Guest Editorial
Special Section on Advances in Discrete-Event Systems for Automation

IN RECENT years, the tremendous growth of computer technology has led to the proliferation of a class of highly complex dynamical systems, with the distinct attribute that their behavior is determined by the asynchronous occurrence of certain event types; because of this attribute these systems are termed *Discrete Event Systems* (DES). Examples of DES are encountered in many traditional application areas, such as automated manufacturing, computer networks, transportation, air traffic control, as well as in emerging areas like healthcare, communication and information processing, and the allocation and management of technical, human and financial resources. Furthermore, in the recent past, a large number of researchers and practitioners have devoted their attention to this class of dynamical systems in order to address a series of difficult problems, often combinatorial in nature, that concern their analysis, optimization and control.

The goal of this Special Section is to bring together researchers and practitioners from, both, academia and industry to highlight the state-of-the-art of the DES-related research endeavor and its applications. The selected papers present efficient scientific and engineering solutions to a series of problems related to DES, including their supervisory control, fault diagnosis, resource allocation, state estimation, and deadlock prevention and avoidance. They also provide a vision for future research and development. Even though a considerable effort has been devoted to the aforementioned topics in the last decades, many theoretical problems in this framework are still open, or their solution is only limited to small case studies, while the scaling of these solutions to problems of industrial relevance remains a challenge.

A more detailed description of the research activity that is currently taking place within the DES-focused research community, can be epitomized as follows:

1) As mentioned above, a major requirement for the field is the effective transfer of its current theoretical developments to the applications that motivated these developments in the first place. A particular challenge along these lines is the very high complexity of the addressed DES problems and their derived solutions. This complexity manifests itself in the computational effort that is involved in the development of the target solutions, but also in the structure and the size of the formal representations of the DES dynamics that are employed by, and result from, the performed computation. The DES community has tried to circumvent these challenges by pursuing the following strategies:
   a) The development of decomposing or approximate solution strategies, based on the qualitative insights and the formal properties that have been established through the complete rigorous analysis of the original problem formulations. Of particular interest along these lines, is the ongoing endeavor to develop effective approximations of the DES dynamics that take place in various application domains through abstracting representations that are based on the modeling framework of Hybrid Systems.
   b) The identification and exploitation of special structure that exists in various DES applications and can lead to customized formulations and solution approaches of reduced (ideally, polynomial) representational and computational complexity. The aforementioned problem of deadlock prevention and avoidance in complex resource allocation systems is a particular DES application domain that has benefited extensively from such a rich special structure.
   c) The development of integrated computational platforms and pertinent interfaces that will automate the involved computation, conceal the underlying computational and representational complexities from the end user, and present the outcome of the performed computation in a way that is more accessible to her.
2) Besides trying to connect more effectively to its traditional application base, the DES community is currently seeking to expand this application base to novel application areas. Some such application areas were already cited in the opening paragraph of this editorial, and they include the areas of healthcare, internet-based information and workflow management systems, security and systems biology.
3) Another driver for expanding, both, the current application and methodological bases of DES is research that develops at the interface between DES and Hybrid Systems. As already mentioned, this research provides an effective tool

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for managing the computational complexity of many DES applications. But it also enables the effective integration of event-driven and time-driven dynamics, and, in this way, it enriches the representational and analytical capabilities of the area.

4) Finally, DES-related research has been traditionally organized into two major areas concerning the "untimed" (or "qualitative") and "timed" (or "quantitative") dynamics of the underlying applications, with the former addressing behavioral concerns for the underlying system and the latter focusing primarily on aspects relating to performance. Besides their aforementioned difference in perspectives, these two areas have also employed substantially different methodological tools in their developments, and therefore, until recently, they have evolved fairly independently from each other. This decoupling has also helped in the management of the involved complexity. Yet, currently, both of these DES areas have reached a maturity level that can support and benefit from a more integrative approach to the overall DES analysis and control problem. Hence, the effective integration of behavioral and performance-oriented modeling, analysis and control of the target DES applications is another important requirement that defines the research frontier of this area.

