ROMSOC — A European Graduate School in Applied Mathematics together with Industry

A Short Survey

Michael Günther

Bergische Universität Wuppertal, IMACM

Reduced Order Modelling, Simulation and Optimization of Coupled Systems (ROMSOC)

BERGISCHE UNIVERSITÄT WUPPERTAL

Eindhoven/NL, February 17, 2020

Funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 765374.

Basic facts

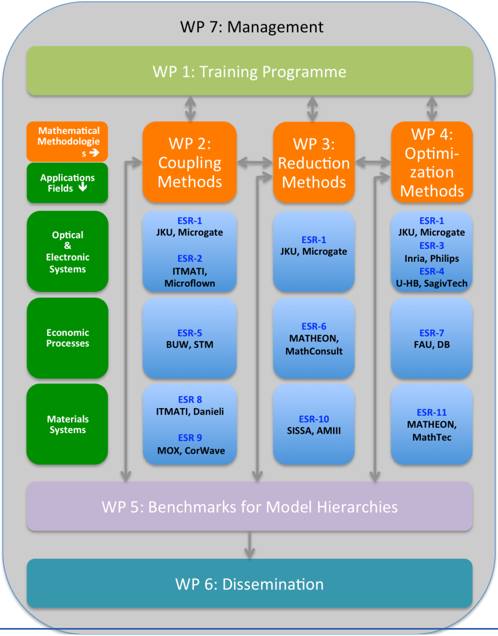
- ROMSOC is a European Innovative Training Network within the Horizon 2020 — Marie Sklodowska-Curie Actions (MSCA)
- especially: ROMSOC is a European Industrial Doctorate Program, i.e., all PhD students have to spent more than 50 % of their time at the industry partner
- 11 PhD students are trained together by an academic-industry tandem on MSO, sharing Reduced Order Modelling and Coupled System Simulation as a common core
- ROMSOC was a successful initiative of EU-MATHS-IN, combing the efforts of ECMI and EMS, coordinated by Volker Mehrmann (MATHEON/TU Berlin)
- project duration: 09/2017-08/2021
- up to 36 person months for each PhD fellow

The consortium: 14 academic partner

- Austria: Industrial Mathematics, JKU, Linz
- France
  - Université Paris-Dauphine
  - Inria
- Germany
  - Research Center MATHEON / TU Berlin
  - Humboldt Universität zu Berlin
  - Friedrich Alexander University Erlangen-Nürnberg
  - University of Bremen
  - Weierstraß Institute for Applied Analysis and Stochastics (WIAS)
  - Bergische Universität Wuppertal
- Italy
  - Scuola Internazionale Superiore di Studi Avanzati di Trieste (SISSA)
  - MOX-Politecnico die Milano
- Spain
  - Consorcio Instituto Tecnoloxico de Matemática Industrial (ITMATI)
  - Universidade de Santiago de Compostela
  - Universidade da Coruna

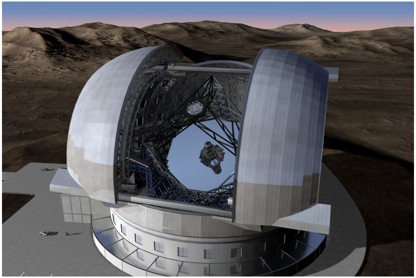
The consortium: 11 industrial partner

- Austria
  - MathConsult GmbH
  - Math. Tec GmbH
- France: CorWave
- Italy
  - ST Microelectronics
  - Microgate Srl
  - Danieli Officine Meccaniche
- Israel SagivTech
- The Netherlands
  - Philips Lighting BV
  - Microflown
- Poland: B Cargo Polska S.A. (DB)
- Spain: ArcelorMittal Innovación Investigación e Inversion S.L. (AMIII)


