



POLITECNICO DI TORINO
Repository ISTITUZIONALE

Model Order Reduction. Volume 3: Applications

Original

Model Order Reduction. Volume 3: Applications / Peter, Benner; Grivet Talocia, Stefano; Alfio, Quarteroni; Gianluigi, Rozza; Wil, Schilders; Luís Miguel Silveira,. - ELETTRONICO. - 3(2021), pp. 1-474.

Availability:

This version is available at: 11583/2859098 since: 2021-01-26T13:52:43Z

Publisher:

De Gruyter

Published

DOI:10.1515/9783110499001

Terms of use:

openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni, Gianluigi Rozza, Wil Schilders,
Luís Miguel Silveira (Eds.)

Model Order Reduction

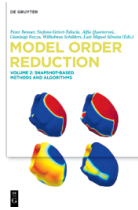
Also of Interest



Model Order Reduction. Volume 1: System- and Data-Driven Methods and Algorithms

Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni, Gianluigi Rozza, Wil Schilders, Luís Miguel Silveira (Eds.), 2020

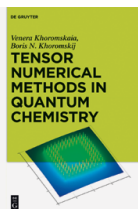
ISBN 978-3-11-050043-1, e-ISBN (PDF) 978-3-11-049896-7,
e-ISBN (EPUB) 978-3-11-049771-7



Model Order Reduction. Volume 2: Snapshot-Based Methods and Algorithms

Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni, Gianluigi Rozza, Wil Schilders, Luís Miguel Silveira (Eds.), 2020

ISBN 978-3-11-067140-7, e-ISBN (PDF) 978-3-11-067149-0,
e-ISBN (EPUB) 978-3-11-067150-6



Tensor Numerical Methods in Quantum Chemistry

Venera Khoromskaia, Boris N. Khoromskij, 2018

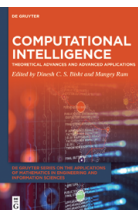
ISBN 978-3-11-037015-7, e-ISBN (PDF) 978-3-11-036583-2,
e-ISBN (EPUB) 978-3-11-039137-4



Maxwell's Equations. Analysis and Numerics

Ulrich Langer, Dirk Pauly, Sergey Repin (Eds.), 2019

ISBN 978-3-11-054264-6, e-ISBN (PDF) 978-3-11-054361-2,
e-ISBN (EPUB) 978-3-11-054269-1



Computational Intelligence. Theoretical Advances and Advanced Applications

Dinesh C.S. Bisht, Mangey Ram (Eds.), 2020

ISBN 978-3-11-065524-7, e-ISBN (PDF) 978-3-11-067135-3,
e-ISBN (EPUB) 978-3-11-066833-9

Model Order Reduction



Volume 3: Applications

Edited by

Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni,
Gianluigi Rozza, Wil Schilders, and Luís Miguel Silveira

DE GRUYTER

Editors

Prof. Dr. Peter Benner
Max Planck Institute for Dynamics of Complex
Technical Systems
Sandtorstr. 1
39106 Magdeburg
Germany
benner@mpi-magdeburg.mpg.de

Prof. Dr. Gianluigi Rozza
Scuola Internazionale Superiore di Studi
Avanzati - SISSA
Via Bonomea 265
34136 Trieste
Italy
gianluigi.rozza@sissa.it

Prof. Dr. Stefano Grivet-Talocia
Politecnico di Torino
Dipartimento di Elettronica
Corso Duca degli Abruzzi 24
10129 Turin
Italy
stefano.grivet@polito.it

Prof. Dr. Wil Schilders
Technische Universiteit Eindhoven
Faculteit Mathematik
Postbus 513
5600 MB Eindhoven
The Netherlands
w.h.a.schilders@tue.nl

Prof. Alfio Quarteroni
Ecole Polytechnique Fédérale de Lausanne
(EPFL) and Politecnico di Milano
Dipartimento di Matematica
Piazza Leonardo da Vinci 32
20133 Milan
Italy
alfio.quarteroni@polimi.it

Prof. Dr. Luís Miguel Silveira
INESC ID Lisboa
IST Técnico Lisboa
Universidade de Lisboa
Rua Alves Redol 9
1000-029 Lisbon
Portugal
lms@inesc-id.pt

ISBN 978-3-11-050044-8
e-ISBN (PDF) 978-3-11-049900-1
e-ISBN (EPUB) 978-3-11-049775-5
DOI <https://doi.org/10.1515/9783110499001>



This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. For details go to <http://creativecommons.org/licenses/by-nc-nd/4.0/>.

Library of Congress Control Number: 2020944453

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.dnb.de>.

© 2021 with the authors, editing © 2021 Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni, Gianluigi Rozza, Wil Schilders, Luís Miguel Silveira, published by Walter de Gruyter GmbH, Berlin/Boston. The book is published open access at www.degruyter.com.
Cover image: Andrea Manzoni, MOX, Department of Mathematics, Politecnico di Milano
Typesetting: VTeX UAB, Lithuania
Printing and binding: CPI books GmbH, Leck

www.degruyter.com

Preface to the third volume of *Model Order Reduction*

The third volume of the *Model Order Reduction* handbook project offers several remarkable instances of applications of model order reduction (MOR) approaches to the solution of problems arising from the most diverse areas of application. Through these examples, we would like to provide the reader with an overview of the maturity of this emerging field and its readiness to address challenging problems of multifaceted complexity.

We start with several chapter contributions to classical fields of engineering.

The first one, by J. Eason and L. Biegler, is on model reduction in the optimization of a variety of heterogeneous chemical processes. In particular, two case studies are presented on CO₂ capture using nonlinear programming and NLP filter models.

