IEEE Control Systems Society
Technical Committee on Discrete Event Systems

Newsletter **April 2020**

Editor: Kai Cai
Chair, IEEE CSS Technical Committee on DES
Associate Professor
Department of Electrical and Information Engineering, Osaka City University
3-3-138 Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan

Phone: (+81) 6-6605-2703
Email: kai.cai@eng.osaka-cu.ac.jp
Website: https://www.control.eng.osaka-cu.ac.jp

Welcome to the 2020 April issue of the newsletter, also available online at
http://discrete-event-systems.ieeecss.org/tc-discrete/newsletters

Editorial

You are welcome to submit new items to the newsletter (topics including schools, workshops, sessions, conferences, journals, books, software, positions). Also please encourage relevant colleagues and students to subscribe to this newsletter.

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Contents

1 Selections of Journal Publications

Contributed by: Xiang Yin (yinxiang@sjtu.edu.cn)

1.1. IEEE Transactions on Automatic Control

Volume: 65, Issue: 4, April 2020

- **Synthesis of Dynamic Masks for Infinite-Step Opacity**
  Authors: Xiang Yin ; Shaoyuan Li
  Abstract: We investigate the problem of synthesizing dynamic masks that preserve the infinite-step opacity in the context of discrete-event systems. Dynamic mask is an information acquisition mechanism that controls the observability of the system's events dynamically online, e.g., by turning sensors on/off . A system equipped with a dynamic mask is said to be infinite-step opaque if an outside intruder that can access all acquired information can never infer that the system was at some secret state for any specific previous instant. Existing works on the dynamic mask synthesis problem can only preserve the current-state opacity. However, synthesizing dynamic masks for the infinite-step opacity, which is stronger than the current-state opacity, is much more challenging. The main reason is that the delayed information is involved in this problem and whether or not a current secret can be revealed depends on sensing decisions to be synthesized in the future. In this paper, a new type of information state is proposed to capture all the delayed information in the infinite-step opacity synthesis problem. An effective algorithm is then presented to solve the synthesis problem, which extends existing dynamic mask synthesis techniques from the current-state opacity to infinite-step opacity. Additionally, an information-state-reduction-based approach is proposed to further mitigate the computational complexity of the synthesis procedure. Finally, we discuss how to generalize our results to a class properties with delayed information including infinite-step K-anonymity and infinite-step indistinguishability.

- **Notions of Centralized and Decentralized Opacity in Linear Systems**
  Authors: Bhaskar Ramasubramanian ; Rance Cleaveland ; Steven I. Marcus
  Abstract: We formulate notions of opacity for cyberphysical systems modeled as discrete-time linear time-invariant systems. A set of secret states is k-ISO with respect to a set of nonsecret states if, starting from these sets at time 0, the outputs at time k are indistinguishable to an adversarial observer. Necessary and sufficient conditions to ensure that a secret specification is k-ISO are established in terms of sets of reachable states. We also show how to adapt techniques for computing underapproximations and overapproximations of the set of reachable states of dynamical systems in order to soundly approximate k -ISO. Furthermore, we provide a condition for output controllability, if k-ISO holds, and show that the converse holds under an additional assumption. We extend the theory of opacity for single-adversary systems to the case of multiple adversaries and develop several notions of decentralized opacity. We study the following scenarios: first, the presence or lack of a centralized coordinator, and, second, the presence or absence of collusion among adversaries. In the case of colluding adversaries, we derive a condition for nonopacity that depends on the structure of the directed graph representing the communication between adversaries. Finally, we relax the condition that the outputs be indistinguishable and define a notion of ϵ-opacity, and also provide an extension to the case of nonlinear systems.

- **Entropy Maximization for Markov Decision Processes Under Temporal Logic Constraints**
  Authors: Yagiz Savas ; Melkior Ornik ; Murat Cubuktepe ; Mustafa O. Karabag ; Ufuk Topcu
  Abstract: We study the problem of synthesizing a policy that maximizes the entropy of a Markov decision process (MDP) subject to a temporal logic constraint. Such a policy minimizes the predictability of the paths it generates, or dually, maximizes the exploration of different paths in an MDP while ensuring the satisfaction of a temporal logic specification. We first show that the maximum entropy of an MDP can be finite, infinite, or unbounded. We provide necessary and sufficient conditions under which the maximum entropy of an MDP is finite, infinite, or unbounded. We then present an algorithm which is based on a convex optimization problem to synthesize a policy that maximizes the entropy of an MDP. We also show that maximizing the entropy of an MDP is equivalent to maximizing the entropy of the paths that reach a certain set of states in the MDP.

