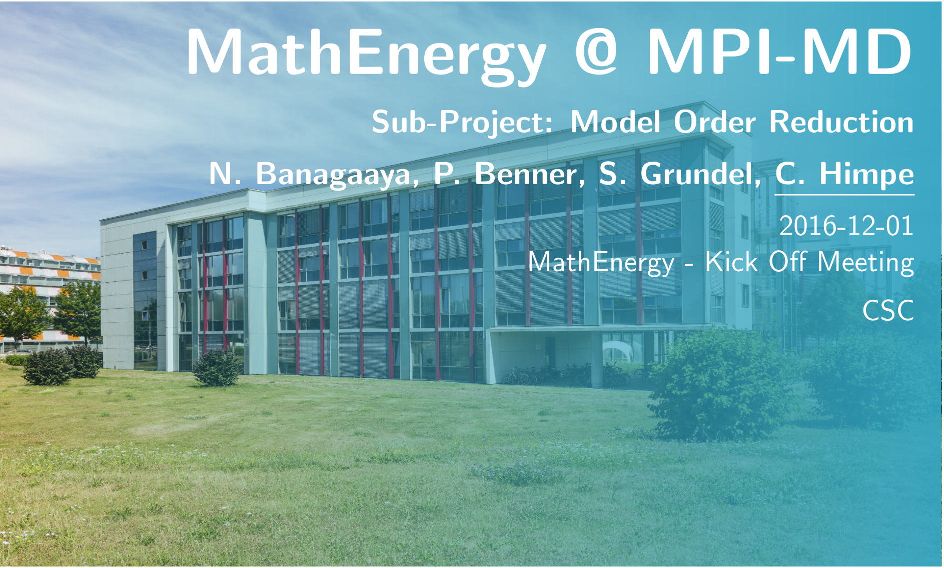
MAX PLANCK INSTITUTE
FOR DYNAMICS OF COMPLEX
TECHNICAL SYSTEMS
MAGDEBURG

CSC

COMPUTATIONAL METHODS IN
SYSTEMS AND CONTROL THEORY



MathEnergy @ MPI-MD

Sub-Project: Model Order Reduction

N. Banagaaya, P. Benner, S. Grundel, C. Himpe

2016-12-01

MathEnergy - Kick Off Meeting

CSC

Outline

Dedicated to the engineering sciences

Bridging the gap between basic research and industrial application

Research Focus
Analysis, design and control of complex processes, with particular focus on applications in **Chemical Engineering, Biotechnology, Systems Theory, Systems Biology and Mathematics**

Member of the **Max Planck Society for the Advancement of Sciences**
non-profit organization with 83 institutes
Total Staff: 22 197
Scientists: 13 276
Budget: 1.8 billion Euros in 2016

Founded in 1996
started work in Magdeburg in 1998

Founding director:
Prof. Dr.-Ing. Em. Ernst Dieter Gilles

Managing director (2015-2016):
Prof. Dr.-Ing. Andreas Seidel-Morgenstern

Staff: about 240 from 32 countries
Scientists: almost 140
(Postdocs and Ph.D. students)

Research groups:
6 research groups + 3 Junior research groups

International Max Planck Research School:
founded in October 2007, around 50 Ph.D students

www.mpi-magdeburg.mpg.de

Project Members

- Prof. Dr. Peter Benner[1] (benner@mpi-magdeburg.mpg.de)
  - Director at MPI Magdeburg
  - Leader of the “Computational Methods in Systems and Control Theory” group
- Dr. Sara Grundel[2] (grundel@mpi-magdeburg.mpg.de)
  - Leader of “Simulation of Energy Systems” team
  - Research Focus: Simulation of large-scale network systems
- Dr. Nicodemus Banagaaya (banagaaya@mpi-magdeburg.mpg.de)
  - Postdoctoral researcher in the “Model Order Reduction” team
  - Research Focus: Model reduction for differential algebraic equations
- Dipl. Math. Christian Himpe (himpe@mpi-magdeburg.mpg.de)
  - Postdoctoral researcher in the “Simulation of Energy Systems” team
  - Research Focus: Model reduction for nonlinear network systems