The second chapter, by B. Lohmann et al., is on MOR in mechanical engineering. Four applications are discussed, concerning the reduction of a thermo-mechanical machining tool of a car body and driver's seat, of an elastic crankshaft, and a leaf spring model.

The third chapter, by E. Deckers et al., presents several case studies of MOR for acoustics and vibrations in mechanical applications. Two different viewpoints are developed: the application of MOR from a purely mathematical perspective and a consideration of expected properties of MOR based on physical arguments from the field of mechanics.

Two chapters devoted to microelectronics and electromagnetism, a very classical and successful arena for MOR methods, follow. The first of those, by B. Nouri et al., pursues a twofold goal: to describe the context in which the need for MOR arose in microelectronics, and to present an overview of their applications to address the issues of high-speed interconnects in microelectronics at various levels of the design hierarchy.

The next chapter, by D. Ioan et al., proposes a computer-aided consistent and accurate description of the behavior of electromagnetic devices at various speeds or frequencies, and describes procedures to generate compact electrical circuits featuring an approximately equivalent behavior.

The chapter by M. Yano is on model reduction in computational aerodynamics. The focus is on techniques that are designed to address nonlinearity, limited stability, limited regularity, and a wide range of scales that have been demonstrated successful for multidimensional large-scale aerodynamic flows.

The next two chapters address a somehow less conventional field of applications, that of life sciences. The chapter by B. Karasözen is on MOR in neurosciences, more specifically on the exploitation of models of large-scale neuronal networks to provide an accurate and fast prediction of patterns and their propagation in different areas of the brain.

The following chapter, by N. Dal Santo et al., introduces MOR methods to face some of the most challenging processes of the cardiovascular system. Two specific

applications are targeted: the simulation of blood flow past a carotid bifurcation and the computation of activation maps in cardiac electrophysiology.

The last five chapters address somewhat more methodological issues arising in various scientific, engineering, societal, and economics applications.

The chapter by J.-C. Loiseau aims at bypassing some difficulties of classical proper orthogonal decomposition approaches to the solution of fluid dynamics problems by using feature-based manifold modeling in which the low-dimensional attractor and nonlinear dynamics are characterized from experimental data: time-resolved sensor data and optional nontime-resolved particle image velocimetry snapshots.

In the chapter by R. Pulch, MOR is used in the framework of uncertainty quantification. Established methods like polynomial chaos, stochastic Galerkin, stochastic collocation, and quadrature sampling are reviewed for dynamical systems consisting of ordinary differential equations or differential algebraic equations. Demonstration of applicability is provided on test examples.

The chapter by X. Cheng et al. addresses MOR methods for networks that describe a wide class of complex systems composed of many interacting subsystems. First, clustering-based approaches are reviewed, with the aim of reducing the network scale. Then, methods based on generalized balanced truncation that reduce interconnection structures of a network and the dynamics of each subsystem are discussed.

The chapter by D. Hartmann et al. presents use cases where MOR is a key enabler for the realization of digital services and the reduction of simulation times and outlines the potential of MOR in the context of realizing the digital twin vision.

The last chapter, by B. Haasdonk, addresses the issue of software. In the first part, as neither full simulation models nor MOR algorithms are to be reprogrammed, but ideally are reused from existing implementations, the interplay of such packages is discussed. Then an overview of the most popular MOR software libraries is provided.

We are confident that the vast set of applications discussed here, combined with the broad variety of numerical techniques and software libraries available, will motivate the reader to embrace MOR approaches to successfully address complex applications arising in computational science and engineering.

Peter Benner, Stefano Grivet-Talocia, Alfio Quarteroni, Gianluigi Rozza,
Wil Schilders, Luís Miguel Silveira

Magdeburg, Germany
Torino, Milano, Trieste, Italy
Eindhoven, The Netherlands
Lisbon, Portugal

June 2020

Contents

Preface to the third volume of *Model Order Reduction* — V

John P. Eason and Lorenz T. Biegler

1 Model reduction in chemical process optimization — 1

B. Lohmann, T. Bechtold, P. Eberhard, J. Fehr, D. J. Rixen, M. Cruz Varona, C. Lerch, C. D. Yuan, E. B. Rudnyi, B. Fröhlich, P. Holzwarth, D. Grunert, C. H. Meyer, and J. B. Rutzmoser

2 Model order reduction in mechanical engineering — 33

Elke Deckers, Wim Desmet, Karl Meerbergen, and Frank Naets

3 Case studies of model order reduction for acoustics and vibrations — 75

Behzad Nouri, Emad Gad, Michel Nakhla, and Ram Achar

4 Model order reduction in microelectronics — 111

Daniel Ioan, Gabriela Ciuprina, and Wilhelmus H. A. Schilders

5 Complexity reduction of electromagnetic systems — 145

Masayuki Yano

6 Model reduction in computational aerodynamics — 201

Bülent Karasözen

7 Model order reduction in neuroscience — 237

Niccolò Dal Santo, Andrea Manzoni, Stefano Pagani, and Alfio Quarteroni

8 Reduced-order modeling for applications to the cardiovascular system — 251

Jean-Christophe Loiseau, Steven L. Brunton, and Bernd R. Noack

9 From the POD-Galerkin method to sparse manifold models — 279

Roland Pulch

10 Model order reduction in uncertainty quantification — 321

Xiaodong Cheng, Jacquélien M. A. Scherpen, and Harry L. Trentelman

11 Reduced-order modeling of large-scale network systems — 345

Dirk Hartmann, Matthias Herz, Meinhard Paffrath, Joost Rommes, Tommaso Tamarozzi, Herman Van der Auweraer, and Utz Wever

VIII — Contents

12 Model order reduction and digital twins — 379

Bernard Haasdonk

13 MOR software — 431

Index — 461