Finally, we extend the algorithm to an MDP subject to a temporal logic specification. In numerical examples, we demonstrate the proposed method on different motion planning scenarios and illustrate the relation between the restrictions imposed on the paths by a specification, the maximum entropy, and the predictability of paths.

- **Structuring Multilevel Discrete-Event Systems With Dependence Structure Matrices**
  Authors: Martijn Goorden ; Joanna van de Mortel-Fronczak ; Michel Reniers ; Wan Fokkink ; Jacobus Rooda
  Abstract: Despite the correct-by-construction property, one of the major drawbacks of supervisory control synthesis is state-space explosion. Several approaches have been proposed to overcome this computational difficulty, such as modular, hierarchical, decentralized, and multilevel supervisory control synthesis. Unfortunately, the modeler needs to provide additional information about the system's structure or controller's structure as input for most of these nonmonolithic synthesis procedures. Multilevel synthesis assumes that the system is provided in a tree-structured format, which may resemble a system decomposition. In this paper, we present a systematic approach to transform a set of plant models and a set of requirement models provided as extended finite automata into a tree-structured multilevel discrete-event system to which multilevel supervisory control synthesis can be applied. By analyzing the dependencies between the plants and the requirements using dependence structure matrix techniques, a multilevel clustering can be calculated. With the modeling framework of extended finite automata, plant models and requirements depend on each other when they share events or variables. We report on experimental results of applying the algorithm's implementation on several models available in the literature to assess the applicability of the proposed method. The benefit of multilevel synthesis based on the calculated clustering is significant for most large-scale systems.

- **Transforming Opacity Verification to Nonblocking Verification in Modular Systems**
  Authors: Sahar Mohajerani ; Stephane Lafortune
  Abstract: We consider the verification of current-state and K -step opacity for systems modeled as interacting nondeterministic finite-state automata. We describe a new methodology for compositional opacity verification that employs abstraction, in the form of a notion called opaque observation equivalence, and that leverages existing compositional nonblocking verification algorithms. The compositional approach is based on a transformation of the system, where the transformed system is nonblocking if and only if the original one is current-state opaque. Furthermore, we prove that K -step opacity can also be inferred if the transformed system is nonblocking. We provide experimental results where current-state opacity is verified efficiently for a large scaled-up system.

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1.2. Automatica

Volume: 114 April 2020

- **Compositional abstraction-based synthesis for networks of stochastic switched systems**
  Authors: Abolfazl Lavaei ; Sadegh Soudjani ; Majid Zamani
  Abstract: In this paper, we provide a compositional approach for constructing finite abstractions (a.k.a. finite Markov decision processes (MDPs)) of interconnected discrete-time stochastic switched systems. The proposed framework is based on a notion of stochastic simulation functions, using which one can employ an abstract system as a substitution of the original one in the controller design process with guaranteed error bounds on their output trajectories. To this end, we first provide probabilistic closeness guarantees between the interconnection of stochastic switched subsystems and that of their finite abstractions via stochastic simulation functions. We then leverage sufficient small-gain type conditions to show compositionality results of this work. Afterwards, we show that under standard assumptions ensuring incremental input-to-state stability of switched systems (i.e., existence of common incremental Lyapunov functions, or multiple incremental Lyapunov functions with dwell-time), one can construct finite MDPs for the general setting of nonlinear stochastic switched systems. We also propose an approach to construct finite MDPs together with their corresponding stochastic simulation functions for a particular class of nonlinear stochastic

switched systems. We show that for this class of systems, the aforementioned incremental stability property can be readily checked by matrix inequalities. To demonstrate the effectiveness of our proposed results, we first apply our approaches to a road traffic network in a circular cascade ring composed of 200 cells, and construct compositionally a finite MDP of the network. We employ the constructed finite abstractions as substitutes to compositionally synthesize policies keeping the density of the traffic lower than 20 vehicles per cell. We then apply our proposed techniques to a fully interconnected network of 500 nonlinear subsystems (totally 1000 dimensions), and construct their finite MDPs with guaranteed error bounds. We compare our proposed results with those available in the literature.

- **Symbolic abstractions for nonlinear control systems via feedback refinement relation**
  Authors: Wei Ren ; Dimos V. Dimarogonas
  Abstract: This paper studies the construction of symbolic abstractions for nonlinear control systems via feedback refinement relation. Both the delay-free and time-delay cases are addressed. For the delay-free case, to reduce the computational complexity, we propose a new approximation approach for the state and input sets based on a static quantizer, and then a novel symbolic model is constructed such that the original system and the symbolic model satisfy the feedback refinement relation. For the time-delay case, both static and dynamic quantizers are combined to approximate the state and input sets. This leads to a novel dynamic symbolic model for time-delay control systems, and a feedback refinement relation is established between the original system and the symbolic model. Finally, a numerical example is presented to illustrate the obtained results.

