

Editors

Professor Dr.-Ing. Manfred Thoma
Institut fuer Regelungstechnik, Universität Hannover, Appelstr. 11, 30167 Hannover,
Germany
E-mail: thoma@irt.uni-hannover.de

Professor Dr. Frank Allgöwer
Institute for Systems Theory and Automatic Control, University of Stuttgart,
Pfaffenwaldring 9, 70550 Stuttgart, Germany
E-mail: allgower@ist.uni-stuttgart.de

Professor Dr. Manfred Morari
ETH/ETL I 29, Physikstr. 3, 8092 Zürich, Switzerland
E-mail: morari@aut.ee.ethz.ch

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Carla Seatzu, Manuel Silva,
and Jan H. van Schuppen (Eds.)

Control of Discrete-Event Systems

Automata and Petri Net Perspectives

Editors

Carla Seatzu
Department of Electrical
and Electronic Engineering
University of Cagliari
Cagliari
Italy

Jan H. van Schuppen
Centrum Wiskunde & Informatica
Amsterdam
The Netherlands

Manuel Silva
Department of Computer Science
and Systems Engineering
University of Zaragoza
Zaragoza
Spain

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Preface

Control of discrete-event dynamic systems is the topic of this book. The aim is to provide an introduction to the field, starting at an elementary level and going to close to the current research front. The reader will find concepts, theorems, algorithms, and examples. Particularly addressed to Ph.D. students and junior researchers working on control of discrete-event dynamic systems (DEDS) and, more generally, on control theory, this monograph only presumes a little background of elementary topics of control theory. The chapters are almost all based on lectures of a summer school for Ph.D. students held in June 2011 in Cagliari, Sardinia, Italy.

Three related modeling formalisms of DEDS are covered: *automata*, *Petri nets*, and *systems in dioids*. The first focus of the book is on control of *decentralized* and of *distributed* DEDS, informally speaking composed by the interconnection of two or more subsystems. Most engineering systems are currently of this type. The second focus of the book deals with heavily loaded or populated DEDS, eventually distributed, for which the so called *state explosion* problem becomes particularly acute. Therefore it becomes important to consider ‘coarse views’ obtained through fluidization of the discrete event model. Those fluid or continuous over-approximated views of DEDS lead to special classes of hybrid systems.

Control theory for DEDS is motivated by the ordering of events or actions. Problems of control of DEDS arise in control engineering, computer engineering, and sciences. Areas in which DEDS control problems arise include manufacturing systems, automated guided vehicles, logistics, aerial vehicles, underwater vehicles, communication networks, mobile phones or chemical engineering systems, but also software systems on computers, laptops, and readers. The research into control of DEDS, heavily loaded or not, is thus well motivated by engineering but also theoretically quite deep.

A brief description of the book by parts and by chapters follows. The first part (nine chapters) concerns control of *automata*. After a chapter on modeling of engineering systems by automata (Chapter 1) there follows one with the concepts of automata, decidability, and complexity (Chapter 2). Supervisory control of automata is summarized first with respect to complete observations and subsequently with respect to partial observations (Chapters 3 and 4, respectively). Observers and

diagnosers for automata, in particular distributed observers, are covered in Chapter 5. Supervisory control of distributed DEDS is introduced by three special cases in Chapter 6. That chapter is followed by one on distributed control with communication (Chapter 7) and one on coordination control (Chapter 8). Finally, Chapter 9 deals with timed automata.

The second part of the book addresses the control of *Petri nets*. It includes eleven chapters and can be seen as structured into two main parts: the first one, including eight chapters, dealing with discrete Petri nets; the second part, including three chapters, dealing with fluid relaxations. The former eight chapters can be divided into two blocks: the first six are devoted to *untimed* models, while the remaining two are related to *timed* models. In particular, Chapters 10 and 11 introduce basic concepts and structural analysis techniques. Chapters 12 and 13 are related to control. After considering supervisory control with languages specifications (Chapter 12), structural methods tailored for resource allocation problems are studied in the following one. Chapters 14 and 15 deal with diagnosis problems, the second one using net unfolding. Petri nets enriched with different temporal metrics and semantics are introduced in Chapter 16 and used in Chapter 17 for fault diagnosis, now on-line over timed models.

