Preface

Special Issue on "Order Reduction of Large-Scale Systems"

Order reduction is a common theme within the simulation, control, and optimization of complex physical processes. The mathematical models used in these computations often result in large-scale systems. For example, such systems arise due to accuracy requirements on the spatial discretization of fluids or structures, in the context of lumped-circuit approximations of distributed electronic circuit elements, such as the interconnect or package of VLSI chips, or in simulations of microelectromechanical systems (MEMS), which have both electrical and mechanical components. Order (or model, dimension) reduction is often crucial to accelerate the simulation of such large-scale systems. In fact, the systems may be so large that simulations or even storage of the data describing such systems are prohibitive without first replacing the original large-scale systems by suitably accurate reduced-order models of much smaller dimensions. This is even more evident if not only the simulation of the physical process is required, but control or optimization is the objective of the computation.

While order reduction has long been a central theme in control theory, most of the reduction methods in that area are designed for small or moderate-size systems and cannot be directly employed in the large-scale case. In recent years, the need for reduction techniques for large-scale systems has triggered a revival of research activities in model order reduction. Many powerful reduction techniques have been devised, in particular for linear time-invariant systems. Despite this progress, there are still many open problems. For example, order reduction of large-scale nonlinear systems is still in its infancy. Also, many reduction methods that were devised in recent years are described in terms that are discipline-oriented or even application-specific, even though they share many common features and origins. The goal of this special issue was to expose the similarities of these approaches, to identify common features, to address application-specific challenges, and to generally describe recent advances in reduction methods for large-scale linear and nonlinear systems.

The papers in this special issue can be grouped in five categories.

The first group of papers describes reduction techniques for large-scale linear systems and comprises:

- Herng-Jer Lee, Chia-Chi Chu, and Wu-Shiung Feng, *A new rational Arnoldi method for model-order reductions of linear time-invariant systems*;
- Tatjana Stykel, *Balanced truncation model reduction for semidiscretized Stokes equation*;
- Athanasios C. Antoulas and Serkan Gugercin, *Model reduction of large-scale systems by least squares*;
- Thilo Penzl, *Algorithms for model reduction of large dynamical systems*;
- K. Jbilou and A.J. Riquet, *Projection methods for large Lyapunov matrix equations*;
- K. Gallivan, X. Rao, P. Van Dooren, *Singular Riccati equations stabilizing large scale systems.*

The methods covered in this group include Krylov-subspace techniques, balanced truncation, and least-squares approaches. Balanced truncation requires the solution of large-scale matrix Lyapunov equations, and the paper by Jbilou and Riquet describes techniques for this subproblem. Gallivan et al. propose an algorithm for stabilizing large-scale discrete-time systems exploiting the system structure in order to reduce the complexity of the problem. The paper by the late Thilo Penzl is a proof-read and edited reprint of the preprint [5] which was completed shortly before Thilo Penzl's sudden death in December 1999. This preprint triggered much of the research in recent years on algorithms for applying balanced truncation to large-scale, sparse systems. The editors of this special issue felt that the impact of Penzl's work should be emphasized by publication in the special issue on order reduction.

The second group of papers focuses on Krylov-subspace methods and balanced truncation for second-order systems, i.e., systems where the dynamics are driven by second-order ordinary differential equations. The following papers fall into this category:

- Younés Chahlaoui, Damien Lemonnier, Antoine Vandendorpe, and Paul Van Dooren, *Second order balanced truncation*;
- Boris Lohmann and Behnam Salimbahrami, *Order reduction of large-scale second order systems using Krylov subspace methods.*

The third group of papers describes approaches for nonlinear and special classes of nonlinear systems:

- Zhaojun Bai and Daniel Skoogh, *A projection method for model reduction of bilinear dynamical systems*;
- Michal Rewienski and Jacob White, *Model order reduction for nonlinear dynamical systems based on trajectory piecewise-linear approximations.*

The methods covered in this group include reduction of bilinear systems and reduction of general nonlinear systems based on trajectory piecewise-linear approximations.

The fourth group of papers discusses reduction techniques for specific applications. Papers in this group are

- Jing-Rebecca Li, *Low order approximation of the three dimensional nonreflecting boundary kernel*;
- Jan Lienemann, Evgenii B. Rudnyi, and Jan G. Korvink, *MST MEMS compact modeling meets model order reduction: requirements and benchmarks*;
- T. Wittig, R. Schuhmann, T. Weiland, *Model order reduction for large systems in computational electromagnetics.*

Here, the paper by Lienemann et al. also provides some benchmark examples for testing order reduction methods for linear and nonlinear systems. These have become part of the Oberwolfach Benchmark Collection, a test set for model reduction algorithms described in [3] and maintained at `http://www.imtek.de/simulation/benchmark`.

The papers in the last group are concerned with the use of reduced-order models in optimal control problems. Papers qualifying for this group are

- Kazufumi Ito and Karl Kunisch, *Reduced order control based on approximate inertial manifolds*;
- Friedemann Leibfritz and Stefan Volkwein, *Reduced order output feedback control design for PDE systems using proper orthogonal decomposition and nonlinear semidefinite programming.*

We hope that the papers in this special issue will have impact on the application of order reduction techniques in engineering and computational science as well as on future research in model and order reduction. Together with the recent books [1,3] and surveys [2,4] on this subject, this special issue should also give a good survey on current trends and state-of-the-art in the field of model reduction.

References

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