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1.3. Nonlinear Analysis: Hybrid Systems

Volume: 36 May 2020

- **Approximate predictability of Pseudo-Metric Systems**
  Authors: Elena De Santis, Maria Domenica Di Benedetto, Gabriella Fiore, Giordano Pola
  Abstract: In this paper, we introduce and characterize the notion of approximate predictability for the general class of pseudo-metric systems, which are a powerful modeling framework to deal with complex heterogeneous systems such as hybrid systems. Approximate predictability corresponds to the possibility of predicting the occurrence of specific states belonging to a particular subset of interest, in advance with respect to their occurrence, on the basis of observations. We establish a relation between approximate predictability of a given pseudo-metric system and approximate predictability of a pseudo-metric system that approximately simulates the given one. This relation allows checking approximate predictability of a system with an infinite number of states, provided that one is able to construct a pseudo-metric system with a finite number of states and inputs, approximating the original one in the sense of approximate simulation. To demonstrate the usefulness of our results, we apply them to the analysis of approximate predictability of Piecewise Affine (PWA) systems, a well studied class of hybrid systems for which, however, to the best of our knowledge, there are no results available in the current literature on predictability. An illustrative example is also included, which demonstrates the applicability of our results.
- **Compositional abstraction of large-scale stochastic systems: A relaxed dissipativity approach**
  Authors: Abolfazl Lavaei, Sadegh Soudjani, Majid Zamani
  Abstract: In this paper, we propose a compositional approach for the construction of finite abstractions (a.k.a. finite Markov decision processes (MDPs)) for networks of discrete-time stochastic control subsystems that are not necessarily stabilizable. The proposed approach leverages the interconnection topology and a notion of finite-step stochastic storage functions, that describes joint dissipativity-type properties of subsystems and their abstractions, and establishes a finite-step stochastic simulation function as a relation between the network and its abstraction. To this end, we first develop a new type of compositionality conditions which is less conservative than the existing ones. In particular, using a relaxation via a finite-step stochastic simulation function, it is possible to construct finite abstractions such that stabilizability of each subsystem is not necessarily required. We then propose an approach to construct finite MDPs together with their corresponding

finite-step storage functions for general discrete-time stochastic control systems satisfying an incremental passivability property. We also construct finite MDPs for a particular class of nonlinear stochastic control systems. To demonstrate the effectiveness of the proposed results, we first apply our approach to an interconnected system composed of 4 subsystems such that 2 of them are not stabilizable. We then consider a road traffic network in a circular cascade ring composed of 50 cells, and construct compositionally a finite MDP of the network. We employ the constructed finite abstractions as substitutes to compositionally synthesize policies keeping the density of the traffic lower than 20 vehicles per cell. Finally, we apply our proposed technique to a fully interconnected network of 500 nonlinear subsystems and construct their finite MDPs with guaranteed error bounds on the probabilistic distance between their output trajectories.

- **On detectability of Boolean control networks**
  Authors: Biao Wang, Jun-e Feng, Haitao Li, Yongyuan Yu
  Abstract: This paper introduces the detectability notions and investigates the detectability properties for Boolean networks (BNs) and Boolean control networks (BCNs). A BN (BCN) possesses the property of detectability if the current state can be determined by limited observed data. According to different situations, three types of detectabilities are defined: strong detectability, detectability and weak detectability. Firstly, using the semi-tensor product of matrices, the BCN is written as an equivalent algebraic expression, which is called the data form. Secondly, some criterion and detection algorithms are provided for checking detectabilities via this novel form. Thirdly, four types of properties: stability, stabilizability, observability and detectability, are compared and analyzed, and then their relationships are clearly described in two diagrams, which provide a new perspective to analyze the characterization of BNs and BCNs. Finally, for better presentation, two practical examples are presented to show the effectiveness of the obtained new results.

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1.4. IEEE/CAA Journal of Automatica Sinica

Volume: 7, Issue: 2, March 2020

- **Post-processing time-aware optimal scheduling of single robotic cluster tools**
  Authors: QingHua Zhu ; Yan Qiao ; NaiQi Wu ; Yan Hou
  Abstract: Integrated circuit chips are produced on silicon wafers. Robotic cluster tools are widely used since they provide a reconfigurable and efficient environment for most wafer fabrication processes. Recent advances in new semiconductor materials bring about new functionality for integrated circuits. After a wafer is processed in a processing chamber, the wafer should be removed from there as fast as possible to guarantee its high-quality integrated circuits. Meanwhile, maximization of the throughput of robotic cluster tools is desired. This work aims to perform post-processing time-aware scheduling for such tools subject to wafer residency time constraints. To do so, closed-form expression algorithms are derived to compute robot waiting time accurately upon the analysis of particular events of robot waiting for single-arm cluster tools. Examples are given to show the application and effectiveness of the proposed algorithms.

