EUROMECH Colloquium 597

"Reduced Order Modeling in Mechanics of Materials"

28-31 August, 2018, Bad Herrenalb, Germany

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The EUROMECH Colloquium 597 on Reduced Order Modeling in Mechanics of Materials took place on August 28-31 2018 in the spa-town of Bad Herrenalb (Germany), which is located on the Northern end of the black forest. The scientific aim of the colloquium was to relate recent trends from the fields of model order reduction, data-driven modeling/simulation and error estimation. A key objective was the identification of promising paths towards certification of reduced order models and/or data-driven surrogates in the presence of nonlinearities and path-dependencies while preserving the computational advantages (i.e. low computing time and memory demand).

The colloquium hosted a total of 40 participants including guest speakers. In order to highlight the key topics of the colloquium, two keynote lectures given by acknowledged top scientists in the field of multiscale simulations (presentation by Prof. Stefanie Reese and co-workers) and data-driven surrogates (presentation by Prof. Ivan Oseledets and co-workers) complemented the program. The scientific program comprised a total of 33 oral presentations of extraordinary scientific quality, which covered all of the previously mentioned themes. The intense interaction of the disciplines found its way into many presentations and induced active discussions. For instance, the use of reduced cubature rules or hyper-reduction can now be considered a rather established method. However, there is still no consensus on the identification procedure for these point sets which influences the quality of the predictions to a massive extent. Besides the oral presentations, 14 accompanying posters were showcased. Extensive discussions evolved around the posters during a separate time slot and the coffee breaks as well as outside of the scientific program during the evenings. Additionally, an external invitee from the University of Stuttgart, Dr. Andrea Beck, showcased the application of machine learning for the treatment of turbulent flow. This was the opener for an open discussion slot which ended up into many intense small group debates that continued beyond the scientific program.

Going into more detail, the scientific presentations were clustered into slots of matching category. During the first day, large scale fluid dynamical simulations with millions of degrees of freedom were compressed using reduced order models (ROM). The use of ROM on parts of the domain was promoted, i.e. a hybrid reduced/full order model approach was suggested—something that was seen in several talks during the workshop. Further, the topic of error estimation and adaptivity was addressed. Interestingly, all presentations related to output oriented error estimation using dual solutions. While these methods can be efficient for linear problems with affine operator decomposition, the situation is complicated in the presence of pronounced nonlinearities. For instance, rigorous bounds are either computationally unattractive or overly pessimistic. The second day started with a session dedicated to model compression for space-time problems, e.g. for cyclic analysis. Various non-classical model reduction strategies in the form of lattice Green functions for atomistic/continuum coupling, the Proper Symplectic Decomposition and Wavelet Reduced Order Models highlighted that there are activities that go well beyond classical subspace identification in the form of POD. After a poster session, the evening program consisted of an introduction to ROM for nonlinear homogenization and a keynote lecture by Prof. Stefanie Reese, who show how the use of FFT-solvers, advanced POD methods and hierarchical tensor decompositions can all contribute to mechanics of materials.

The third day continued on the topic of nonlinear homogenization including coupled problems as well as reduced microstructure representations using Wang tiles. The afternoon and evening sessions were devoted to the upcoming field of data-driven modeling and simulation. It was opened by a keynote lecture of Ivan Oseledets who gave an overview on the many different domains that can benefit from deep learning while not giving up on supporting modeling. The final day of the colloquium evolved around nonintrusive model reduction, which is a field that is of outstanding importance for practical applications in industry.

The scientific discussions during the colloquium resulted in several consensus statements:

First, the attendees agreed that purely data-driven surrogation—i.e. excluding mathematical structure and physical laws—will likely not lead to the anticipated predictivity and robustness. Another concern was the little transferability of machine learning based predictions for complex material behavior: While likely effective for certain materials, the lack of a direct translation of the results without the need for extensive data generation and time-consuming parameter fiddling without physical guiding was not seen as an attractive option.

Second, the extension of error estimation and control to highly nonlinear and path-dependent problems remains a massive challenge. The key problem in this regard is related to the computational demands of the estimators which can easily make up for the distinct savings of reduced order models and which renders the error estimation computationally unattractive.

Third, the attendees agreed that the interaction of data-driven modeling using deep learning, sparse tensor decompositions and alike should be combined with dedicated physical and mathematical approaches. There was an overall agreement that using intelligent data-processing can complement but not completely substitute the other developments. The development of hybrid techniques is seen as a key goal for the next years.

The feedback given by the guests was very positive and, therefore, the organizers conclude that the event was successful in bringing into contact scientist from different geographic areas—i.e. across Europe and beyond—as well as from different scientific origins—i.e. from mathematics, engineering and computer science. The audience consisted of well-balanced mix of master and doctoral students, post-docs and established professors. Our personal perception was

that the communication barrier within the group was low, which led to many interesting in-depth discussions. Several bilateral cooperations were initiated and existing collaborations were deepened. Among the 39 participants (20 from Germany, 7 from France, 3 from Sweden and Switzerland, 2 from the Czech Republic and the Netherlands, 1 from Belgium and Russia), were 9 EUROMECH members and 12 others expressed their willingness to become a member.

In view of future activities, the colloquium chairs have set up a special issue in "Mathematics and Computational Applications" entitled "Machine Learning, Low-Rank Approximations and Reduced Order Modeling in Computational Mechanics" as guest editors. Several participants of the colloquium committed for submitting a manuscript to the special issue. The chairpersons also decided to definitely propose a follow-up workshop (also in the spirit of their previous workshops WORM2013, WORM2014 and WORM2016) with the particular objective of maintaining continuity in the participants and preserving a good balance of young, intermediate and senior researchers.

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