WP 7: Management
WP 1: Training Programme
Mathematical Methodologies
Applications Fields
WP 2: Coupling Methods
WP 3: Reduction Methods
WP 4: Optimi-zation Methods
Optical & Electronic Systems
ESR-1 JKU, Microgate
ESR-2 ITMATI, Microflown
ESR-1 JKU, Microgate
ESR-1 JKU, Microgate
ESR-3 Inria, Philips
ESR-4 U-HB, SagivTech
Economic Processes
ESR-5 BUW, STM
ESR-6 MATHEON, MathConsult
ESR-7 FAU, DB
Materials Systems
ESR 8 ITMATI, Danieli
ESR 9 MOX, CorWave
ESR-10 SISSA, AMIII
ESR-11 MATHEON, MathTec
WP 5: Benchmarks for Model Hierarchies
WP 6: Dissemination

Extremely Large Telescope (ELT)

- planned to be the world's largest optical/near-infrared telescope
- requires highly efficient algorithms to achieve an excellent image quality
- relies on adaptive optics, to compensate rapidly changing optical distortions in the atmosphere
- requires the reconstruction of the turbulent layers in the atmosphere, called atmospheric tomography



- **goal:** reconstruct turbulent layers ϕ from measurements s
- mathematical problem formulation:

$$s = A\phi$$

- **approach:** Bayesian framework and maximum a-posteriori estimate

$$(A^* C_\eta^{-1} A + C_\phi^{-1})\phi = A^* C_\eta^{-1} s$$

where C_ϕ and C_η are the covariance matrices of layers ϕ and noise η

Challenges:

- inverse problem
- computationally very expensive operations
- to be solved in real-time

$\Rightarrow$ **need an efficient solver**

Results

- comparison of two solvers for atmospheric tomography
  - standard approach called MVM (based on matrix vector multiplication)
  - novel approach developed at the JKU in Linz called FEWHA
- comparison of number of floating point operations and memory usage
- analysis of parallelization possibilities

⇒ FEWHA is a lot faster and has less memory usage (for details see [1])

- decision on real-time hardware for the ELT
- parallel implementation of FEWHA on real-time hardware
  - NVIDIA Tesla V100 GPU
  - High Performance Computing cluster

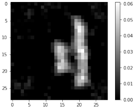
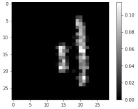
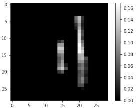
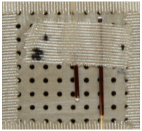
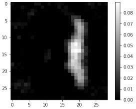
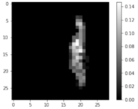
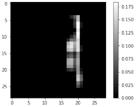
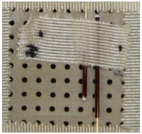
[1] *B. Stadler, R. Biasi, R. Ramlau, Feasibility of standard and novel solvers in atmospheric tomography for the ELT*

Task/Problem

- Magnetic particle imaging (MPI) is a non-invasive tomographic imaging technique that directly detects superparamagnetic iron oxide nanoparticles (SPIO).
- MPI is usually modeled by a linear Fredholm integral equation of the first kind describing the relationship between particle concentration and the measured voltage.
- The main goal of MPI is to reconstruct the spatially dependent concentration of particles.
- Computationally efficient reconstruction methods are required to allow real time observations.

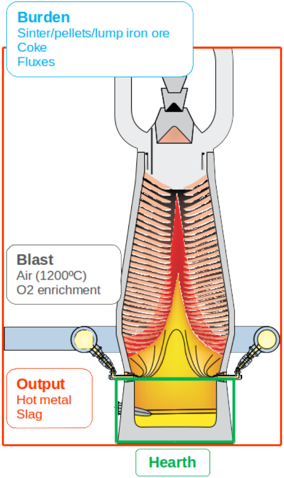
Methodology

- Apply data-driven approaches to inverse problems, using neural networks as a regularization functional.
- Deep Image Prior:
$$F_\theta(u) = \|u - Ac(\theta)\|_2^2$$
where u is the measured signal, A the MPI operator and c (the output of an untrained neural network parameterized by θ whose input is a constant) the concentration.
- Test the capability of the Deep Imaging Prior approach to improve image reconstruction obtained by standard Tikhonov regularization.
- The approach was tested in two benchmark datasets: 2D phantomdataset and Open MPI dataset.