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2 Conferences

Contributed by: Xiang Yin (yinxiang@sjtu.edu.cn)

2.1 **2020 International Workshop on Discrete Event Systems**
Rio de Janeiro, Brazil, May 13-15, 2020 (Postponed)
https://wodes2020.eventos.ufrj.br

2.2 **2020 International Conference on Control, Decision and Information Technologies**
Prague, Czech Republic, June 29 - July 02, 2020
https://codit2020.com

2.3 **2020 American Control Conference**
Denver, Colorado, USA, July 1-3, 2020
http://acc2020.a2c2.org

2.4 **2020 IEEE International Conference on Control & Automation**
Sapporo, Hokkaido, Japan, July 6-9, 2020
http://www.ieee-icca.org

2.5 **2020 IFAC World Congress**
Berlin, Germany, July 12-17, 2020
https://www.ifac2020.org

2.6 **2020 IEEE Conference on Automation Science and Engineering**
Hong Kong, China, August 20-24, 2020
https://www.imse.hku.hk/case2020

2.7 **2020 IEEE Conference on Control Technology and Applications**
Montréal, Canada, August 24-26, 2020
https://ccta2020.ieeecss.org

2.8 **2020 IEEE Conference on Decision and Control**
Jeju Island, Republic of Korea, December 8-11, 2020
https://cdc2020.ieeecss.org

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3 International Graduate School on Control

Introduction to Discrete Event Systems

Lecturers: Stéphane Lafortune, Christos Cassandras

Location: Marseille, France, June 8-12, 2020

Message from Lecturers:
Dear Colleagues,

We are pleased to inform you that we will be the main lecturers for a module of 21 hours on "Introduction to Discrete Event Systems", to be offered as part of the European Embedded Control Institute (EECI) International Graduate School on Control in 2020. This course will be held from June 8 to 12, 2020 in Marseilles, France. See: http://www.eeci-igsc.eu/venues/

While the area of discrete event systems started as a sub-discipline in control engineering almost 40 years ago, the study of discrete event systems (DES) remains highly relevant to control engineering problems nowadays, such as in cyber-physical systems, transportation, software engineering, and in the study of privacy and security in engineered systems. In fact, DES form the centerpiece of the event-driven (cyber) component in the hybrid systems that comprise much of today's technology, complementing the time-driven (physical) components.

This course will strike a balance between introducing the students to the key concepts, models, and results of discrete-event control theory for logical and stochastic models, while at the same time emphasizing current research trends in DES theory and applications.

More details about the program can be found at:
https://www.web-events.net//doc/users/395/bib/2019-2020/eeciigsc2020summariesvf31oct.pdf
Students can apply to get financial support. The registration is open at:
http://www.eeci-igsc.eu/registration/
The early registration deadline is March 8. Please register by that date to ensure participation.

Best regards,

Stéphane Lafortune and Christos Cassandras

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4 Books

4.1 **Estimation and Inference in Discrete Event Systems — A Model-Based Approach with Finite Automata**

Author: Christoforos N. Hadjicostis

Description: Estimation and Inference in Discrete Event Systems chooses a popular model for emerging automation systems—finite automata under partial observation—and focuses on a comprehensive study of the key problems of state estimation and event inference. The text includes treatment of current, delayed, and initial state estimation. Related applications for assessing and enforcing resiliency—fault detection and diagnosis—and security—privacy and opacity—properties are discussed, enabling the reader to apply these techniques in a variety of emerging applications, among them automated manufacturing processes, intelligent vehicle/highway systems, and autonomous vehicles.

The book provides a systematic development of recursive algorithms for state estimation and event inference. The author also deals with the verification of pertinent properties such as:
• the ability to determine the exact state of a system, "detectability";
• the ability to ensure that certain classes of faults can be detected/identified, "diagnosability"; and
• the ability to ensure that certain internal state variables of the system remain "hidden" from the outside world regardless of the type of activity that is taking place, "opacity".
This book allows students, researchers and practicing engineers alike to grasp basic aspects of state estimation in discrete event systems, aspects like distributivity and probabilistic inference, quickly and without having to master the entire breadth of models that are available in the literature.

More details: https://www.springer.com/gp/book/9783030308209

4.2 **Path Planning and Control of Cooperative Mobile Robots Using Discrete Event Models**

Authors: Cristian Mahulea, Marius Kloetzer, Ramon Gonzalez
ISBN: 978-1-119-48632-9, January 2020, Wiley-IEEE Press, 240 Pages
https://bit.ly/2MYphKe

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