Chapters 18, 19 and 20 are based on fluid relaxation of DEDS. In particular, the fluid or continuous views of Petri nets are introduced in Chapter 18 on both untimed and timed models, dealing even with improvements of the relaxation with respect to the underlying discrete case. Finally, Chapters 19 and 20 are devoted to observability and diagnosis, and controllability and control, respectively.

The third and last part deals with the modeling and control of DEDS in dioids. A *dioid* is a mathematical structure with two operations, usually referred to as addition and multiplication, where the former, unlike in standard algebra, is idempotent. The most well known example for a dioid is the so-called max-plus algebra. Restricted classes of timed DEDS, in particular timed event graphs, become linear in a suitable dioid framework. For such systems, control does not involve logical decisions, only choices regarding the timing of events. They frequently appear in the context of manufacturing systems, but also arise in other engineering areas. Chapter 21 shows how to model timed event graphs in dioid frameworks and provides a detailed example from the area of high-throughput screening. Chapter 22 summarizes and illustrates control synthesis for systems in dioids.

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Carla Seatzu
Manuel Silva
Jan H. van Schuppen
Editors

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List of Contributors

Béatrice Bérard

LIP6, Université Pierre & Marie Curie and CNRS UMR 7606

BC 169, 4 place Jussieu, 75005 Paris, France

e-mail: Beatrice.Berard@lip6.fr

René K. Boel

EESA SYSTeMS Research Group, Ghent University

Technologiepark 914, Zwijnaarde 9052, Belgium

e-mail: rene.boel@ugent.be

Olivier Boutin

Calle Santiago 2 – 4°C, 11005 Cadiz, Spain

e-mail: olivier.research@gmail.com

Thomas Brunsch

Fachgebiet Regelungssysteme, TU Berlin, Sekr. EN11, Einsteinufer 17, 10587 Berlin, Germany.

Also: Laboratoire d'Ingénierie des Systèmes Automatisés, Université d'Angers, 62

Avenue Notre-Dame du Lac, 49000 Angers, France

e-mail: brunsch@control.tu-berlin.de

Maria Paola Cabasino

Department of Electrical and Electronic Engineering, University of Cagliari

Piazza D'Armi, 09123 Cagliari, Italy

e-mail: cabasino@diee.unica.it

José-Manuel Colom

Instituto de Investigación en Ingeniería de Aragón (I3A), University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: jm@unizar.es

Bertrand Cottenceau

LUNAM, University of Angers, LISA, ISTIA

62 Av. Notre-Dame du Lac, 49000 Angers, France

e-mail: bertrand.cottenceau@univ-angers.fr

Angela Di Febbraro

Department of Mechanical Engineering, Energetics, Production, Transportation
and Mathematical Models, University of Genova

Via Montallegro 1, 16145 Genova, Italy

e-mail: angela.difebbraro@unige.it

Eric Fabre

INRIA Rennes Bretagne Atlantique

Campus de Beaulieu, 35042 Rennes Cedex, France

e-mail: eric.fabre@inria.fr

Alessandro Giua

Department of Electrical and Electronic Engineering, University of Cagliari

Piazza D'Armi, 09123 Cagliari, Italy

e-mail: giua@diee.unica.it

Stefan Haar

INRIA/LSV, CNRS & ENS de Cachan

61, avenue du Président Wilson, 94235 CACHAN Cedex, France

e-mail: Stefan.Haar@inria.fr

Laurent Hardouin

Laboratoire d'Ingénierie des Systèmes Automatisés, Université d'Angers

62 Avenue Notre-Dame du Lac, 49000 Angers, France

e-mail: laurent.hardouin@istia.univ-angers.fr

George Jiroveanu

Transelectrica SA - Romanian National Power Grid Company

Brești 5, 200581, Craiova, Romania

e-mail: george.jiroveanu@transelectrica.ro

Jorge Júlvez

Instituto de Investigación en Ingeniería de Aragón (I3A), University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: julvez@unizar.es

Juan-Pablo López-Grao

Department of Computer Science and Systems Engineering, University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: jpablo@unizar.es

Jan Komenda

Institute of Mathematics, Academy of Sciences of the Czech Republic

Žitkova 22, 616 62 Brno, Czech Republic

e-mail: komenda@math.cas.cz

Cristian Mahulea

Instituto de Investigación en Ingeniería de Aragón (I3A), University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: cmahulea@unizar.es

Tomáš Masopust

Institute of Mathematics, Academy of Sciences of the Czech Republic

Žitkova 22, 616 62 Brno, Czech Republic

e-mail: masopust@math.cas.cz

Jörg Raisch

Fachgebiet Regelungssysteme, TU Berlin, Sekr. EN11, Einsteinufer 17, 10587

Berlin, Germany.

