Invited Mini-symposium Proposal for the *European Conference on Numerical Mathematics* ENUMATH 2007 University of Graz, September 10–14, 2007:

Model Reduction

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The following talks are planned within this mini-symposium:

Part I: Model Reduction with Structure Preservation

1. **Dan Sorensen** (Rice University, USA):

   Passivity Preserving Model Reduction

   Abstract: Preservation of passivity is an important aspect of model order reduction. This is particularly important in circuit simulation applications. This talk will present a methodology for passivity preserving model reduction based upon approximate computation of a basis for a selected invariant subspace of a block structured skew-symmetric/symmetric matrix pencil. This pencil is constructed so that its eigenvalues are the spectral zeros of the transfer function of a related linear time invariant system. It is shown how to construct low rank approximate solutions to Algebraic Riccati Equations (ARE) , in particular to the maximal and minimal symmetric solutions.

   Approximate passive balancing is obtained via approximate low rank factored form solutions of ARE that are minimal for reachability and observability Riccati equations respectively. Balanced reduction is derived from the minimal passive low rank factors. This leads to approximation results that guarantee stability, passivity and balancing for every truncation obtained from the balanced Riccati equations.

2. **David Bindel** (New York University, USA):

   Structure-Preserving Model Reduction for Resonant MEMS
   Abstract: In the design of resonant micro-electro-mechanical systems (MEMS), controlling the amount of damping is critical. These simulations lead to non-Hermitian problems which depend nonlinearly on a frequency parameter. In this talk, we discuss model reduction methods which use two types of structure present in the full discrete model: algebraic structure, such as complex symmetry of the system matrices, that is inherited from the underlying PDEs; and geometric structure, such as the presence of beam-like or plate-like components. We illustrate our methods with models of anchor loss and thermoelastic damping in a variety of resonant microstructures.

3. **Wil Schilders** (NXP Semiconductors, NL):

   MOR for coupled simulations of RF systems
   Abstract: In this presentation, we will address the problem of simulating complete RF blocks. As it is not possible to simulate such blocks as one entity, a divide and conquer approach needs to be used. A complicating issue is the fact that a combination of circuit, device and electromagnetic simulations is needed to adequately address the behaviour of such systems. After having simulated the different parts of the RF block, model order reduction techniques are used to reduce the size of the systems to be coupled. The coupling of the blocks provides an additional problem, as straightforward coupling may lead to loss of passivity and other important properties. Several methods have been suggested. These will be discussed, as well as some recent new developments by our research group.

4. **Serkan Gugercin (speaker) and Chris Beattie** (Virginia Tech., USA):

   Structured perturbation theory for inexact Krylov projection methods in model reduction
   Abstract: In this talk, we introduce the use of inexact solves in a Krylov-based model reduction setting and present the resulting structured perturbation effects on the underlying model reduction problem. For a selection of interpolation points that satisfy first-order necessary H_2- optimality conditions, a primitive basis remains remarkably well-conditioned and errors due to inexact solves do not tend to degrade the reduced order models. Conversely, for poorly selected interpolation points, errors can be greatly magnified through the model reduction process.

   When inexact solves are performed within a Petrov-Galerkin framework, the resulting reduced order models are backward stable with respect to the approximating transfer function. As a consequence, Krylov-based model reduction with well chosen interpolation points is robust with respect to the structured perturbations due to inexact solves. General bounds on the H_2 system error associated with an inexact reduced order model are introduced that provide a new tool to understand the structured backward error and stopping criteria.

Part II: Model Reduction for PDEs

1. **Peter Benner** (TU Chemnitz, Germany):

   Balancing-related model reduction for parabolic control systems
   Abstract: We will discuss model reduction techniques for (optimal) control of dynamical processes described by parabolic partial differential equations from a system-theoretic point of view. The methods considered here are based on spatial semi-discretization of the PDE followed by balanced truncation techniques applied to the resulting large-scale system of ordinary differential equations. Several choices of the system Gramians that are used for balancing will be presented. We will discuss open-loop and closed-loop techniques that allow to preserve system properties important for controller design. Furthermore we will discuss an error estimate based on a combination of FEM and model reduction error bounds. We will also discuss how the state of the full-order system can be recovered from the reduced-order model. Several numerical examples will be used to demonstrate the proposed model reduction techniques.

2. **Stefan Volkwein** (University of Graz, Austria):

   POD Model Reduction for Parameter Estimation in Elliptic PDEs
   Abstract: Proper orthogonal decomposition (POD) is a powerful technique for model reduction of linear and nonlinear systems. It is based on a Galerkin type discretization with basis elements created from the system itself. In this work POD is applied to estimate parameters in elliptic partial differential equations (PDEs). The parameter estimation is formulated in terms of an optimal control problem that is solved by an augmented Lagrangian method combined with a sequential quadratic programming (SQP) algorithm. Numerical examples illustrate the efficiency of the proposed approach.
   (This is joint work with Martin Kahlbacher (Institute for Mathematics and Scientific Computing, University of Graz, Heinrichstrasse 36, 8010 Graz, Austria).)

3. **Ekkehard W. Sachs** (Virginia Tech, USA and Universitaet Trier, Germany):

   Applications of Reduced Order Models in Finance
   Abstract: Pricing of derivatives can be carried out either by a solution formula in several instances or in the more general case by solving a system of stochastic ordinary differential equations numerically or by solving a partial differential equation. If one considers model calibration, it is necessary to solve these many times in the course of the optimization. In this talk, we explore the possibility to use

reduced order models for the partial differential equation in particular and discuss the feasibility of this approach.

4. **Heinrich Voß** (TU Hamburg-Harburg, Germany):

Reducing a Rational Eigenproblemn in Fluid-Structure Interaction by AMLS

Abstract: Over the last few years, a new method for huge eigenvalue problems, known as *Automated Multi–Level Substructuring (AMLS)*, has been developed by Bennighof and co-authors, and has been applied to frequency response analysis of complex structures. Here the large finite element model is recursively divided into very many substructures on several levels based on the sparsity structure of the system matrices. Assuming that the interior degrees of freedom of substructures depend quasistatically on the interface degrees of freedom, and modeling the deviation from quasistatic dependence in terms of a small number of selected substructure eigenmodes, the size of the finite element model is reduced substantially yet yielding satisfactory accuracy over a wide frequency range of interest. Recent studies in vibro-acoustic analysis of passenger car bodies where huge FE models with more than six million degrees of freedom appear and several hundreds of eigenfrequencies and eigenmodes are needed have shown that AMLS is considerably faster than Lanczos type approaches for this sort of problems.