22nd Int. Conf. on Application and Theory of Petri Nets* and *2nd Int. Conf. on Application of Concurrency to Systems Design*.

[2] Held in Paris, France, in July 2001 as a satellite event of the *13th Conf. on Computer Aided Verification*.

track of the occurrence time of each event. Typical problems that are considered within this framework are: satisfaction of timing constraints, optimization of process time and routing, scheduling, and so on.

The book only deals with logical DES and presents recent developments concerning three approaches that in the last years have proved to be mostly successful for logical DES. These approaches will be briefly described in the following.

- The most interesting and original approach to the control of DES, that has directly or indirectly shaped much of the research in this area, is *Supervisory Control Theory* (SCT). This theory, originated by the work of P.J. Ramadge and W.M. Wonham, considers a discrete event system as a generator of a formal language whose behavior must be controlled by a supervisor, preventing event occurrences so as to satisfy a given specification.

  SCT is a perfect example of a paradigm that bridges the two worlds of computer science and control theory. In fact, although SCT is deeply rooted in formal language theory, it was directly inspired by the geometric approach to control theory. As explained by W.M. Wonham[3], the geometric approach to linear systems made essential use of partially ordered sets, in particular the lattice of subspaces of a vector space. This led to the notion of "supremal controllability subspace", which made possible the effective solution of several long-standing synthesis problems in linear multivariable control (decoupling with internal stability, asymptotic regulation with internal stability, among others). The dual notion of congruence on a vector space was central to observability, where again the lattice structure supported the concept of an observer. This duality, between control (substructures) and observation (quotient structures), on which the geometric theory rested, carried over very naturally to the lattices of sublanguages and quotients (congruences) in the setting of languages and automata, where it plays much the same role. In this sense, there were no "surprises" in going over from classical control theory to the new setting of SCT, other than perhaps the unpleasant fact that automata are by no means as well-behaved as linear systems.

  From this point of view, although the models considered by supervisory control may look more familiar to a computer scientist, SCT follows in the tradition of the work by R.E. Kalman (who was the first to formalize the notion of a fundamental duality between control and observation around 1960), and by R. Bellman and A.A.

[3]Personal communication, 2003.

Feldbaum (Bellman's classic book on adaptive control stressed the interrelationship of control and observation, as did Feldbaum's theory of dual control).

- A second research area that has played a key role in developing the field of logical DES is *Concurrency Theory*. A concurrent system can be viewed as a collection of sequential processes, possibly running on different processors, that interact and exchange results with each other and with the external environment. Among the most meaningful ideas that are central to this research area, one can mention at least two that are well represented in this book.

  Distributed systems and decentralized control. This approach has also deeply influenced SCT where it has often merged with the classical notion of partially observed systems and observer design (that was also central to the research area on fault diagnosis).

  Model equivalence and bisimulation. This approach has proved to be an important theoretical tool not only in the domain of DES, but in the domain of Hybrid Systems as well.

- A third research area that is extremely important for DES is *Petri nets* (PN). A Petri net is an algebraic and graphical formalism that generalizes automata theory and has primitives to explicitly represent the notion of concurrency among events. Properly speaking, PN can be seen as a particular model of concurrent systems: however, the basic research on PN has assumed such a relevance and has found application in so many domains, that it is common to consider PN a full-fledged research field.

  The goal of PN research in DES is to exploit the structural properties of PN models. In fact Petri nets offer a structured model of DES dynamics that often allows the designer to derive more computationally efficient algorithms for controller synthesis. The PN approach has proved to be extremely successful for interesting classes of control problems, e.g., those known as "forbidden markings" where the specification partitions the reachability set into forbidden and legal states.

Although it would be extremely difficult to unify all of the above mentioned approaches under a common framework, there are many topics that are common between them. The authors of the book have made a careful selection of papers at the intersection of two or more of these approaches, collecting them into four parts.