Phantom	Kaczmarz with ℓ_2	ℓ_1	DIP	Photo
"4mm" (DS1)				
	$\tilde{\lambda} = 5e - 4$	$\tilde{\lambda} = 5e - 3$	$\eta = 5e - 5$	
"2mm" (DS1)				
	$\tilde{\lambda} = 5e - 4$	$\tilde{\lambda} = 5e - 3$	$\eta = 5e - 5$	

Overview of the physical problem

- **Coupled thermomechanical system**
- High temperature processes $\Longrightarrow$ **High Thermal stresses**
- Blast furnace campaign depends on **hearth lifetime**
- Variation in material properties $\Longrightarrow$ **Heterogeneous system**
- **Geometric parameters** such as size, orientation and number of blocks
- Application of **reduced order modeling** for **parametric partial differential equations**

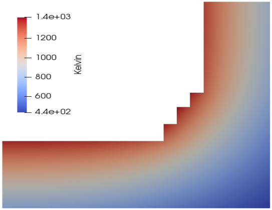


Blast furnace Layout [Courtesy:ArcelorMittal]

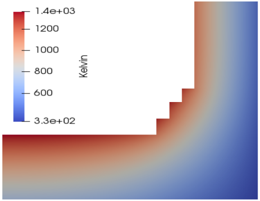
- **Full order model (FOM)** : the **thermoelasticity** equations
  - Energy equation : $-Div(\boldsymbol{K}\nabla T) = 0$
  - Momentum equation : $-Div(\boldsymbol{\sigma}[T](\varepsilon(\overrightarrow{u}))) = \overrightarrow{0}$
  - Stress-strain relationship :
    $\boldsymbol{\sigma}(\overrightarrow{u})[T] = \lambda Tr(\varepsilon(\overrightarrow{u}))\boldsymbol{I} + 2\mu\varepsilon(\overrightarrow{u}) - (2\mu + 3\lambda)\alpha(T - T_0)\boldsymbol{I}$
- **Physical parameters** :
  - Thermal conductivity $\boldsymbol{K}$, Lamé parameters λ and μ, Thermal expansion coefficient α
- **Geometric parameters** :
  - Thickness and diameter at each section of the hearth
- **Reduced order model (ROM)** : **POD-Galerkin projection** of individual subphysical systems (thermal and mechanical)
- **Numerical treatment** : **FOM** implementation in **FEniCS**[1]and **ROM** implementation in **RBniCS**[2]

[1] https://fenicsproject.org/
[2] https://mathlab.sissa.it/rbnics

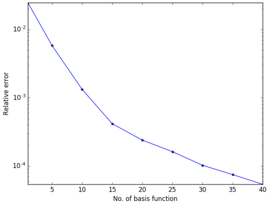
Preliminary results



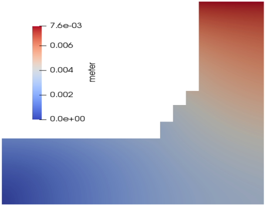
FOM : Temperature



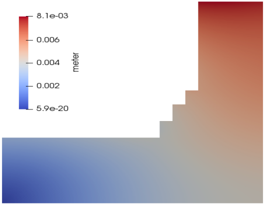
ROM : Temperature



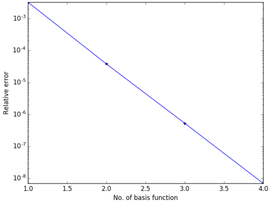
ROM : Temperature relative error



FOM : Displacement (magnitude)



ROM : Displacement (magnitude)



ROM : Displacement relative error

An option for our community?

- ROMSOC consortium quite diverse in applications, but homogeneous in mathematical methodologies
- for SCEE: can be more homogeneous in applications, too
- but: low success rate, increasing from 3-5 % to more than 10 % for ETN — EID — EJD
- high quality in research part is only necessary, but not sufficient for success
- discussion at ECMI SIG MSOEE meeting on Thursday, 2 pm