Also: Fachgruppe System-und Regelungstheorie, Max-Planck-Institut für Dynamik
komplexer technischer Systeme, Magdeburg

e-mail: raisch@control.tu-berlin.de

S. Laurie Ricker

Department of Mathematics & Computer Science, Mount Allison University

67 York St. Sackville, NB Canada E4L 1E6

e-mail: lricker@mta.ca

Carla Seatzu

Department of Electrical and Electronic Engineering, University of Cagliari

Piazza D'Armi, 09123 Cagliari, Italy

e-mail: seatzu@diee.unica.it

Manuel Silva

Instituto de Investigación en Ingeniería de Aragón (I3A), University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: silva@unizar.es

Jan H. van Schuppen

CWI, P.O. Box 94079, 1090 GB Amsterdam, Netherlands

e-mail: J.H.van.Schuppen@cwi.nl

C. Renato Vázquez

Instituto de Investigación en Ingeniería de Aragón (I3A), University of Zaragoza

María de Luna 1, E-50018, Zaragoza, Spain

e-mail: cvazquez@unizar.es

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Acronyms

AGV	Automated Guided Vehicle
BIC	Bounded Input Controllable
BRG	Basis Reachability Graph
CDFG	Controlled Deterministic Finite Generator
CPN	Continuous Petri Net
CS	Controllability Space
CSS	Cooperating Sequential System
CTMC	Continuous Time Markov Chain
DcontPN	Distributed Continuous Petri Net
DEDS	Discrete Event Dynamic Systems
DES	Discrete Event System
DFA	Deterministic Finite Automaton
DFG	Deterministic Finite Generator
DFMeA	Deterministic Finite Mealy Automaton
DFMoA	Deterministic Finite Moore Automaton
DTPN	Deterministic Timed Petri Net
DuSCOP	Dual Supervisory Control and Observation
ELCP	Extended Linear Complementarity Problem
EQ	Equal Conflict
FMS	Flexible Manufacturing System
FSM	Finite State Machine
FSS	Finite Server Semantics
GTS	Graph Transformation System
HC	Hamiltonian Circuit
HTS	High-Throughput Screening
ILP	Integer Linear Programming
ILPP	Integer Linear Programming Problem
ISS	Infinite Server Semantics
JF	Join Free
LPP	Linear Programming Problem
L-S ³ PR	Linear System of Simple Sequential Processes with Resources

MPC	Model Predictive Control
MPN	Markovian Petri Net
MRI	Magnetic Resonance Imaging
MTS	Mono-T-Semiflow
MVN	Modified Verifier Net
NDFG	Nondeterministic Finite Generator
NDFMeA	Nondeterministic Finite Mealy Automaton
NDFMoA	Nondeterministic Finite Moore Automaton
NFA	Nondeterministic Finite Automaton
NS-RAS	Non-Sequential Resource Allocation System
OCC	Output Control Consistent
PC ² R	Processes Competing for Conservative Resources
PDA	PushDown Automaton
PLC	Programmable Logic Controller
PN	Petri Net
QPP	Quadratic Programming Problem
RAP	Resource Allocation Problem
RAS	Resource Allocation System
SAT	Satisfiability
SB	Structurally Bounded
SCTdMG	Strongly Connected Timed Marked Graph
SL	Structurally Live
SPQR	System of Processes Quarrelling over Resources
S ³ PR	System of Simple Sequential Processes with Resources
S-RAS	Sequential Resource Allocation System
STdPN	Stochastic Timed Petri Net
TCPN	Timed Continuous Petri Net
TdPN	Timed Petri Net
TEG	Timed Event Graph
TM	Turing Machines
TMG	Timed Marked Graph
TPN	Time Petri Net
VN	Verifier Net
WP	Weighted Path