The papers included in this Special Section exemplify and corroborate the aforecited trends. More specifically, in response to the corresponding call for papers, 32 submissions were received and carefully reviewed. Twelve were accepted and appear as papers in the Special Section. Conceptually, it is possible to divide these papers into two sets: the first eight papers deal with general DES control problems, while the second set of four papers addresses other particular DES problems such as diagnosability analysis, state estimation, deadlock avoidance, and testing. Moreover, the aforementioned contributions consider, both, industrial control problems and other more general applications.

Five papers in the first set are in the DES supervisory control area. In particular, Miremadi *et al.* show that augmenting the model of *timed* discrete-event systems with a finite set of digital clocks (timed extended finite automata) allows an efficient computation of the supervisor for large-scale systems. The main feature of this approach is the symbolic computation based on binary decision diagrams that leads to significant efficiencies in the supervisor design procedure.

Theunissen *et al.* present a specific application of the Ramadge and Wonham supervisory control theory to solve problems arising in mechatronic systems. More precisely, the control of a patient-support table for a magnetic resonance imaging scanner is addressed. The system is modeled as a finite-state automaton and the obtained controller is built in a modular way that decreases the computational complexity of the synthesis.

A control synthesis procedure is developed by Lennartson *et al.* for a generic state-vector transition model including flexible synchronous composition. In this approach, supervisor guards are generated in order to guarantee a controllable, nonblocking and maximally permissive supervisor that can be easily implemented in industrial control systems.

With the intent of bridging the gap between design and implementation of supervisory control systems modeled by *extended* Petri nets, Moreira and Basilio present a methodology to construct in a systematic way the ladder diagram that will be used eventually by the industrial controllers; the conversion is such that any modification in the discrete-event controller can be easily implemented in the existing ladder diagram.

Finally, focusing on the DES liveness problem, Hu and Liu consider a Petri net framework to synthesize liveness enforcing supervisors based on generalized mutual exclusion constraints. Taking into account the independent and dependent inequalities, the authors present a method to remove redundant inequalities in order to reduce the size of the supervisor.

The remaining three papers in the area of DES control deal with three different application settings. The first one, by Shu and Lin, investigates fault tolerant control to ensure safety of a DES. Modeling the system by an automaton, the authors present a controller that under full or partial observation of the state is able to ensure that the controlled system never visits the illegal states.

Fanti *et al.* present a hybrid model to describe and control freeway traffic dynamics. In a First-Order Hybrid Petri Net Framework, the authors present a Model Predictive Control strategy based on an online optimal control coordination with the objective of maximizing the flow density.

A hybrid model is also used by Toyoshima *et al.* to describe the switching mechanism of the states of a wheeled snake robot. Based on this hybrid model, a control strategy is presented for switching the motion patterns of the robot in order to optimize constraint forces and energy efficiency.

The second part of the Special Section includes four papers that deal with some challenging problems in the considered DES framework by capitalizing upon the special structure that is present in the corresponding formulations.

In particular, Cabasino *et al.* present a novel diagnosability analysis approach for DES modeled with *labeled* Petri nets. The presented procedure is inspired by automata-based approaches, but, thanks to the notion of *basis markings*, it possesses the main advantage of not requiring the enumeration of the whole state space.

Declerck and Bonhomme focus on the problem of the online state estimation of *timed* Petri nets with unobservable transitions, following the observation of firing occurrences of a transition subset on a sliding horizon. The significance of such an estimation method stems from the possibility of dealing with a limited amount of data, instead of using all the information available from the beginning.

Nazeem and Reveliotis consider a problem that has received extensive attention in the DES literature over the last few decades, namely, the establishment of deadlock-free resource allocation. The authors present an original approach for the deployment of the maximally permissive deadlock avoidance policy for complex resource allocation systems, that is based on a novel algorithm for the efficient identification and storage of a critical subset of the system states; this subset collects the states that are reached by transitions taking the system outside its safe region, and its availability enables the implementation of the target policy through one-step-lookahead.

Finally, Pocci *et al.* investigate the problem of computing synchronizing sequences for systems modeled by *synchronized* Petri nets. In order to look for an efficient way to solve the testing problems for DES, the authors provide some techniques, based on Petri net models, that avoid state explosion problems by means of structural analysis. The presented tool is applied to randomly generated Petri nets and some example DES taken from the manufacturing domain.

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