[1] Principal Investigator
[2] Project Lead

Recent and Current Work

- Book Chapter:
  S. Grundel, L. Jansen, N. Hornung, T. Clees, C. Tischendorf and P. Benner. **Model Order Reduction of Differential Algebraic Equations Arising from the Simulation of Gas Transport Networks**. Progress in Differential-Algebraic Equations, pages: 183–205, 2014. DOI: 10.1007/978-3-662-44926-4_9

- Book Chapter:
  S. Grundel, N. Hornung and S. Roggendorf. **Numerical Aspects of Model Order Reduction for Gas Transportation Networks**. Simulation-Driven Modeling and Optimization, pages: 1–28, 2016. DOI: 10.1007/978-3-319-27517-8_1

- Poster:
  P. Benner, S. Grundel and C. Himpe. **Model Reduction for Gas Networks**. Mathematics of Gas Transports, 2016.
  URL: http://himpe.science/poster/himpe16-trr154.pdf

- Research Software:
  C. Himpe. morgen - **M**odel **O**rder **R**eduction for **G**as and **E**nergy **N**etworks (Under Development), 2016.

Related Activities

- CDS / Altmark-Energie:
  - Gas flow modelling, power-to-gas, bio-gas, connection to power networks;
  - cooperation with Avacon AG [tentatively]
  - Postdoctoral researcher: Dr. Yue Qiu
- Integration of Max Planck Fellow group "Data-Driven System Reduction and Identification"
  - Expertise in data-driven model reduction and
  - model reduction for switched systems
  - Postdoctoral researcher: Ion Victor Gosea [tentatively]
- Support by basic research:
  - on hierarchical system reduction
  - Postdoctoral researcher: Igor Pontes-Duff

Common Acronyms

MOR	**M**odel **O**rder **R**eduction
nMOR	**N**onlinear **M**odel **O**rder **R**eduction
pMOR	**P**arametric **M**odel **O**rder **R**eduction
FOM	**F**ull **O**rder **M**odel
ROM	**R**educed **O**rder **M**odel
POD	**P**roper **O**rthogonal **D**ecomposition
DAE	**D**ifferential **A**lgebraic **E**quation
QoI	**Q**uantities **o**f **I**nterest

WP2 Model Order Reduction

WP 2.1 **Nonlinear Model Reduction Methods**

- Appliction of established methods to gas network models
- Extension to realistic gas networks
- Adaptation for power networks
- Data-driven model order reduction

WP 2.2 **Data-driven Parameteric Model Order Reduction**

- Extension of data-driven methods to parametric model reduction
- Uncertainty quantification for data-driven methods

WP 2.3 **Reduction of Hierarchical Systems**

- Enhancement of existing methods
- Verification and validation

WP 2.4 **Optimal Combination and Packaging**

- Packaging
- Demonstrators

WP 3.2 **pMOR-Based Scenario Analysis**

- Initial scenario analysis
- Splitting methods
- Real-time scenario analysis

WP4 Development and Integration

WP 4.2 **Integration**

- Implementation
- Integration

WP5 Demonstrators

WP 5.2 **Demonstrators**

- Benchmark
- Power-to-gas demonstrator

Milestones & Time Table

M 1 **2017-Q1**

- WP 2 Application of existing MOR methods

M 2 **2017-Q3**

- WP 2 Complete module for pMOR / nMOR

M 3 **2018-Q3**

- WP 2 Version 1: MOR
- WP 3 Version 1: Scenario analysis
- WP 5 Simulation of power-to-gas

M 4 **2019-Q3**

- WP 2 Version 2: Software
- WP 3 Full scenario analysis of demonstrator

M 5 **2020-Q1**

- WP 2 Final version of MOR algrithm and module
- WP 4 Final MOR library
- WP 5 Version 2: Scenario analysis of demonstrator

What We Need

- **Data Format**
  - Networks
  - Operational Data
- **Networks**
  - Target network specification
  - Test and benchmark networks with varying complexity
- **Operating Specification**
  - Input classification (Demand, Supply, etc.)
  - Parametrization (Components & Ranges)
- **Interface Specification**
  - Existing Libraries
  - Industry Standards
- **Overall Workflow Description**
  - Target implementation (Language, Hardware, Time Budgets)
  - Solvers (Types, Availability, Requirements), Sampling
- **Complex Model Components**
  - Compressors
  - Transformers
- **First Steps?**

Our Responsibilities:

- Development of suitable model order reduction techniques, and
- implementation of power-to-gas scenario analysis demonstrator
- using state- and parameter-space reduced order models.

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