Part I gathers important contributions on the synthesis of decentralized systems and control. Combining different approaches such as SCT, concurrency theory, formal languages

and formal verification, this part can be considered the most central and mature topic of the book. Lafortune *et al.* deal with partially observed discrete event systems, reviewing and discussing recent advances in the synthesis of centralized and decentralized supervisory control architectures. Mukund addresses the problem of determining whether there exists a distributed transition system composed of k modules such that its overall behavior is equivalent (in terms of state-space isomorphism, language equivalence or bisimulation) to a given global transition system. Puri *et al.* discuss the existence of finite state observers and controller for decentralized systems: the approach of the authors is based on SCT but they also show the link to other theoretical approaches based on formal languages. Yakovlev and Xia present a PN approach for the synthesis of asynchronous data communication mechanisms of the Signal type, and for their distributed implementation. Zhang and Wonham address the issue of computational complexity in supervisory control and propose efficient control synthesis algorithms based on integer decision diagrams.

Part II presents three papers dealing with modular modelling approaches in different settings. Bernardinello *et al.* show an approach to compose transitions systems when the state space of each module is partitioned in "regions" and the composed modules must synchronize over the events moving from one region to another one. Boel outlines a modular paradigm for extending the supervisory control framework in an adaptive fashion. Juhás and Lorenz discuss a modular modelling approach where each subsystem is represented by a Petri net and interacts with the other ones by condition and event signals.

Part III deals with recent advances in supervisory control of place/transition nets when the control specification requires avoiding a set of forbidden markings. A feature common to all these papers is the use of computationally appealing linear or integer programming techniques for control design; this possibility offered by Petri nets is one of their major advantages over other models. Basile *et al.* consider a PN model where the classical notion of controllable/uncontrollable event is relaxed assigning a control cost to each transition and is used to design optimal controllers. Ghaffari *et al.* apply the PN synthesis approach called "theory of regions" to the design of a maximally permissive controller given a specification that in addition to avoiding a set of forbidden markings also requires to preserve liveness. Giua and Seatzu discuss an approach for the estimation of the marking of a PN and the use of such an observer in a control loop together with a state feedback controller.

Part IV considers three papers dealing with specific problems, that, although interesting, are not too strongly related between them. Dietrich *et al.* consider the problem of supervisory implementation, i.e., the problem of designing a control agent that select only one

event among all those that are not disabled by the supervisor. Reveliotis surveys recent results and identifies open issues in the area of liveness-enforcing supervision for sequential resource allocation systems: PN models and analysis techniques can be successfully used in this framework. Bednarczyk and Darondeau consider a structural semi-characterization of concurrency for several classes of Petri nets, showing that, in almost all cases, two initially live transitions that do not form any diamond in the reachable state of the a net system have non disjoint neighborhoods in the saturated version of the net system.

In conclusion, I found all papers well written and interesting. Many of them provide a nice survey of the recent research in the considered topic. Almost all of them contain enough background material to make a useful tutorial reading. As a result, although the book is a collection of several articles, the presented material coalesce into a single focused picture, providing a view of the current trends in the field of logic DES that will be useful to many researchers.

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About the reviewer

Alessandro Giua received the Laurea degree in Electric Engineering from the University of Cagliari (Italy) in 1988. He was awarded the M.Sc. and Ph.D. degrees in computer and systems engineering from Rensselaer Polytechnic Institute, Troy, NY, in 1990 and 1992, respectively. He joined the Department of Electric and Electronic Engineering of the University of Cagliari in 1993 and is currently Associate Professor of Automatic Control. He has been a visiting researcher at the: University of Zaragoza (Spain), INRIA Rocquencourt e Lorraine (France), University of Angers (France), University of Metz (France), CINVESTAV Guadalajara (Mexico). He is currently serving as an Associate Editor of the IEEE Trans. on Automatic Control and of the European Journal of Control; he is a member of the Editorial Board of the journal Discrete Event Dynamic Systems, and a member of the steering committee of the Workshop Series on Discrete Event Systems (WODES). His current research interests include control engineering, discrete event systems, hybrid systems, automated manufacturing, and Petri nets.